Achievements and Experiences of Agricultural Water Management Research and Development in Amhara Region

Proceedings of the First Workshop on Agricultural Water Management Research and Development in Amhara Region
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Editors: Gizaw Desta and Menelik Getaneh

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Foreword

It is known that our agriculture in Amhara region and in Ethiopia in general is heavily dependent on rain. This heavy dependence on rain predisposes agriculture to inter-annual and seasonal fluctuations in performance with erratic rainfall. Such precarious conditions also increase the risk and uncertainty which farmers face in making production decisions. Consequently, smallholder farmers, who make up the vast majority of the farming population, tend to adopt low input-low output and less risky production decisions. This in turn ultimately leads to low aggregate production and productivity levels, and food insecurity.

One of the solutions to this problem is, undoubtedly, designing and implementing improved agricultural water management techniques such as irrigation. Improved agricultural water management techniques increase moisture availability for plant growth as well as decrease uncertainty and risk associated with erratic rainfall. By so doing, it encourages farmers to use inputs such as improved seeds and inorganic fertilizers which contribute a great deal to boost productivity.

Realizing this fact, the Ethiopian federal government and that of the Amhara region have given utmost emphasis to improved agricultural water management such as small scale water harvesting and the development of irrigation infrastructure using the country's ample water resources. Consequently, rain and ground water harvesting technologies were promoted in drought prone areas of the region. Numerous small-scale and a few large scale irrigation projects such as the Koga and Kobo irrigation schemes have been commissioned and started operation. Other similar projects such as the Ribb and Megech irrigation schemes are under construction. These endeavours have greatly increased the area under irrigation.

With increasing area of irrigated land, the demand for improved agricultural technologies suitable for irrigation conditions is growing. Farmers and extension agencies, both governmental and non-governmental, are knocking our doors looking for improved varieties of traditional irrigation crops such as tomato, pepper and onions as well as for other crops which were in the past predominantly rain fed. There are growing technology demands for disease and pest control, improved farm implements, improved forage varieties, animal breeds as well as water and fertilizer application rates. There are demands in the area of socioeconomics such as recommendations for financially optimal sets of enterprises under different agro-ecologic and market conditions and institutional aspects of the governance of irrigation schemes. There are also demands for extension demonstrations and scaling up of existing irrigation technologies for farmers, development agents and as well as subject matter specialists.

Responding to these demands needs a well thought out strategy that caters for short and long term plan for research as well as infrastructure and human resources development. We need to give irrigation as much emphasis as the rainfed agriculture. In order to do that it is logical to review of what has been done in the past and undertake an inventory of existing irrigation technologies and recommendations as it can help in the identification of gaps and future water research and development directions in the water sector of the region.

Apart from this, synthesizing the available information, experiences and technologies in irrigation and related water harvesting and water resources management as well as developing context specific technology manuals goes a long way in supporting the development endeavours of the region. With these aims in mind, contained in this proceeding are important papers in the area of water governance, irrigation scheme performance, crop water productivity, water harvesting management and impact, water demand management as well as water resource accounting issues. The papers elaborate studies and research finding on the water sector with emphasis on agricultural water management and irrigation. I greatly hope that the research findings in these papers will reach other researchers, university lectures, extension personnel and even large scale farmers in the region and prove useful as reference materials and guide to practical farming activities. Finally, I would like to thank SWHISA and ENIDP which have co-sponsored this workshop and proceeding. In addition to this, I would like to thank all those who participated in the workshop as well as the authors, reviewers and editors who contributed to this proceeding.

Tilaye Teklewold Deneke (PhD)

Deputy Director General, ARARI

Acknowledgement

This proceedings contain the results of the workshop conducted during March 28-30, 2012 and present findings from various field researchs, studies, reviews and experiences in agricultural water management conducted mainly with the financial support and participation of SWHISA and ENIDP. The authors wish to acknowledge the support provided by SWHISA and ENIDP for financing the workshop. We also thank very much ARARI and its research centers and individual researchers and experts, in particular, those who participated and presented their papers in the workshop.

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Abbreviations and Acronyms

ADMU	Agriculture Development and Management Unit
AET	Actual Evapotranspiration
AMAREW	Amhara Microenterprise Development, Agricultural Research, Extension and Watershed Management
ANOVA	Analysis of Variance
ANRS	Amhara National Regional State
ARARI	Amhara Region Agricultural Research Institute
BDU	Bahir Dar University
BI	Block Inspector
BIS	Basin Information System
BOARD	Bureau of Agriculture and Rural Development
BoWRD	Bureau of Water Resources Development
CIDA	Canadian International Development Agency
CPA	Cooperative Promotion Agency
CPR	Common Pool Resources
CSA	Central Statistical Agency
CWGD	CropWat Generated Depth
CWR	Crop water requirement
DA	Development Agents
DAP	Diamonium Phosphate
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DRI	Drought Risk Index
E.C.	Ethiopian Calendar
EC	Electrical Conductivity
ECA	Economic Commision for Africa
ENIDP	Ethiopian Nile Irrigation and Drainage Project
ERH	Effective Rainfall Hytograph
ESP	Exchangeable Sodium Percentage
ETB	Ethiopian Birr
ETo	Reference Evapotranspiration

FAO	Food for Agriculture
FOP	Field Outlet Pipes
FTC	Farmers Training Centre
G.C.	Grigorian Calendar
GCM	Global Climate Model
GTP	Growth and Transformation Plan
HH	Household
IADP	Irrigated Agriculture Development Process
ICARDA	International Center for Agriculutural Research in Dryland Areas
ICs	Irrigation Cooperatives
IDA	Irrigation Development Agents
IDDP	Irrigation Design and Development Process
IDW	Inverse Distance Weight
IMT	Irrigation Management Transfer
IPCC	Intergovernmental Panel on Climate Change
ISF	Irrigation Service Fee
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
IWUE	Irrigation Water Use Efficiency
LGP	Length of Growing Period
MAE	Mean Absolute Error
MC	Management Committee
MD	Moisture Deficiet
MOA	Ministry of Agriculture
MoWE	Ministry of Water and Energy
MRR	Marginal Rate of Return
NGO	Non-governmental Organization
NMSA	National Meteorological Service Agency
NSW	Night Storage Weirs
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development
PASDEP	Plan for Accelerated and Sustainable Development to End Poverty
PBIAS	Percent Bias

PEC	Present Effective Cost
PET	Potential Evapotranspiration
PIDM	Participatory Irrigation Development and Management
PIM	Participatory Irrigation Management
PM	Penman Monthieth
PRA	Participatory Rural Appraisal
RCBP	Rural Capacity Building Project
RMSE	Root Mean Square Error
SAR	Sodium Adsorpition Ratio
SCF	Save the Children Fund
SDE	Sub-Division Engineer
SDSM	Statistical Downscaling Model
SE	Storage efficiency
SMD	Soil Moisture Depletion/Deficiet
SSIS	Small Scale Irrigation Systems
SUH	Synthetic Unit Hydrograph
SWHISA	Sustainable Water Harvesting and Institutional Strengthening in Amhara
SWI	Soil Water Index
TAM	Total Available Moisture
TLU	Tropical Livestock Unit
UH	Unit Hydrograph
USDA	United States Department of Agriculture
WB	World Bank
WHC	Water Holding Capacity
WMO	World Meteorological Organization
WOARD	Woreda Office of Agriculture and Rural Development
WRSI	Water Requirement Satisfaction Index
WSDP	Water Sector Development Program
WUA	Water Users Association
WUE	Water Use Efficiency
WUG	Water User Groups
WUO	Water Users Organization

Welcome and Opening Speech

Fentahun Mengistu
Director General, Amhara Region Agricultural Research Institute (ARARI)

Dear Researchers, Development experts, Invited guests,

First of all, I would like to express my most sincere welcome to you all to the regional workshop on *"Achievements and Experiences of Agricultural Water Management Research and Development in Amhara Region*".

As you all know water is a basis for socio-economic development and is, of course, a source of human civilization. Apart its domestic use water is a basis for agriculture development, which uses 70-80% of global freshwater. Water used for domestic consumption and industry accounts only 10 % and 20%, respectively.

Within about 40 years, the global population will double and necessitates doubling agricultural production to provide food for the burgeoning population. To meet that demand, agriculture needs more than twice the amount of water that it uses today. On the other hand, on the lookout for better nutrition food habit of people is changing towards animal products especially meat. To produce the latter it requires 6-20 times more water than cereals. On the other hand, for increased urbanization and industrial development the water used by agriculture will have to decline by 60-70% by 2050. It would therefore be a great challenge to meet the water requirement of various sectors and achieve at the same time water security, and food and nutrition security. Climate change, which is currently high on the agenda, is basically a change in water supply. Because, one of the major manifestations of a change in climate is a change in water access. Accordingly, when we talk about climate change mitigation we mainly mean about management and use of water resources.

In general, as water is a non-renewable scarce resource, which in addition to agriculture, has to be used for domestic service and industry we need to utilize it sparingly and increase its productivity. For instance, we need to shift from flood irrigation, which is more common practice with our farmer's traditional irrigation system to drip irrigation, we may need to re-cycle water, etc.

Coming to our country, literature indicate that Ethiopia is a water rich country with a potential of 123 billion m^3 surface and 2.6 billion m^3 ground water and 3.5 million hectare irrigable land. Nonetheless, until very recently for our failure to give due emphasis to water as an important input to our agriculture development, our agricultural productivity has remained low and we have not been able to achieve food security. Recently, however, because of the existence of enabling policies and improved implementation capacity, natural resources conservation-based water resources utilization has been given prominence. Accordingly, small scale irrigation sourced from rain water harvesting, hand dug wells, spring development, river diversion, etc. is expanding very fast. Likewise, extensive medium and large scale irrigation projects and hydro-power development are on the move.

In the Five Years Growth and Transformation Plan (GTP), one of the three pillar strategies set to increase farmers' productivity is natural resources conservation-based surface and ground water development and expansion of small scale as well as medium scale irrigation. Accordingly, Amhara region has targeted to increase the land area under irrigation from 444,620 (in 2010) to 950,000 hectares (in 2014) and enhance production from 51.38 to 100 million quintals during the same period. To achieve this, a large volume of information and technology input is required.

To buttress this endeavor, Amhara Agricultural Research Institute (ARARI) has developed agricultural water management research strategy and has been aggressively working on agricultural water management in collaboration with and support of SWHISA, IWMI, ICARDA, ENIDP, etc. The institute has also been able to build modern irrigation research facilities at Kobo and Koga irrigation experiment sites. And it has for the first time given out irrigation technology package recommendations for some of the irrigated crops of the region. It is also known that several governmental and non-governmental organizations are carrying out research and development activities on water in the region.

This fragented information, knowledge, and technology need to be gathered and used as an input in the region's agriculture development. Cognizant of this, the Amhara Agricultural Research Institute, by virtue of the powers vested in it to consolidate the region's agricultural and natural resources management research outputs it has been able to organize this workshop on agricultural water management. Therefore, the goal of this gathering is to discuss on and share experiences on research outputs on water management and utilization and identify gaps and forward recommendations for future research and development directions. The proceeds of the workshop will be compiled and published for wider dissemination to users.

Finally, I would like to thank all people and organizations who made utmost effort for the realization of this workshop. Especially, I am very grateful to Ethiopian Nile and Drainage Project (ENIDP) and Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) for financing the workshop. I also thank very much the organizing committee and researchers and experts who are ready to present and share us their findings.

I wish you a successful deliberation and pleasant stay.

Fentahun Mengistu (PhD)
Director General, ARARI

PART 1

CONTEXT OF IRRIGATION WATER MANAGEMENT IN AMHARA REGION

Overview of Water Resources Management Policy Framework of Ethiopia

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Abstract

Ethiopia has already set out progressive water policy, strategy, proclamations and regulations to promote and enhances the development, management and protection of water. But the degree to which the development has done was highly important rather than the focus of management and protection, though it has been stated in the instruments indicated. But continuous and more use of water for different purposes has been grown from time to time for the last two decades and scarcity of water is becoming an important issue in the nation. Therefore such issues can be solved by strictly focusing to the management and protection of the resources which again requires the way how the legal instruments of Ethiopia is set up. Review of the capacity of implementing institutions and the creation of awareness about the legal instruments and how these tools can be practiced in the community is therefore essential. This paper therefore gives review of some basic policy issues and enactments which are practiced in the country.

Key words: Water policy, Water Proclamations, Regulations, Institutions,

Introduction

The geographical location of Ethiopia and its endowment with favorable climate provides a relatively higher amount of rainfall in the region. Much of the runoff water, however, flows across the borders being carried away by the trans-boundary Rivers to the neighboring countries. Preliminary studies indicate that the country has an annual surface runoff of close to 122 billion cubic meters of water and ground water potential of about 2.6 Billion cubic meters (policy document of Ethiopia). The main water resources problem in Ethiopia is that of uneven spatial and temporal occurrence and distribution. Between 80-90% of Ethiopia's water resources is found in the four main river basins namely, Abay (Blue Nile), Tekeze, Baro Akobo, and Omo Gibe in the west and south-western part of Ethiopia where the population is no more than 30 to 40 percent. On the other hand, the water resources available in the east and central river basins are only 10 to 20 percent whereas the population in these basins is over 60 percent.

In order to alleviate the problems on agricultural development and other water uses, sustainable and reliable development and proper use of the water resources of Ethiopia becomes an imperative. This calls for a priority setting and judicious water resources management policy, associated finance and capacity building.

Perceptions of Water

Water has multiple aspects and is perceived by different people in different ways: ***as a commodity, as common resource, as a basic right and as a sacred resource***. We need to be aware that what is true of one of the multiple dimensions or aspects of water may not hold for another. Unfortunately, at any given time, one or more perceptions tend to dominate our thinking, and thus lead us to draw wrong conclusions and formulating wrong prescriptions (Ramaswamy, 2003).

Water as a commodity

To many of us, especially for Ethiopians, the notion of water as a commodity seems unacceptable when we see it in terms of religious aspects. However, the use of water for irrigation in commercial agriculture, the use of water for cooling or steam generation or industrial processes, luxury uses by the affluent in swimming pools, gardening and so on would describe water as a commodity. A hotel may need large quantities of water for keeping its kitchens, bathrooms, toilets, laundry, swimming pools and other recreational facilities operational, and may enter into contracts with supplying agencies for bulk water supplies on a regular basis in such transactions water is definitely described as a commodity.

Questions of equity, social justice and resource conservation do arise in such cases, and we may wish to limit or relate or discourage the use, or ensure that proper prices are charged but it seems hardly possible to rule out such uses or the related transactions altogether, and to the extent that they take place, water is indeed a commodity in these contexts. However, no one is quite comfortable with the crude description of water as a commodity, so a more sophisticated formulation has been found: water is now generally described as '*an economic and social good*'.

Water as a common resource

The view of water as 'commons' or as a 'common pool resource' (CPR) is strongly advocated and is attractive, but two points need to be noted. The first is that the notion of 'commons' is of easy application in the context of a small lake or pond or tank or other water body on common land, we can think of it as owned by the community. With larger water bodies, and with streams and rivers, difficulties begin to arise in the form of 'upstream versus downstream' issues, riparian rights and so on. However, we can still argue that the water source belongs to the community as a whole, and that the conflicts that arise can be resolved within that overall framework. The notion of commons also runs into difficulties in the context of urban water supply systems (where an agency, whether public or private, supplies water to citizens by a network pipelines from its storages), or in that of the supply of irrigation water through canals from large reservoirs, whether state owned or privately owned.

The notion of commons has a value even in such contexts. What we are trying to do is to deny the private or state ownership of water and to vest that ownership in 'civil society'. But does any person, body or institution - even civil society - own water? (Ramaswamy, 2003). Incidentally, we must be wary of unduly enlarging the geographical scope of the ideas of 'commons' and 'community'. If we widen the notion of 'community' to cover the state as a whole, or go one step further and encompass of entire nation and we might wish to do so for certain legitimate purposes - it may be difficult to resist further expansion to the globe as a whole, There are serious implications to accept a description of water as a 'global commons', a natural resource that belongs to all humanity, the dangers are obvious enough. When we use expressions such as 'commons' or 'community management' we usually have local context in mind (one village or a cluster of villages/watershed) (Ramaswamy, 2003).

Water as a basic right

Water sustains life. In that aspect it is a basic need and therefore a basic right. This does not automatically follow from a description of water as 'commons'. In the traditional societies of the past, people might not have needed the language of rights. However in the legalistic societies of today 'formal law' has become more important, and that is why it has become necessary to talk about 'rights to water'. Water as life-support or drinking water is a basic or fundamental right. The perception of water as a basic right is very important and we need both perceptions (water as basic right and water as commons) and must learn to harmonize them.

Water as a sacred resource

The fact that water supports life, and that it is also as part of the natural environment, sustaining it and in turn being sustained by it, leads to its being regarded as 'sacred'. Especially in the Christians, some waters are hollied and used for treatment of any physical and spiritual defects in the society. Water has also a special value in Muslim society.

Water and the Constitution of Ethiopia

Water is an invaluable natural endowment whose ownership has undisputedly been vested in the state and all the peoples of Ethiopia. It is not something to be claimed as an out-right item of private property in an exclusive manner. That is at least the constitutional tone of formalizing and treating the nature and functions of our existing relationships with land and other natural resources in Ethiopia today.

Art. 40 Sub-Art.3 of the 1995 Constitution of the Federal Democratic Republic of Ethiopia (FDRE) provides for "an exclusive ownership of rural and urban land as well as of all natural resources" by the state and its entire population. More specifically, it is the federal government which is "competent to formulate and implement the country's policies, strategies and plans in respect of overall economic, social and development matters and to enact laws for the utilization and conservation of land and other natural resources" pursuant to Art. 51 Sub-articles (2) and (5) of the same constitution.

An interesting departure is also laid down under Art.51 Sub-Art. (11), as far as the determination and management of the country's surface water resources are concerned. Here, the constitutional mandate of the Federal Government is somehow compromised and explicitly confined to the virtual determination and administration of the utilization of those waters or rivers and lakes linking two or more Regional States or crossing the boundaries of the national territorial jurisdiction. This naturally flows from the general clause under Art. 50 Sub-Art. (5) which already empowers the Regional Legislatures to also enact and implement their own subsidiary laws and regulations with respect to those matters falling under their jurisdictional mandates as are to be further elaborated under the subsequent provisions of Art. 52 Sub-Articles (2) (B) (C) and (D) of the Federal constitution.

Regardless of its diverse forms, water is a publicly owned natural asset to which all Ethiopians are entitled for normal use and enjoyment without any possible discrimination, wherever it might be available. Art. 90 Entry 1 of the constitution declares the following Social Objectives which states as: "To the extent the country's resources permit, policies shall aim to provide all Ethiopians access to public health and education, clean water, housing, food and social security". To satisfy the Economic Objectives of the people, Art. 89 Entry 1 of the constitution also states that "Government shall have the duty to formulate policies which ensure that all Ethiopians can benefit from the country's legacy of intellectual and material resources".

Policy and Legislative Regimes

Water Resources Management Policy

In order to alleviate the problems on agricultural outputs and other water uses, sustainable and reliable development and proper use of the water resources of Ethiopia becomes an imperative. This calls for a priority setting and judicious water resources management policy and associated finance.

Development activities carried out so far before 1999 G.C (i.e before the formulation document of the water policy) in the water sector in totality or individually reveal a very low level of performance in the water development sector. The cause for this poor achievement and the dilemma for low use of the country's water resources to significantly contribute to the overall socio-economic development of the Ethiopians laid mainly in the absence of a well defined coherent policy and the lack of the required huge investment, as it was stated in policy document of Ethiopia, 1999. Taking this pressing need in to account, the Ethiopian Water Resource Management Policy was initiated, formulated and adopted at the national level for the very first time in 1999. According to this pioneering and qualitatively-transformative document of its kind (as compared with predecessors) released by the Federal Government, "every Ethiopian citizen , as far as conditions permit, have access to sufficient water of acceptable quality in order to satisfy his/her basic human need".

The policy was formulated to achieve the basic overall goals which states as "… to enhance and promote all national efforts towards the efficient, equitable and optimum utilization of the available Water Resources of Ethiopia for significant socioeconomic development on sustainable basis" (Entry 1).

In this policy goal, the phrases **efficient, equitable and optimum utilization** of the National water resources are very important. To fulfill this policy goal in the rate of the above terms the general water resources management policy objectives fall in **development, management and protection and conservation** (Entry 1.2).

The objectives are generated from fundamental policy principles which guide the **equitable, sustainable and efficient** development, utilization, conservation and protection of water resources of Ethiopia (Entry 1.3). These principles include: 1) water is a natural endowment commonly owned by all the peoples of Ethiopia, 2) every Ethiopian citizen shall have access to sufficient water of acceptable quality, to satisfy basic human needs, 3) water shall be recognized both as an economic and a social good, and 4) water resources development shall be underpinned on rural-centered, decentralized management, participatory approach as well as integrated framework.

Water Resources Management Strategy

Development of the water sector strategic document was essential with the main objective of translating the national water resources management policy into action. The national water strategy aims at providing a road map in terms of ways and means to attain the water policy objectives - with due recognition to the principles around which these objectives have been developed in 2001. The general objectives and fundamental principles of developing the water sector strategic document are similar to that of the National Water Policy. Towards this aim, the following strategic directions have been adapted with respect to main elements of the strategy.

- ✓ Water Resource Development (1 Lists)
  - Design and construct water schemes for different uses
- ✓ Water Resources Management (4 Lists)
  - Water resource inventory
  - Watershed management
  - Basin information management (BIS)
  - River management
- ✓ The Enabling Environment
  - Institutions (National, Regional, Zonal, Woreda, WUA)
  - Research Institutes
  - Water Universities
  - Private sector consultants and contractors
- ✓ Transboundary Waters
- ✓ Finance and Economics
- ✓ Research and Development
- ✓ Stakeholders Participation
- ✓ Gender Mainstreaming
- ✓ Disasters and Public Safety
- ✓ Environment and Health Standards
- ✓ Technology and Engineering

Understandably, it is to address this critical shortfall with multi-dimensional purposes that the Water Sector Development Program (WSDP) (2002-2016) was next put into effect in 2002. The program had five wings, i.e water supply and sewerage, irrigation and drainage, hydro- power development, water resources and institutional capacity building, among others.

Water Resources Management Proclamation

In as much as the Ethiopian Water Resource Management Policy generally promotes the sustainable development of existing water resources for equitable social and economic benefits through public participation with particular emphasis on the expansion of water supply and sanitation, irrigation development and power generation. Consequently, the need for a stronger legal framework also became visible with the view to redefining the emerging concepts and clarifying both the specific and crosscutting duties and responsibilities of these key institutions and other stakeholders which might be involved in the sector.

The lead piece of legislation in this regard which the Federal Government has enacted following the issuance of the policy is the Water Resource Management Proclamation No. 197/2000. Having replaced the earlier Proclamation No. 92/1994 which happened to solely provide for the utilization of water resources, the latest piece of legislation represents a multi-dimensional instrument, with its core element of regulation being the responsible management and equitable exploitation of the country's vast surface and ground water resources of course, its underlining purpose is "to ensure that all surface and ground waters existing throughout the country are properly managed and protected for the common good of the people" at large.

According to Art. 5 of the proclamation, "all water resources of Ethiopia are declared common property" in conformity with the constitutional statement elaborated by the preceding section. Moreover, Art. 6 set out the fundamental principles of water management and administration. In that respect, the use of water for domestic purposes is declared to prevail over all other uses, potential and actual. Article 7 of same also set out the priority of water use in accordance with the orders of **domestic, livestock, irrigation and other water uses**. It also states that pre-allocation of water resources to a given purpose or its being planned shall not give it a priority over and above any other use (Art. 7 Entry 2).

The Ethiopian integrated water resource management proclamation also states how the water bodies and banks can be protected. It states that the supervising body, in collaboration and consultation with the appropriate public body may (Art. 25): delimit the boundaries of banks of the water bodies, prohibit clearing, cutting trees and construction of towns within the delimited banks of water bodies. Article 26 also states that the appropriate public bodies shall, before allowing the founding of towns or villages, request the supervising body for technical advice.

Apart from the general and transitory provisions, the proclamation contains a wide range of specific stipulations on the **inventory of the country's water resources and registry of actions, permits and professional licenses, fees and water charges, servitude, water banks and harmful effect of water, association of water users as well as the duties and responsibilities of the supervising body charged** with the overall implementation of the legislation and subsequent regulations at the national level. For instance, **supply or transfer of water, release or discharge of waste into water bodies as well as construction or maintenance of water works requires a necessary permit** to be issued by the supervising body which, in this case, might be either the Ministry of Water and Energy or any other organ delegated by it in accordance with Arts. 11 through 18 of the proclamation under discussion. Obviously, Art.12 lists those water uses, for which no prior permit is required, under the circumstances.

Water Resources Management Regulation

On closer examination, one can find out that almost every substantive provision of the proclamation requires an enabling legislation to be eventually put into effect. Nevertheless, it was after half a decade that the Federal Government had finally succeeded in issuing the Council of Ministers Regulations No. 115/2005 necessary for the effective implementation of the proclamation. Of course, a considerable range of crucial issues including water resource utilization, water quality control, water works' permit, fees and charges, water users' associations, dispute settlement and certification of professional competence are regulated under this executive instrument to a sufficient detail required for an outright implementation.

River Basin Councils and Authorities Proclamation

The distribution of the water resources of Ethiopia is uneven in time and space, and on top of that, the country's economic growth is causing a correlative increase in water uses with quantitative as well as qualitative impacts. Given this natural disparity, the Integrated Water Resource Management (IWRM) process necessitates a systematized mediation and reconciliation of the various uses of water resources available within the limit of a defined river basin with the view to maintaining the required balance as between the competing interests and thereby ensuring sustainable development of the resource potential, not to jeopardize the opportunity of future exploitation by our succeeding generations. To that end, the mechanism requires all the outstanding stakeholders of a river basin to act and utilize the resource in a coordinated manner, in spite of their differences of approaches, interests and perceptions of the effects of their decisions, plans and activities on the state of the hydrological cycle and on other users alike. In accordance with this notion the Ethiopian Water Resources Management Policy envisages the establishment of river basin councils and authorities as one of the main instruments to implement integrated water resources management which is actually the pillar of the policy.

Therefore the establishment of river basin councils and authorities shall have significant contributions in creating efficient and stable mechanisms for the implementation of the Ethiopian Water Resources Management Policy through river basin plans and effective and sustainable joint management by relevant stakeholders of the water resources of the basins.

To do that "River Basin Councils and Authorities" have been established whose overall objectives shall be to promote and monitor the integrated water resources management process in the river basins falling under their jurisdictions with a view to using of the basins' water resources for the socio-economic welfare of the people in an equitable and participatory manner, and without compromising the sustainability of the aquatic ecosystems (River Basin Councils and Authorithies Proclamation No. 534/2007).

According to Art. 2 sub-arts. (1) Of the proclamation under consideration, the term “Basin” stands for “A geographical area described by the watershed limits of a water system including surface and underground water flowing into a common terminus”. In an apparent compliance with the requirements of this definition, 11 river basins and one Rift Valley Lakes’ basin are identified throughout the country, although a significant number of them naturally form part and parcel of the international water system flowing into our neighboring countries and beyond. Unless one wishes to complicate it, therefore, IWRM is nothing other than a cooperative arrangement between and among stakeholders for a balanced and sustainable development of water as an economic, social and environmental resource by having equitably reconciled its various uses in an identified river basin pursuant to Art.2 sub Art. (4) of the same proclamation.

Using this general framework, it is the Federal Council of Ministers that has been legally mandated to establish, one by one, the country’s River Basin High Councils and Authorities by separate regulations as envisaged under Art. 21 sub-arts. (1) of the said proclamation. However, only a couple of them are so far declared to have officially been established by law. These are the Abbay and Awash Basin high Councils and Authorities consecutively established as per the Council of Ministers’ Regulations No. 151 and 156/2008 respectively, with their official seats being in Bahir Dar, Amhara and Amibara, Afar Regional States, respectively.

As might be gathered from the cumulative reading of the establishing regulations the overall objective of each one of these authorities in the form of river basin organizations is to promote and monitor the implementation of the IWRM process in an equitable and participatory manner within the geographical limit of the basin concerned.

A River Basin Authority shall also give permits relating to water use and water works in compliance with the provisions of the Ethiopian Water Resources Management Proclamation No. 197/2000 and Regulations No. 115/2005. To that end, they are both generously entrusted with a wide range of identical duties and responsibilities listed under Art. (6) of their respective instruments of establishment.

Nevertheless, it remains to be seen in real practice how such executive powers as the issuance of permits for water use and water works as well as the collection of water charges are to be exercised by the authorities without prejudice to the powers of the relevant Regional States legally having comparable jurisdiction over the resources in and around the river basins.

Review and Analysis of ANRS Water Resources Management Legislations

Present-day Ethiopia is a relatively-young Federation constituted by nine State Governments and two Chartered City Administrations. The ANRS is just such an entity with its own separate legislative, executive and judicial structures in the making as of 1995.

In its short-lived experience as a functional Regional Authority overwhelmed by scores of profound development challenges, one would perhaps be naive to expect that water resource management has been much of an ideal priority for a strategic action, mainly due to capacity constraints. Nevertheless, there have been protracted efforts on the legislative front, with their primary concern normally being on the provision, and participatory management of potable water supply and sewerage services for urban dwellers as well as the corresponding water delivery points for the benefit of the rural communities.

Apart from such rudimentary actions, the rather huge task of identifying the very potential, leave alone systematically regulating the actual utilization of both the surface and ground water resources across the Regional State should have technically been beyond the reach of the State Government in its early formation. On top of this, the very functions reserved for the State Government at the Regional level must have been substantially affected by persistent changes in terms of institutional mandate and operational dynamics, from the very outset.

In other words, the overall development, management, and utilization of the resource at the regional and local levels has been a bone of ever-lasting contention between and among various executive government institutions striving for one's artificial domination over another, mainly due to the multiplicity of its uses and characterizations. Without stressing much on the corresponding institutional fluctuations which had occurred to the regional executive organs in charge of agriculture, natural resources' development, environmental protection as well as rural land administration and land use affairs, the lead agency responsible for the sector, i.e, the Water Resource Development Bureau itself had to traverse through a terribly-repetitive and turbulent course of modifications and alterations in terms of structural and functional aspects. In fact, the bureau has officially been established and re-established six times to this date, within the entire period of not more than 15 years as of the constitutional existence of the Regional State.

Following the end of the Transitional Period in which all the newly-structured Regions had to experiment with the start of self-rule and local administration pursuant to the July 1991 Charter and the National-Regional self-Governments' Establishment Proclamation No. 7/1992 enacted by the Central Transitional Government, the ANRS introduces its own 12 executive organs and broadly defines their respective powers and duties for the very first time by virtue of a locally-initiated legislation in Oct. 1995. One such executive organ established by Art. 3 sub-art. 4 of the Regional Proclamation No. 4/1995 was the Water Resource, Mining and Energy Development Bureau to primarily assume, among others, the official duties and responsibilities pertaining to the sector under consideration. In fact, those specific function of the bureau having to do with the energy promotion and development were later omitted in Nov. 2001 when the original piece of legislation was repealed and replaced by other incoming Proclamation No. 60/2001 reforming the organizational structure and composition of the Regional Government following the extensive revision of the State Constitution. At any rate, the Water and Mineral Resources' Development Bureau, (as it had been referred to by the time), was allowed to carry out its normal functions customary to the utilization and protection of the region's water resources as were originally defined under Art. 10 sub-Arts. 1 through 7 plus sub-Arts. 9 and 14 of the former Proclamation No.4/1995, with no substantial modifications and further adjustments experienced for a few more years to follow.

As far as the evolutionary process and growing dynamisms of the water resource management in the Regional State is concerned, the most important breakthrough must have probably been observed in April 2004. This time around, the Amhara National Regional Water Resource Development Bureau was separately conceived and autonomously established by the Regional Proclamation No.99/2004 in order that it would be able to fully and exclusively focus on such demanding and inter-related activities as the development, utilization, conservation, protection and control of the region's surface and ground water resources far and wide in an integrated and systematic manner.

The apparent quality and modernity of this latest legal instrument issued by the Regional State is presumably attributable to the inevitable influence of National Water Resource Management Policy of 1999 followed by the country's grand Water Resource Management Proclamation No. 197/2000, whose fundamental principles and operative provisions concurrently adhere to the adoption and implementation of the IWRM with the view to reconciling and balancing different interests in the areas of water allocation and use.

Consequently, all the ensuing Regional Proclamations No.120/2006, No.167/2009 and No.176/2010 relevant to the never-ending process of cabinet restructuring do more or less, tend to reproduce the underlying theme and content of that particular piece of legislation Gazetted in 2004 with minor alterations, when it comes to similar restructuring and adjustment of the Regional Water Resource Development Bureau from time to time. All the time the Bureau was and is mandated to develop, utilize, protect, administer and manage the water resource of the region. But there was no clear mandate boundary between the MoW and the bureau indicated in the water proclamation.

Starting from the regional Proclamation of BPR restructuring institutional frame work (2008), the bureau has been established in three wings as follows:

- ✓ Water supply and sanitation core process
- ✓ Irrigation and drainage study, design and construction core process
- ✓ Water resource management core process

Basically the IWRM part of the regional mandate was supervised by the water resource management core process with the main job titles of water research coordination team, data management team, water resource management (utilization, protection and administration) team and permit licensing team at the regional Bureau, data collection and water resource management (utilization, protection and administration) at each zone (10) and at each woreda.

Key issues

- The roles and responsibilities of the MoWE and the Regional Bureaus as a supervising body must have been clearly set in the proclamation rather than keeping it centralized both the regulatory and service provision functions. In other words, roles of national and sub-regional bodies are not clearly devolved and have little boundaries.
- The priority for water allocation to different uses such as domestic, environmental and socio economic activities depending on the availability of water resources was not strongly stated either in the proclamation or Regulation. There is no detail directive to implement well.
- The policy and proclamation instruments of the nation state the complete right of access for pure water and even food but same did not clearly state that every person residing in Ethiopia shall have a duty to safeguard and protect water resources. It also did not inform the relevant authority of any activity and phenomenon that may affect the quantity and quality of the water resource significantly and to whom to do so and also the legal protection for doing so.
- The legal instrument (Regulation) did not clearly state that the owner of any land may construct any works for rainwater harvesting or for recycling of used water other than in a river or stream and abstract and use the water so conserved or recycled for domestic purposes without a water use permit . It only stated that traditional irrigation diversion (1 l/s based on the proclamation definition) and hand dug wells shall not require water use and construction permit.
- Roles and responsibilities of Federal and regional states administration versus the basin water administration (Federal) has no clear boundary and become a challenge.

- The procedures of permit for waste water discharge in to the water bodies, construction along water body banks, dry waste dumping along the water bodies is indicated in the proclamation but the offence settlement is not stated.
- As a federal system, regional governments have the constitutional right to administer, protect, develop and put proclamations in line with the national proclamation, but MoWE is still resisting.

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Review of Concepts and Practices of Integrated Water Resource Management, Ethiopia

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Abstract

This paper presents an overview of integrated water resources management (IWRM) with particular reference to the context and practice of IWRM in Ethiopia. The IWRM concepts and principles and importance of adopting IWRM approach to analyze water availability and assess the possibilities for integrated and coordinated water resources development is highlighted. The role of decentralized functions, stakeholder participation, water allocation and demand management are discussed. The importance of effective and user-friendly policy and institutional mechanisms to promote uptake of and derive optimum benefits from technological and management advances is underlined. IWRM tools and approaches are also described for the assessment of water resources and management of demand, social change, conflict resolution, and for regulatory and economic plans.

Key words: IWRM, Water allocation, Demand management, Tools and approaches

Introduction

According to Seckler et al. (1998; 1999) shows that almost all countries in Africa would face either absolute or economic water scarcity in 2025. In addition, these studies project that almost all the African countries will have to import over 10% of their total cereal consumption in 2025. In Ethiopia, rainfed agriculture is practiced extensively. But rainfed agriculture is highly dependent on the quantity and reliability of rainfall, which determine critical decisions such as crop choice and planting dates. Irrigation, if properly designed and managed, helps overcome many of the disadvantages inherent to rainfed agriculture (Sally, 2006). Increasing competition for available fresh water resources means that countries are obliged to make hard choices in developing and allocating water between agriculture and other uses. If water allocations to agriculture are reduced and instead diverted to other sectors, prospects for increasing food production may be further undermined. Population growth and greater demand for water exert increasing pressure on available water resources and lead to water scarcity in many countries and regions. In addition, rising demand intensifies competition among water uses and water users and may trigger disputes and conflicts.

Current and past approaches of water resources management (WRM) have proven inadequate for the global water challenges. These approaches are mostly sectoral management, where each sector (domestic use, agriculture, industry, environmental protection, etc.) has been managed separately, with limited coordination between sectors. These approach lead to fragmented and uncoordinated development of water resources. Water is by nature a flowing resource, which crosses sector boundaries. This is especially true for river basins where upstream water and land practices impact directly the quantity and quality of water in downstream areas. As water becomes scarcer, it is becoming increasingly inefficient to manage water without recognizing the interdependencies between agencies, jurisdictions, sectors and geographical areas. Top-down approaches have dominated the traditional approaches to water resources development, with many central governments directing development of water supplies, provision of water services, and regulation of water uses. This approach has had questionable effectiveness. Central governments have emphasized supply augmentation over demand management, leading to inefficient water resources developments. In many cases, such services would have been more effectively provided by local governments, user groups, or the private sector.

Supply management is dominating the past and current water management. Without demand management, supply management alone has caused negative externalities, making the opportunity cost of water to rise to unsustainable levels. As demand for scarce water resources increases, new sources of water need to be obtained, often at greater cost than previous sources, and with greater potential ecological and social consequences. Water service providers, particularly in developing countries, struggle with financial sustainability, as inefficient operations and low quality of service create a vicious cycle where dissatisfied users refuse to pay water tariffs, limiting the service providers' ability to maintain infrastructure effectively and causing service quality to decline.

The current water issue is often more a crisis of governance than a crisis of physical scarcity, as scarce water resources are allocated inefficiently, unregulated pollution compromises water quality, weak water service providers fail to serve the public, social and environmental concerns are left unaddressed. Given the above shortcomings with traditional WRM approaches, Integrated Water Resources Management (IWRM) has emerged as a means of addressing the global water problems and working toward a sustainable future for water management following the Rio Earth Summit in 1992 through the comprehensive articles stated in Agenda 21 chapter 18 and again Dublin 1992 IWRM principles. The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectoral water plans and programs within the framework of national economic and social policy are of paramount importance. Effective implementation and coordination mechanisms are required. IWRM is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. Since the Rio Summit, states are guided and tried to formulate water policy by adopting IWRM approach.

What does the concept of IWRM mean?

Sally (2006) clearly put the concept of integrated water resources management (IWRM). It underlines that IWRM was emerged of the realization that water policy and water management were often too fragmented to effectively address important questions such as:

- How can society's needs for water be met in a sustainable way?
- How can the aspirations and priorities of different categories of users at local, national and regional levels be addressed?
- How to strike a rational balance between beneficial utilization of the resource and resource protection?

IWRM is a comprehensive approach to water management that takes into account different types of water, combining both quantitative and qualitative aspects. IWRM also offers a platform for managing actual and potential conflicts among various interests and users (e.g. households, industries, agriculture, nature, fisheries, energy and navigation). In general, IWRM means making decisions on the development and management of water resources from a multi-disciplinary, quantitative, qualitative and ecological perspective involving all uses and users of water. IWRM is thus defined as,

> *"Water resources development and management should be planned in an integrated manner, taking into account long-term planning needs as well as those with narrower horizons, that is to say, they should incorporate environmental, economic and social considerations based on the principle of sustainability; include the requirements of all users as well as those relating to the prevention and mitigation of water-related hazards; and constitute an integral part of the socio-economic development planning process."*
>
> Rio Earth Summit, Agenda 21, Chapter 18

> "It is a *process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*."
>
> Global Water Partnership (GWP)

> *"*It *is a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long*-term needs for water resources while maintaining essential ecological services and economic benefits."*
>
> United States Agency for International Development (USAID)

From these definitions, a few key elements can be emphasized: IWRM is a *coordinated* process that *brings together stakeholders*; it also focuses on both *economic and social* *welfare and equity* as well as *protecting ecosystems*; it uses *scientific data or* tools to provide sound base for judgment; and it emphasizes *proper governance* involving *democratic participation*. IWRM is a process of change in order to better achieve 3 key strategic objectives: **efficiency** – maximizing the economic and social welfare; **equity** – in allocation of costs and benefits to promote sustainable social development; and **environmental sustainability.**

Framework of IWRM

In order to address the common challenges and problems of water resources and achieve the strategic objectives, IWRM is framed to guide the water management and development effort at global scale (Fig.1). The framework includes four guiding principles (Dublin principles), key approaches to put the principles into practice, and tools designed to support the development and application of IWRM approaches.

IWRM Principles

At the International Conference on Water and the Environment (ICWE), held in Dublin, Ireland in 1992, over 500 participants representing 100 countries and 80 international and nongovernmental organizations, the following principles were recommended to guide global water management and development efforts.

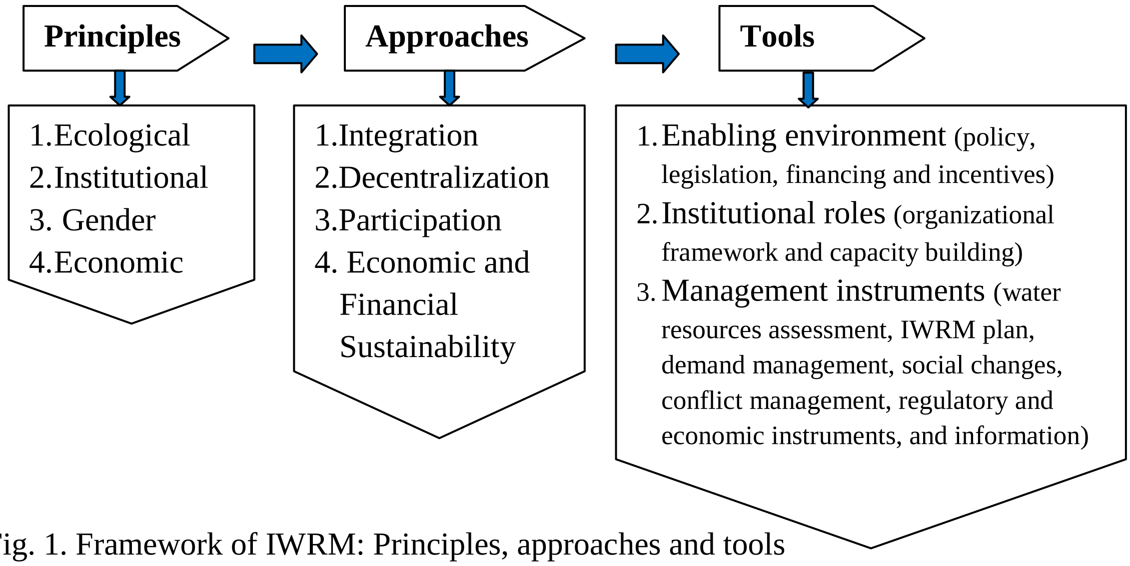

Fig. 1. Framework of IWRM: Principles, approaches and tools

The four principles are discussed below, together with how they guide general IWRM approaches:

Principle 1 - "Ecological": Fresh water is a **finite and vulnerable** resource, essential to sustain life, development and the environment. It calls for a holistic approach to water resources management (WRM), "linking social and economic development with protection of natural systems" (ICWE 1992). Recognizing the river basin as the most appropriate unit for WRM, Principle 1 calls for ***coordination*** across the range of human activities that use and affect water in a given river basin. IWRM approaches incorporate this principle into its emphasis on ***integration*** between all concerned water sectors.

Principle 2 "Institutional": Water development and management should be based on a **participatory** approach, involving users, planners and policy-makers at all levels. This participatory approach is to raise awareness of water issues among policy-makers and the general public. It emphasizes *subsidiarity* – management decisions should be taken at the lowest appropriate level, with central government retaining regulatory and support roles. It advocates increased accountability of management institutions and full consultation and involvement of users in the planning and implementation of water developments. IWRM applies this principle through its concepts of ***decentralization and participation***.

Principle 3 "Gender": **Women** play a central part in the provision, management, and safeguarding of water. The approach emphasizes the important synergy that exists between gender equity and sustainable water management. IWRM includes an emphasis on ***empowering women*** in its focus on participatory management and capacity building.

Principle 4 "Instrument": Water has an **economic** value in all its competing uses and should be recognized as an economic good. The approach emphasizes the importance of economic tools in helping achieve efficient and equitable use of water resources. The human right to access clean water and sanitation at affordable prices must be recognized, but the scarcity of water demands that economic perspectives should not be ignored. In conditions where water is especially limiting, where supply augmentation is not a feasible option, economic tools should play a larger role in determining how limited water resources should be distributed efficiently and equitably. Managing water as an economic good is also a key to achieving financial sustainability of water service provision, by making sure that water is priced at levels that ensure full cost recovery. IWRM approaches include this principle by giving emphasize on ***economic and financial sustainability***.

IWRM Approaches

Seeking to put the Dublin Principles into practice, IWRM emphasizes the key concepts of **I*ntegration***, ***Decentralization, Participation,*** and ***Economic and Financial Sustainability***.

Integration - In contrast to sectoral approaches that have largely failed in the past, IWRM's first approach to the Dublin Principle-1 is by advocating a holistic approach that emphasizes the three goals of **economic development, social welfare, and environmental protection** and that integrates management of all *horizontal* sectors that use and/or affect water. Recognizing the multifaceted value of water, IWRM demands that social concerns and environmental values be recognized while still emphasizing the need to develop water resources for sustainable economic development. In order to effectively coordinate between water supply and sanitation, agriculture use, energy generation, industrial use, environmental protection, and other sectors, new institutions and policies are required. IWRM advocates creating and empowering basin-level organizations to direct water resource management efforts in a hydrological boundary. To facilitate coordinated water resource management, rigorous data collection and distribution is required for multiple physical and socio-economic measures.

Decentralization - The second approach of IWRM is to place responsibility for water resource management at the lowest effective administrative level, satisfying the subsidiarity priority of the second Dublin principle. River basin organizations, in addition to facilitating inter-sectoral integration, also provide a means of decentralizing management authority from national governments to the basin or sub-basin level, where special attention can be paid to specific local problems and where institutional accountability is greater. The private sector can play a role in providing water services and should be allowed to bring its technical expertise and efficient management practices into areas where central government has struggled to provide sustainable service.

Participation – The third approach of IWRM is to strengthen community-based organizations, water user associations, and other stakeholders to enable them to take a greater role in management decisions. Giving a voice to all user groups and affected groups ensures that social welfare considerations are given proper weight. Full and effective participation requires gender awareness and special efforts to allow women and vulnerable groups to participate in management decisions, in accordance with the third Dublin Principle. IWRM emphasizes broad-based capacity building and support for the formation of user groups and representative associations.

Economic and Financial Sustainability - The increasing costs of water supply and the widespread inefficiencies in water service delivery in many parts of the world demand that proper attention be given to the ***economic value of water***. To achieve long-term economic sustainability, water must be priced at its full cost, accounting for the cost of withdrawing and delivering the water, as well as the opportunity cost and both economic and environmental externalities associated with using that water. Laws and policies should establish clear water use rights and create markets for these rights to be traded, allowing water to be used by those sectors for which it has the greatest value while still protecting social and environmental concerns. To achieve financial sustainability of water service delivery, user fees should at a minimum cover O&M costs of service provision, so that water service providers can achieve full cost recovery and satisfy the public water needs. Often, short-term policy targets must be limited to financial sustainability of water services, but full economic sustainability is the long-term goal of IWRM.

IWRM Tools

The Global Water Partnership has created an IWRM toolbox designed to support the development and application of IWRM approaches. Because IWRM is such a broad process, requiring change in multiple sectors and at multiple levels, there is no specific blueprint that can be applied to any given situation. Consequently, GWP's toolbox aims to provide IWRM practitioners with a wide range of tools and instruments that they can select and apply according to their needs. The tools fall into three main categories: (a) Enabling Environment, (b) Institutional Roles, and (c) Management Instruments. Each category has several sub-categories, which in turn consist of several tools, with 49 tools in all (GWP 2003a).

a) ***Enabling Environment***. This category consists of three sub-categories:

- *Policies* to set goals for water use, protection and conservation. Policy development is important for setting national objectives for managing water resources and delivering water services. Policies should embody the IWRM concepts of integration, decentralization, participation, and sustainability, taking a holistic view of water's value and considering potential users of water, land uses and water quality.
- *Legislative framework* to translate water policy into law. This covers ownership of water, permits and rights to use water, and the legal status of water user groups.
- *Financing/incentives* to allocate financial resources to meet water needs. Financing and incentive structures are needed to fund capital-intensive water projects, support water service delivery, and provide other public goods such as flood control and drought preparedness. They can be resources from the public sector, private finance, and joint public-private partnership.

b) ***Institutional Roles***. This category consists of two sub-categories:

- *Creating an organizational framework*. Tools focus on developing the institutions needed to manage water resources within an IWRM framework, shifting from top-down, centralized management to decentralized and participatory management. Such institutions include river and lake basin organizations, regulatory bodies, enforcement agencies, coordinating apex bodies of user associations, and public and private service providers. These organizations need to be given clear rights and responsibilities, and allow integration between them.

- *Building Institutional Capacity*: Developing human resources is an integral part of developing effective water institutions at all levels, as regulatory bodies, civil society organizations, service providers, and central and local government officials will all need to be educated in IWRM principles and trained in the skills and tools of effective water management. Capacity-building should focus particularly on strengthening the ability of women and other disenfranchised groups to participate in water management.

c) ***Management Instruments***. Once the proper enabling environment and institutions are in place, these instruments address specific management problems. This category consists of eight sub-categories:

- *Water Resources Assessment* - understand resources (quantity and quality) and social, economic and environmental needs of water, involving data collection and analysis in order to inform decision-making with a comprehensive view of water resources and water users.
- *Plans for IWRM*: combine development options, to assess impact of resource use and human interaction. They can be water allocation plan, land use plan, or environmental plan at national, regional, sectoral and basin scales.
- *Demand management*: Includes efficiency in water use to manage all sectoral demands and the supply, to improve supply efficiency, increase water reuse. Subsidies and regulation to encourage technology improvements, price signals, improved metering or measurements, and public awareness campaigns to change user behavior are all instruments that can be used to improve efficiencies.
- *Social inclusion:* Promote general public awareness, stakeholder participation, and transparency of institutions, in order to better enable the public to take a participatory role in IWRM.
- *Conflict resolution:* Manage disputes and ensuring equitable share of water benefits
- *Regulatory and economic instruments*: allocate water, set water use limits, use prices for efficiency and equity. Regulatory tools include emission standards,

technology standards, and price controls, while economic tools include pollution charges, targeted subsidies and incentives , and markets for water use rights or pollution permits

- *Information Management and Exchange*: Sharing of knowledge for better water management.

Many of the tools are complementary, and successful application of one tool to a given problem may depend on simultaneous application of a number of other tools. For example, successful implementation of emission standards or fees will depend on a fully empowered monitoring and regulatory agency.

IWRM Practices in Ethiopia

How is the context of the water sector towards practicing IWRM? Do the existing policy instruments practiced in order to meet the strategic objectives (economic efficiency, equity, environmental sustainability)? The practices of IWRM in Ethiopia are thus reviewed through the assessment of policy reforms, the establishment of basin level management, and application of IWRM tools and concepts such as stakeholder participation, economic and regulatory instruments.

How are the IWRM principles reflected in the Water Policy?

Review of policy, legislative and institutions from IWRM concept against the division of regulatory and service functions, decentralisation, commercialisation (water as an economic good, commercial principles) and the participation of private sector and the community is described in this section. Following the Rio Earth Summit (1992), IWRM has gained wide acceptance in water policy reforms of Ethiopia as the best way to tackle the challenges by ensuring **equity** in water allocation; ensuring improvements in **water use efficiency** and **effectiveness;** ensuring sustainable **water availability** for environment, development, poverty reduction; and maintain **environmental** sustainability. Accordingly, in 1999, Water Resources Management policy of Ethiopia was formulated by adopting the principles of IWRM. Fundamental principles of the policy include water is a natural endowment commonly owned by all the peoples of

Ethiopia. Some of the main elements of the policy are: every Ethiopian citizen shall have access to sufficient water of acceptable quality, to satisfy basic human needs; water shall be recognized both as an economic and a social good; water resources development shall be underpinned on rural-centered, decentralized management, participatory approach as well as integrated framework; and management of water resources shall ensure social equity, economic efficiently, systems reliability and sustainability norms (MOWR, 1999). Sound institutions and policies, together with the development of the required organizational capacity and skills for enforcement and regulation, are vital to ensure uptake of technological innovations and advances and that the ensuing benefits are equitably distributed, particularly among the most disadvantaged sectors of society. Key institutional attributes include: demarcation of the roles, rights and responsibilities of the various actors in the water sector; promotion of new forms of partnerships for investment, operation and maintenance of facilities; participation of stakeholders at all levels and scales; and emergence of financially self-reliant service delivery organizations that are responsive and accountable to water users.

The need for a stronger legal framework also became visible with the view to redefining the emerging IWRM concepts and clarifying both the specific and crosscutting duties and responsibilities of key institutions and other stakeholders which might be involved in the sector. The Federal Government has enacted the Water Resource Management Proclamation No. 197/2000. This act empowers the Ministry of Water Resources (MOWR) to: (i) issue permits for water use; (ii) determine the allocations and manner of use of water resources between various users; (iii) prepare directives in consultation with the public bodies concerned; (iv) issue directives regarding water use restrictions and rights; (v) set water use priorities on the basis of a basin master plan and ensure adherence to them; (vi) encourage the establishment of water user associations (WUAs) and service providers at the initiation and will of the users; (vii) settle disputes among various water users; (viii) delegate powers and duties to the appropriate body, etc. Thus the proclamation clearly stipulates that it is legally possible for MoWR to issue water use permits to WUAs through regional and district entities, implying that the mandate for establishment of a legalized WUA rests with MoWR and affiliated bureaus at different levels in the regions.

Later, the Council of Ministers Regulations No. 115/2005, which is a necessary instrument for the effective implementation of the proclamation, was issued. Subsequently, the River Basin Councils and Authorities Proclamation No. 534/2007 was formulated aiming towards establishment of river basin councils and authorities as one of the main instruments to implement IWRM which is actually the pillar of the policy. Therefore River Basin Councils and Authorities have been established whose overall objectives shall be to promote and monitor the IWRM process. Out of the 12 or more basins, these proclamations led to the creation of the Abbay and Awash Basin High Councils and Authorities consecutively established as per the Council of Ministers' Regulations No. 151/2008 and 156/2008 respectively. In fact, the inclusion of water user groups in the Council is questionable.

Although it is too early to review several components of IWRM, the policy framework, proclamations and regulations are clearly set and formulated. However, institutional development is critical to the formulation and implementation of IWRM policies and programmes. The organizational structure of the Ministry of Water and Energy indicates there are a lot of departments and divisions working for development and regulatory. First of all there is no clear demarcation of regulatory and service functions at Ministry level, many of the water, energy and irrigation functions are still centralized by the Ministry. Flawed demarcation of responsibilities between actors, inadequate co-ordination mechanisms, jurisdictional gaps or overlaps, and the failure to match responsibilities, authority and capacities for action are all major sources of difficulty with implementing IWRM. For example, the basin executive body, i.e., the River Basin Authority has given overlapping duties and responsibilities with the executive powers of the Regional States. And yet, traditional, sectoral and fragmented approaches to water resources management with different agencies and departments pursuing divergent interests (e.g. the promotion of irrigation development at the expense of ecological services) must be overcome. Upstream and downstream water-users need to develop a better understanding of their inter-dependencies through stakeholder platforms and water user associations. Water management decision-makers should not only have good technical skills and competencies, but should also be encouraged to consult with, and be sensitive to the views of all stakeholders. The organizational structure of the Ministry of Water and Energy is indicated in Fig. 2. The organizational setup of the water sector did not consider the mechanism to involve the water users, the private sector and other stakeholders and sectors. A stakeholder group has to be set up by the Government to evaluate various water allocation options and the development of a co-operative framework to make decisions based on full stakeholder participation. Without clear set up of institutional roles and the development of necessary functions and platforms, the holistic IWRM cannot be realized.

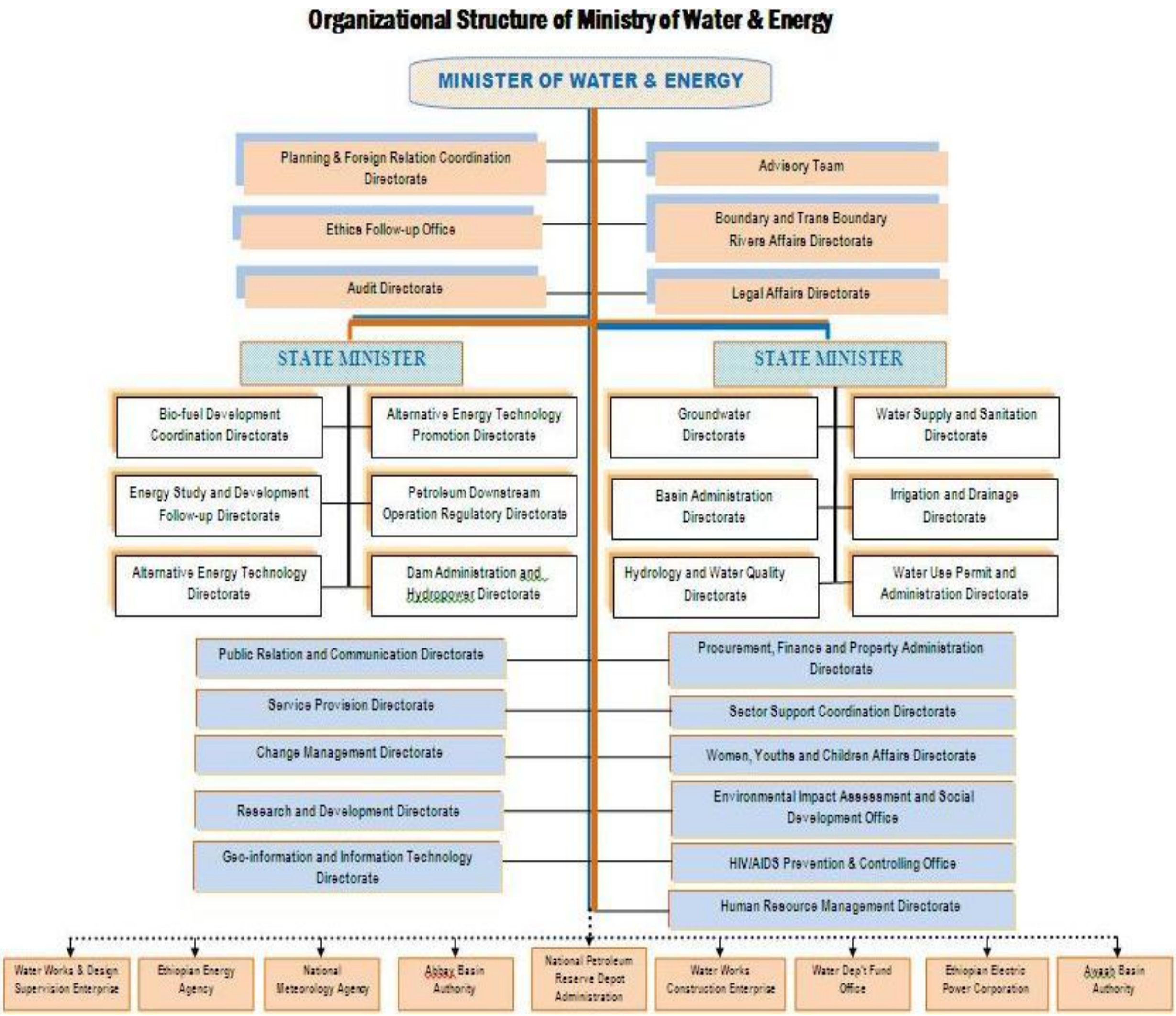

Fig. 2. Organizational structure of Ministry of Water, Irrigation and Energy

For comparison and as an example of a good practice, the institutional roles and organizational framework of Kenya is presented in Fig. 3. This can be used as a reference how IWRM principles are devolving into practice having clear demarcation of regulatory and service functions and the roles and responsibilities of the institutions from higher to the user's level.

The implementation of important regulatory instruments is vital even though the enforcement of these instruments is very much dependent on the establishment of strong institutional framework. The contexts of some of the important regulatory instruments are highlighted in the following paragraphs.

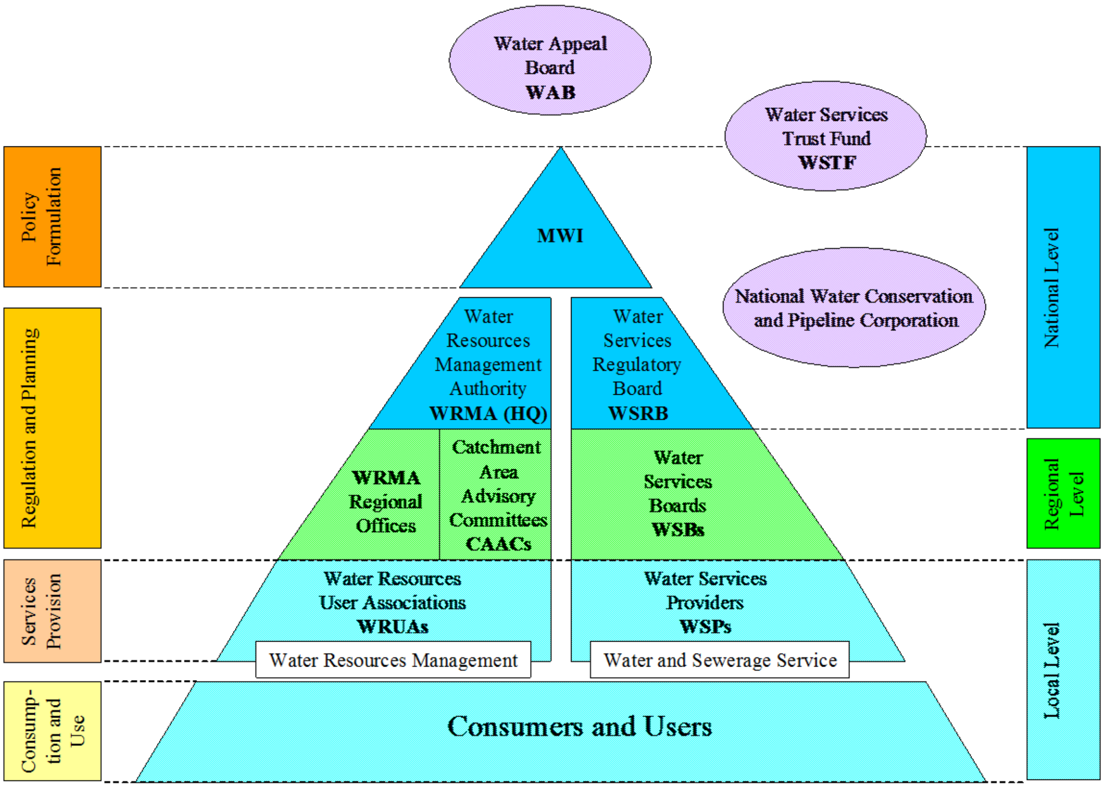

Fig. 3. The Organizational setup of Ministry of water and irrigation of Kenya

Table 1. Roles and responsibilities of institutions in Kenya

Institutions	Roles and Responsibilities
Ministry of Water and Irrigation (MWI)	Development of legislation, policy formulation, sector coordination and guidance, and monitoring and evaluation
Water Resources Management Authority (WRMA)	Planning, regulation and management of water resources and to contributing to policy formulation
Catchment Area Advisory Committees (CAACs)	Regional bodies set up at catchment level to advise WRMA on the management of water resources
Water Resource Users Associations (WRUAs)	Local bodies set up by water resource users to enable communities and water users to participate in water resource management
Water Services Regulatory Board (WSRB)	Regulate matters related to water services
Water Service Boards (WSBs)	Regional bodies responsible for regulation and planning of water and sewerage services
Water Service Providers (WSPs)	Local bodies set up for the provision of water and sewerage services under license from the WSBs
Water Services Trust Fund (WSTF)	Financing provision of water and sanitation to disadvantaged groups
Water Appeal Board (WAB)	Arbitration of water related disputes and conflicts
National Water Conservation and Pipeline Corporation (NWCPC)	Construction of dams and drilling of boreholes
Kenya Water Institute (KEWI)	Training and Research
National Irrigation Board (NIB)	Development of Irrigation Infrastructure

Standards and guidelines: This includes to control the quantity of water withdrawn by users from the natural water system within set time periods; control the discharge of waste products (on the quantity, quality, timing and location of discharges) into water courses; and require specific technologies to be employed to either reduce water use or waste loads, etc. These standards are not effectively implemented at all levels likely due to low power and implementation capacity of the regulatory agencies.

Land use planning controls: In the context of IWRM the management of land use is as important as managing the water resource itself since it will affect flows, patterns of demand and pollution loads. Moreover, effective land use planning can also help promote water recycling and planned reuse. Land uses may be regulated in upstream recharge areas and around reservoirs to prevent pollution, siltation and changed run-off regimes. However, although it has been formulated for the region since long time, this regulation is not under implementation.

Position of consumptive and non-consumptive users within the basin: "Consumptive" water use raises questions about the exact location of each user along a river, suggesting that the possibilities for sequential use of water be considered when locating water-depending activities. However, it should be noted that currently the Basin Authorities are not fully capable to regulate the consumptive and non-consumptive uses under the situation where there is low environmental concerns.

Efficiency of economic tools: The use of economic instruments primarily requires the standard of allocation of water based on the consideration of social and economic demands. Prerequisites for successful application of most economic instruments are appropriate standards, effective administrative, monitoring and enforcement capacities, institutional coordination, and economic stability. Some notable examples of economic instruments include water prices, tariffs and subsidies, incentives, fees and fee structures, water markets, and taxes. The implementation of economic tools is however, not possible or become difficult under the existing unregulated water demand management and without the database both quantitative and qualitative status of the basin resources which are the basis of the economic tools. However, economic tools may offer several advantages, such as providing incentives to change behaviour, raising revenue to help finance necessary investments, establishing user priorities and achieving management objectives at the least possible overall cost to society.

Lessons from IWRM Applications

- The changes required by IWRM can be sometimes revolutionary, and involve drastic modifications of the current ways of doing business. Top-level political support is critical, as well as a broad base of popular support for any large-scale changes to take place. The factors that could trigger demand for water reforms through IWRM include financial struggles of government administrations, water scarcity and droughts, natural disasters, water quality /pollution crises, and dissatisfaction of users with water services. All affected stakeholders must be convinced of the value of IWRM and any reform brought by it. Stakeholder consultations that give voice to all concerns and that provide clear justifications for reforms, backed up with solid data, can help build support for IWRM.

- While the IWRM principles provide general directions, the institutional context of a given water management problem must dictate the specific approach used. Numerous gradual steps must therefore be taken to break the vicious cycle of poor water service delivery and low willingness-to-pay, involving institutional reform to remove political influence, formation of user associations and capacity-building, improved stakeholder consultation and participatory management, and private sector participation. IWRM approach must focus on building on existing strengths and fixing weaknesses.

- Experience shows that implementation of IWRM is a process that could take several decades. For example, France took near 30 years while Spain has spent over 20 years to reach to today's stage of river basin management and to implement IWRM. Certain goals such as full economic sustainability and reconciling human water needs with the needs of ecosystems will require substantial changes to current practice and culture, and will therefore take even longer to achieve. Given the short-term focus of politicians and policymakers in most areas, there is always the temptation to seek quick solutions and abandon the IWRM process if immediate gains are insufficient. But persistent, patient progress on multiple fronts is necessary to achieve the ultimate goals of IWRM.

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SWHISA's Experience in Participatory Development and Management of Smallscale Irrigation Schemes, Amhara Region

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Abstract

Farmers' participation is commonly perceived as being necessary only in the project implementation phase where by the community is expected to merely contribute unskilled labor, locally available construction materials and some token cash. However, participation is an all-encompassing process that requires active involvements of beneficiaries in decision making in all project phases from inception to monitoring and evaluation in collaboration with other stakeholders. However, the performance of the existing irrigation schemes is below expectation mainly due to low participation of farmers in planning, design and construction process.

In view of the increased focus on operation and maintenance and Participatory Irrigation Management, Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) expressed the need to develop a cohesive strategy to improve Participatory Irrigation Management aimed at improving the performance of SSIS in the Amhara region. An implementation guideline has been developed and distributed to wereda CPA and IADP. Based on the PIDM approach, the willingness of the water users has been checked during the awareness campaigns and sensitization workshops and formation of users' organization were some of the activities undertaken at the new irrigation schemes before the construction work started. This paper presents a step-by-step PIDM procedures and resulting outcomes based on four new small scale irrigation schemes as case studies in the Amhara region.

To develop a sense of ownership and responsibility for O&M among the users of irrigation schemes, it is required that the users are involved in all the stages of the development of an irrigation system. Especially during the design of the scheme, maximum users' participation is a prerequisite for successful scheme development, because the most important decisions are made during this stage. To enable farmers to participate effectively in the design of irrigation scheme, it is important to consider the elaboration of the design as a step-by-step process during which farmers' priorities and preferences are matched with technical and financial possibilities.

Key words: Participation, Participatory procedures Water users, SWHISA

Introduction

The concept of an irrigation system refers not only to the physical aspect, such as channels and control structures, but also to the management structure by which the physical system is planned, designed, constructed and operated. These two aspects are functionally interdependent and need to be understood as a whole. Managing an irrigation system is a much more complex and difficult problem than is commonly recognized. Part of the explanation for limited success lays in the inadequate recognition that delivery and allocation of water involves complicated social, organizational, legal and economic questions in addition to the undoubtedly important technical matters.

The most underrated and misunderstood dimension of irrigation development today is that of the farmer, who has to use the water supplied by the irrigation system. Much is known about the design and construction of dams and canals, crop water requirements and operational irrigation practices. The social and organizational aspects of irrigation, unfortunately, continue to be the Achilles heel of system development, improvement, and operation. Governments and donors are slowly realizing the high economic and socio-political costs that occur when farmers and users are only spectators in designing, organizing, and operating irrigation projects and programmes, which directly affect them and depend on their willing participation (Verheijen, 2010).

To avoid deterioration of irrigation infrastructure and decreasing productivity of irrigated agriculture due to deficient irrigation systems, governments and financing institutions are now aware that effective farmer participation in the development and management of irrigation systems is required. The main objective of this review paper is to understand application and importance of participatory approach towards the development and management of Small Scale Irrigation Systems (SSIS). The material for this paper consisted of the participatory irrigation development and management (PIDM) procedure prepared by Sustainable Water Harvesting and Institutional Strengthening for Amhara (SWHISA) and reviewing the field reports and observations during exercising the approach at the new SSIS under SWHISA support.

Definition and purposes of participation

The terms 'participation' in development and 'participatory approaches to development' are now used widely –so widely that they have almost lost their meaning. These terms were introduced to emphasize the importance of people having control over their own development. The emphasis on participatory approaches is based on the observation that well-being is closely linked to the capacity to act (Mathie and Samuel, 2006)

Farmers' participation is commonly perceived as being necessary only in the project implementation phase where by the community is expected to merely contribute unskilled labor, locally available construction materials and some token cash. However, participation is an all-encompassing process that requires active involvements of beneficiaries in decision making in all project phases from inception to monitoring and evaluation in collaboration with other stakeholders (BDU, BOWRD and SWHISA, 2009).

There are basically seven ways that development organizations interpret and use the term participation ranging from passive participation, where people are involved merely by being told what is to happen to self mobilization, to active participation, where people take initiatives independently of external institutions (Box 1). However, if the objective is to achieve sustainable development, then nothing less than functional participation will suffice (Jerry et al, 1995).

Key factors for effective participation are (Verheijen, 2010).

a) Participation of any kind stems from people's decisions to devote a portion of their time, thought and energy to deal with problems through some form of collective action;
b) Organization of the concerned people makes participation patterned and predictable enough to acquire some recognizable and productive structure;
c) Incentives give people motivation and make participation more sustainable; and
d) Leadership makes participation more coordinated and effective by providing direction, encouragement and discipline.

The main purposes of participation are to: a) enable people to define and choose their own objectives; b) enable people to define their own ways to achieve their own objectives; and c) enable people to have full control over the benefits from the activities undertaken by them in their own ways to achieve their own objectives.

Box 1: Typology of Participation (adapted from Pretty et al, 1995).

Greatest dependence on external agents

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Passive: No feedback (the information shared belongs to the external agent only)

Participate in information giving: People answer the questions posed, but have no opportunity to influence decisions as information is not shared

Consultation*:* People's views taken into account, but decisions made by external agent who is under no obligation to accept local viewpoints

Participate for incentives: Time-bound, so participation ends when the incentives run out

Functional participation: form groups to meet pre-determined objectives driven by external stakeholders, usually after the planning phase

Interactive participation: People closely involved in information gathering, planning and decision-making; local perspectives favored, thus giving local stakeholders an incentive in maintaining structures and practices

Self mobilization: People take the initiative in planning, decision-making and action. Outside agencies provide technical support and play a facilitating or catalytic role, rather than directing the activities

Greatest self-reliance ↓

Approaches for participatory irrigation development and management

The regional government of the Amhara National Regional State (ANRS) has recognized irrigation as a vital component for the improvement of food security in the region. However, the performance of the existing irrigation schemes is below expectation mainly due to low participation of farmers in planning, design and construction process. Diagnostic survey report of pilot irrigation schemes conducted by

SWHISA revealed that water shortage , overtopping caused by the poor physical conditions of existing irrigation infrastructure and inadequate maintenance of irrigation infrastructure are reasons for the low performance as the water users' organizations (WUOs) have a chronic lack of funds for the proper management of irrigation systems. In addition, lack of an integrated approach in the provision of technical support and follow up to WUOs, and weak coordination and linkages among stakeholders involved in irrigation development and water management have also aggravated the problem.

In view of the increased focus on operation and maintenance (O&M) and Participatory Irrigation Management (PIM) Sustainable Water Harvesting and Institutional Strengthening in Amhara (Project expressed the need to develop a cohesive strategy to improve Participatory Irrigation Management (PIM) aimed at improving the performance of SSIS in the Amhara region.

Based on the aforementioned concept of participation, review of existing strategies and practices as well as the experience with the implementation of projects based on farmers' participation in the development and management of irrigation systems in various countries in Africa and elsewhere, SWHISA has developed a step-by-step approach for the participatory development and management of small-scale irrigation systems in the Amhara region.

Participatory Irrigation Development and Management (PIDM) refers to the (active) involvement of farmers in the development and management of (their) irrigation systems along with the government, ranging from: a) being only informed; b) being informed and consulted; c) being informed, consulted and involved in decision making; and d) being informed, consulted, involved in decision making and responsible for irrigation management.

Irrigation Management Transfer (IMT) usually refers to the relocation of responsibilities and authority for irrigation management from government agencies to WUOs at sub-system levels (i.e. secondary and/or tertiary canals) or for entire irrigation systems, including: a) transfer of irrigation management functions, including maintenance and payment for irrigation services; and b) transfer of decision-making authority, ownership of scheme infrastructure and water rights. Terms as "turnover, take-over, handing over, devolution, privatization, self-management and disengagement" are used synonymously with IMT.

Expected benefits of PIDM

It is expected that the successful implementation of PIDM will have the following main important benefits as clearly stated in the subsequent sections of the procedure manual:

- Better functioning of irrigation systems due to "sense of ownership" among farmers due to their active involvement in the planning, design and construction supervision of the rehabilitation/modernization works;
- Improved operation and maintenance (O&M) of the irrigation schemes as farmers have full control over the planning and execution of the maintenance works and water distribution;
- Lower O&M costs as farmers are able to undertake the works at cheaper rates with their own (financial) resources (cost awareness);
- More efficient and equitable distribution of irrigation water as farmers have better control over irrigation supply and distribution;
- Improved payment of Irrigation Service Fee (ISF) as farmers are allowed to keep a significant portion of the collected fees for the O&M of the irrigation and drainage facilities;
- Less dependency on Government budget for development and O&M of irrigation and drainage systems as farmers will share in the costs;
- More transparent and accountable relations between farmers and the irrigation agency as farmers will only pay for the services provided in accordance with the terms and conditions of service contracts and;
- Increased irrigated area and higher yields due to more adequate, timely and equitable supply of irrigation water

Phases of PIDM Approach

The PIDM approach is sub-divided in the following 4 phases:

1. Study and Awareness Phase;
2. Design and Formation Phase;
3. Capacity Building and Construction Phase; and
4. Irrigation Management Phase.

The 15 steps of the PIDM approach are also shown in the flowchart below (Figure 1).

SWHISA's experience in introducing PIDM

SWHISA project, as part of the overall project activities, supports the construction of four irrigation schemes with full financial and technical assistance at East Belesa, Wereillu and Menz mama woredas. SWHISA has allocated a total budget of Birr 6.24 million for the four schemes. Details are presented in Table 1.

Table 1. Irrigation Cooperatives (ICs) formed at the New Irrigation Schemes

Wereda	**Name of Scheme**	**Command area (ha)**	**Project Cost**	**Number of Beneficiaries**		
				Male	Female	Total
Were Illu	Barneb	81	1,317,028.38	397	65	462
Goncha	Gedil Ager	12	105,966.52	50	5	55
E. Belessa	Genet	24	3,802 693.89	137	6	143
Menz Mama	Enat Wuha	12	405,722.76	62	24	86

Obviously, one of the primary objectives of Water User Associations (WUA) and Irrigation Cooperatives (IC) is to operate and maintain the irrigation system efficiently and economically, and with the full and active participation of all the water users, as much as possible, in the various management activities.

However, the current challenge with regard to irrigation schemes in the project weredas is water users' "lack of sense of ownership" in the overall operation and maintenance activities. It has been clearly mentioned in one of the reports of the Canada International Development Agency (CIDA) monitor, who frequently monitors the performances of the project:

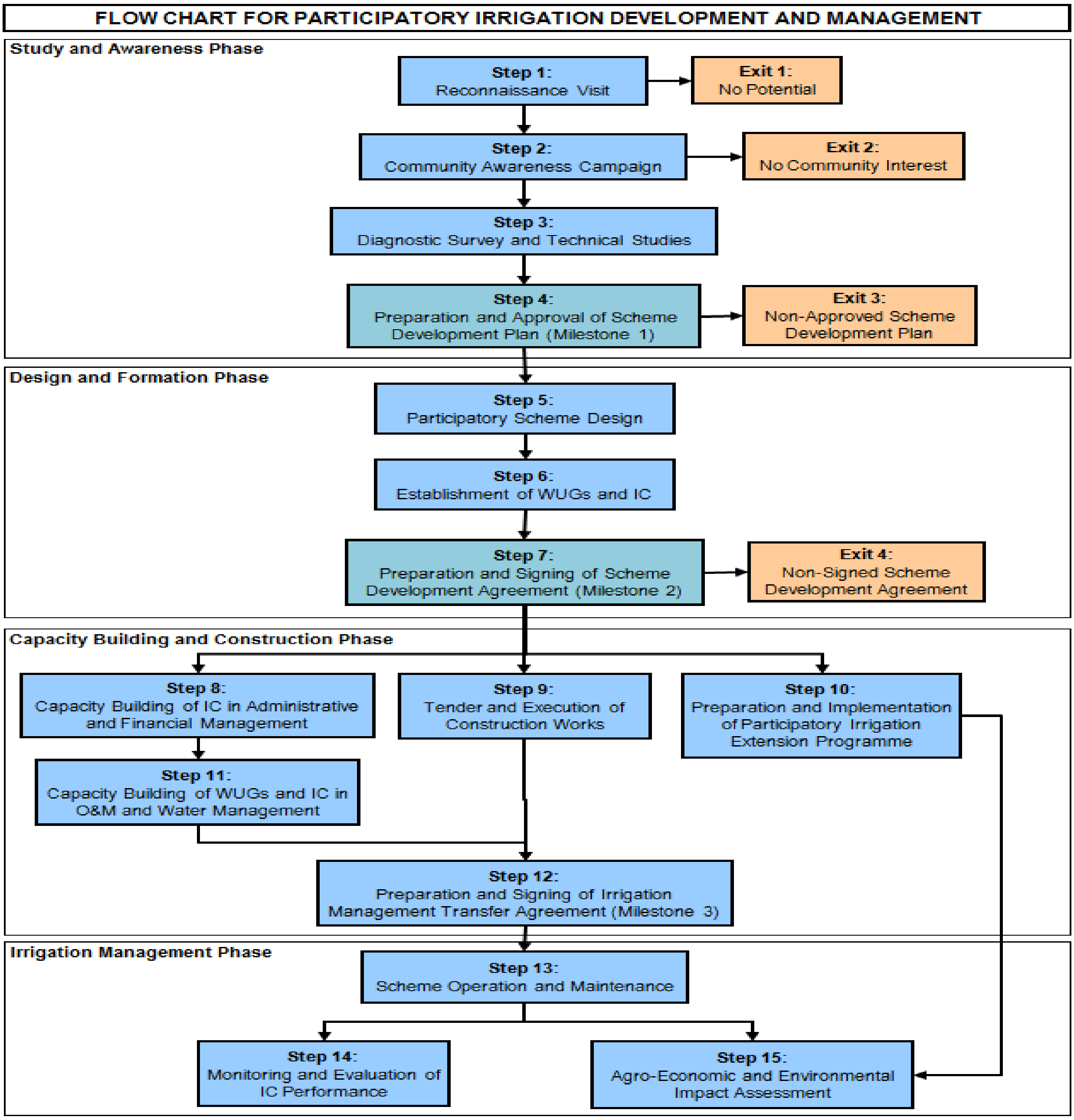

Fig. 1. Flow Chart for PIDM (Adapted from PIDM Procedural Manual, SWHISA 2011)

"There are concerns about the lack of involvement of water users as well as Wereda Irrigated Agriculture Development Process (IADP), Cooperatives Promotion Agency (CPA) and extension staff in the implementation of rehabilitation works by contractors. This seems to be a wide spread concern and is very worrisome. That's because nearly all reviews of existing small scale

schemes point to lack of "ownership" by water users of these schemes. And this lack of ownership is a significant, if not the greatest constraint to scheme success.

Following the development of PIDM strategy document and subsequent trainings, a concrete action has been made in implementation of important steps of the strategy particularly at the newly constructed irrigation schemes with SWHISA support. An implementation guideline has been developed and distRibbuted to wereda CPA and IADP. Based on the PIDM approach, from the very beginning the willingness of the water users has been checked during the awareness campaigns and sensitization workshops and formation of users' organization were some of the activities undertaken at the new irrigation schemes before the construction work started.

PIDM procedures and results of the case studies

Community awareness campaigns

One of the main aims of the Community Awareness Campaign is that the farmers have to become aware that they themselves have to participate actively in all stages of the PIDM approach. Accordingly, the awareness campaigns have been organized and conducted with the presence of wereda and regional level stakeholders. Generally the objectives of the awareness campaign were to:

- ensure the willingness of the beneficiaries; and upper- and down-stream water users towards the construction of the schemes,
- assess the extent and type of beneficiaries' participation during the development and management of the schemes,
- discuss with the community on the importance of establishing irrigation water users' organization and,
- identify and discuss duties and responsibilities of stakeholders to be involved in the implementation of the stated SSIS.

Formation of Water User Groups (WUGs) and the IC

ICs have been organized before the construction work of these new schemes. The formation of the ICs was on the basis of the newly approved organizational guideline of the regional CPA, which was recently reviewed based on the recommendations stated in the PIDM guideline document. At this stage review and adoption of the IC bylaws and the election of the members of the Management Committee (MC) is also included.

The ICs have been legally registered and opened a bank account after fulfilling the requirements stated by the new guideline, one amongst which states at least 51% of the water users (majority) should be a member of the water users' organization. The ICs have already discussed the issue of collecting an ISF in order to have sufficient funds for the O&M of the irrigation scheme, but the level of the ISF has not been set yet.

Diagnostic survey

The general objective of the Diagnostic Survey is to assess the existing social, economic and institutional conditions of the irrigation system, to descRibbe layout of the irrigation system as well as to establish baseline data for the irrigation scheme. The implementation of the Diagnostic Survey has been conducted by private consultants. During the study and design process the involvement of users was not as envisaged by the PIDM procedure. The challenge to the consultants was that, the participatory process is time taking, incurring additional costs and low capacity in terms of applying participatory tools and techniques during study and design. This has resulted in limited users' participation. Hence, this needs to be reconsidered as the current trend towards SSIS study; design and supervision work seems to require out-sourcing to the private companies.

Participatory scheme design review meetings

The result of the diagnostic survey, using PRA tools, conducted at the existing pilot irrigation schemes at SWHISA project weredas revealed that, traditionally, irrigation schemes have been designed by engineers without consulting the farmers as the main users of these schemes. Consequently, the built schemes were not responsive to the needs and preferences of the farmers. The final result was that the users did not consider the O&M of the schemes as their responsibility, because they did not consider themselves as the owners of the irrigation schemes. The farmers regarded the irrigation agency, which had designed and constructed the schemes, to be responsible for O&M.

But, these agencies were often not capable or willing to perform the required O&M tasks, because they consider the work as the mandate of the users. . Consequently, the performance of irrigation systems is poor and its sustainability is low.

During the preparation of the scheme designs, the farmers' preferences with regard to the layout of the scheme were not properly assessed and discussed at SSIS, including the supply of irrigation water.

It is clear that in the case of Genet SSIS of East Belessa wereda, the "water rights" of the households on the left bank of the river were not respected. Because the supply of irrigation water to the left bank was not considered in the final scheme designs at all. It resulted in a conflict between the landholders having land on the right bank and those with land on the left bank. However, during scheme design review meetings organized with the support of SWHISA in 2011, the water users have mentioned the problem and request to modify the existing scheme design. The farmers' request was appreciated by the team and immediately it was proposed to modify the design by reducing the length of the secondary canals on the right bank in order to have funds for the construction of a canal to the left bank. The IC management has also confirmed that the IC fully supports the idea to supply irrigation water to the left bank. The amendments in the scheme design were also fully accepted by BoWRD and SWHISA. Later the contractor has been informed about the proposed changes in the scheme design and received the modified designs for implementation.

The same is true for Barneb SSIS of Wereillu Wereda that water users requested to revise the scheme design by including a retaining wall on the main canal. SWHISA and BoWRD including wereda level partners appreciated the request of the farmers and responded positively to revise the design accordingly. This has demonstrated that users' participation in the overall scheme construction is more than contRibbution of labor and construction materials.

Handing over the scheme construction work to the contractor

Though the ICs management members were not involved during the scheme construction bid process, a formal meeting was organized to hand over the construction site and to introduce the contractors with the ICs management and wereda stakeholders. The contractors were also openly informed that the ICs are the owners of the scheme and would be actively involved during the subsequent formal construction supervision activities with the concerned government agencies at wereda, zonal and regional level. In the mean time the IC management was informed about the total cost of the scheme construction project, date for completion and handing over of the scheme.

Monitoring and quality control during the execution of the construction works

The role of the ICs and users' expected contRibbution during the construction of the schemes including monitoring and evaluation has been clearly defined. The ICs formed at these new irrigation projects are being actively involved in the day-to-day follow up of scheme construction and participate during the joint monitoring and construction supervision with the regional and zonal Irrigation Design and Development Process (IDDP) and SWHISA experts. The users' participation at these schemes is more than labor and local construction material contRibbution. The ICs have taken the initiative to assign their representatives on daily basis to follow up the quality of construction works and to inform the wereda IADP and zonal and regional IDDP whenever the need arises. In this regard Genet and Barneb ICs have demonstrated better sense of scheme ownership from the very beginning and actively took part in decision making.

Moreover, concrete actions are being taken by the water users whenever sub-standard construction materials and improper material ratio such as sand-cement-gravel are used. Though it was challenging to accept, the contractors are also well aware and recognized the water users as the owner of the scheme and have the authority to stop the construction work if they believe that quality of the construction work is compromised.

IC capacity building

As it is envisaged from the beginning, upon completion of the construction, the ICs will take over the O&M responsibility for the irrigation schemes. The weredas have organized a training to develop the capacity of the newly established ICs in administrative and financial management and scheme O&M. This capacity building training includes the assessment, billing and collection of ISF. This is a preparatory work for the IC management to be fully functional after the scheme construction work is completed and handed over to the beneficiaries.

Gender issues

In principle, during all stages of the PIDM approach, the specific needs and preferences of female farmers needs to be taken into account with regard to the planning, design and management of the irrigation system. As it is recommended in the procedure manual and amended in the ICs establishment guideline, at least 20% of the seats in the Management Committee (MC) of the IC are reserved for female farmers to ensure that the specific needs and preferences of female farmers are taken into account during the planning and execution of the O&M activities.

To develop a sense of ownership and responsibility for O&M among the users of irrigation schemes, it is required that the users are involved in all the stages of the development of an irrigation system. Especially during the design of the scheme, maximum users' participation is a prerequisite for successful scheme development, because the most important decisions are made during this stage. To enable farmers to participate effectively in the design of irrigation scheme, it is important to consider the elaboration of the design as a step-by-step process during which farmers' priorities and preferences are matched with technical and financial possibilities.

Lessons Learned

- Involving farmers as early as the planning phase ensure that project planning, design, construction and management are acceptable to individual farmers and it also enhances farmers' sense of ownership.
- The strongly participatory processes imbedded in PIDM promotes both individual and community participation. It also encourages commitment and contributions towards a set of common goals and objectives, as articulated by the consensus-driven Action Plan.

- Firmly-grounded community engagement fosters self-reliance and helps to decentralize planning, thus reducing the long-term dependency of irrigation water users on the government budget for O&M of irrigation schemes. It is a truly bottom-up approach to facilitating the development of irrigation projects, both large and small scale.
- Evidence to date from Genet and Barneb SSIS suggest that the PIDM based engagement process will lead to better designed irrigation projects because of required engagement conditions in participatory scheme design that ensure better appreciation of the development and management objectives of irrigation.
- Establishing users' organization at the early stage of the process allows irrigation water user's participation for open and transparent reporting, good record-keeping and on-going construction supervision and quality control, and participatory scheme monitoring and evaluation.

Recommendations

- The existing institutional set up is not appropriate to fully implement the PIDM approach. To ensure that the PIDM approach is implemented in an integrated and coordinated manner, it is vital that the main government stakeholders (i.e. IDDP, IADP and CPA) work closely together. It is therefore, recommended that there is a need to establish a platform comprising an inter-disciplinary Scheme Development Team comprising the three main stakeholders.
- There is a need to build the capacity of private and governmental enterprises involved in study, design, supervision and construction of small scale irrigation schemes on the implementation of PIDM procedures and application of participatory tools and techniques.
- Capacity building of farmers in organizational management and scheme O&M needs to be delivered side by side with the ongoing scheme construction activities so that the scheme could be operational immediately after the formal handing over to the IC is completed.

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Assessment of Skill Gaps in Irrigation Extension, Amhara Region

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Abstract

It is widely recognized that for sustainable food security irrigation extension service plays an important role in the dissemination of improved irrigation technologies to water users. Despite this, the performance of most irrigation schemes in the region is below expectation. This is due to many reasons among which, low implementation capacity of irrigation extension officers (Woreda IADP experts and IDAs) are said to be part of the cause affecting increased irrigated crop production. The situation has been aggravated as a result of poor irrigation extension service and weak institutional set-up particularly in farmers' organizations. Experiences in SWHISA indicated that in addition to some limitations with regard to irrigation engineering aspects, limitations in the capacity of farmers to effectively utilize the irrigation technology, and low capacity of irrigation extension officers working at woredas and scheme levels in supporting farmers are all affecting the effectiveness of irrigation development and management. Consequently skill capacity gap analysis of irrigation extension officers was done and the current level of knowledge and skill gaps of the irrigation extension officers and water users were identified with key recommendations and a way forward for improvement of existing irrigation extension services in the region.

Key words: Skill gaps, Irrigation extension, Experts, Water users, SWHISA, Amhara region

Introduction

It is widely recognized that irrigation extension service plays an important role in the dissemination of improved irrigation technologies to the water users for sustainable food security. According to the available reports in IADP and experiences, the performance of most irrigation schemes in the region is below expectation. This is due to many reasons among which, low implementation capacity of irrigation extension officers (*Woreda* IADP experts and IDAs) is one which needs future intervention. The situation has been aggravated as a result of poor irrigation extension service and weak institutional set-up particularly in farmers' organizations.

IADP's mandate to bring about changes in the existing poorly managed irrigation system, although encouraging, has not yet brought satisfactory results in addressing water users' needs and improvement of the schemes as anticipated by the water users and farming communities. IADP was able to set up its offices at *Woreda* levels but in some cases the offices are not fully functional, mainly due to lack of experts and logistics support. For example, *Woreda* IADP office in West Belessa has currently no experts and a process owner. The organizational attitude of many *Woreda* offices of Agriculture and Rural Development is still geared towards rainfed *agriculture* extension; emphasizes on rainfed farming and credit facilities, not providing adequate attention to irrigation water management. The irrigation schemes lack attention and support both from woreda experts and DAs. Such irrigation schemes are either left to water user associations (WUA) or irrigation cooperatives (IC) or irrigation block teams where their own institutional set-up is unstable and linkages with IDAs and woreda IADP support service providers are weak.

Furthermore, irrigation extension services are weakened by lack of well-trained IDAs, experts and resources to carry out the task properly. IADP experts and DAs have little to offer farmers about water management and do not have adequate skills to cope up with existing farmers needs. Water users rarely participate in irrigation planning and in decision-making process with the stakeholders. The water users have no full control over water management and so the use of scientific methods to schedule irrigation is very difficult. Given this fact, it is foreseen that the impact of irrigation interventions on human assets, in the form of development of skills and knowledge of both water users and irrigation extension officers, and improving the quality of institutional support are integral component of irrigation intervention where IADP needs to emphasize more.

One of the major problems persisting in the irrigation system is the lack of coordinated link between the institutional support service providers. Unless there is an effective coordination and linkage between the stakeholders, the capacity development will not be sustainable, rather it will weaken the performance of extension officers. This institutional support problem is known fact to IADP/ BoARD including stakeholders. The region has made a large amount of investment to develop services and participatory methods on irrigation extension. There exists a large gap between the availability of irrigation extension service for effective water use and the application of right irrigation extension communication methods to transfer improved irrigation technologies. IADP initiated some interventions to establish an effective irrigation support service system; however, the pace of its implementation procedure is still slow to assist water users in the adoption of improved irrigation technologies. As a result, the impact of the investments in many irrigation schemes is considerably low in terms of crop production and water savings evolving big concerns on system sustainability.

Objectives of the assessment were:

- To assess the efficacy of existing irrigation extension approach/methods and advisory services provided by *Woreda* IADP and kebele/scheme IDAs
- To identify and analyse the gaps in terms of current level of irrigation extension planning capacity of IDAs, and *Woreda* IADP experts commensurate with their job descriptions;
- To identify and analyse the capacity gaps of water users in adoption of irrigation technologies, and
- To develop plans to fill the capacity gaps so that IADP is able to deliver on irrigation extension strategic results and outcomes efficiently and effectively

Methodology

Prior to undertaking the assessment, a methodology approach paper on “capacity gap analysis of extension officers and farmers at selected sample irrigation schemes” was developed by AEA Consultant of SWHISA, the draft discussed with IADP and SWHISA experts group and produced the final, that guided the overall capacity analysis process. Relevant data was collected in desk review and through field discussion with *Woreda* IADP experts, IDAs/DAs, experts of Agriculture Development and Management Unit (ADMU) of Koga Irrigation Project and water users through administering open-ended assessment questionnaires and following strength, weakness, opportunity and threat (SWOT) guidelines. The excerpts of the methodology were as follows:

Considering time limitation and resources, the field visit for capacity assessment was conducted in three project *Woredas,* namely, West Belessa, Goncha Sisso Enesse and Mecha focusing on three categories of irrigation schemes. This assessment was undertaken during the period September 27 to October 5, 2010 in three categories of irrigation schemes: Kalai traditional irrigation scheme in West Balessa, Azwari modern small-scale irrigation scheme in Goncha, and Koga large-scale irrigation scheme in Mecha. In the irrigation schemes, the team conducted discussions by probing key questions to water users in three *Woredas*. A total of 30 water users (10 in each scheme/w*oreda*) were randomly-selected for assessment. About 25 IDAs/DAs (6 female) from three *Woredas* responsible for irrigation schemes management were interviewed. Interviews were conducted using structured questionnaires to assess the current expertise and skill gaps of the IDAs/DAs. In addition, capacity gaps of total of 13 *Woreda* IADP (from Goncha and Mecha Woredas only) irrigation experts and including the unit head of ADMU was assessed and analyzed through capacity assessment scores in relation to irrigation extension. Questions were posed to respondents using simple semi-structured questionnaires commensurate with the key assessment points for capacity analysis. Their views and opinions were assessed. Finally, data analysis was carried out by irrigation extension group of SWHISA in collaboration with IADP.

Results and Discussion

During the course of assessment, the team assessed the key capacity gaps of individuals (IDAs, IADP irrigation experts and water users) which are specifically and broadly illustrated in the following section keeping in view of their level of performance in three categories of irrigation schemes. In this section, a summary of key findings with regard to overall performance of irrigation extension service is presented to get a better understanding of the present situation, and also to know how IADP is addressing the issues of capacity development and the needs of the water users for promoting improved irrigation technologies.

Irrigation extension implementation guidelines

There is lack of irrigation extension implementation guideline or manual to lead irrigation extension implementation strategies for IDAs and *Woreda* IADP experts. These guidelines/ manuals are important to know the impetus of irrigation extension approaches and communication methods, irrigation management system, roles and responsibilities of experts and IDAs, training techniques, linkage mechanism, farmers' institutions, market strategies, logistics support and programming. Due to lack of such guideline/manual, the irrigation extension officers are unaware of participatory irrigation extension approaches and communication methods and more importantly of their responsibilities in carrying out day-to-day tasks. Likewise, guidelines on operation and maintenance of irrigation and drainage systems, and farmers' organization and management deemed necessary.

Work schedule of irrigation extension officers

In the Business Processing Re-engineering document some form of job descriptions for IADP experts and IDAs are articulated but does not specifically detail out the roles and responsibilities for each experts. The *Woreda* IADP experts and IDAs have neither specific job descriptions nor aware of their routine activities pertinent to irrigation extension service. Their performance is evaluated on the basis of business score cards at the end of fiscal year. At present there is no systematic work schedule on delivery of irrigation extension for IDAs, as a result, their mobility is relatively unknown to the water user communities. IDAs meet water users in the form of informal individual contact and rarely through formal group contacts. Low motivation of IDAs to conduct water management activities at irrigation scheme levels was observed and assessed. This is due to the fact that technical guidance, supervisory visits and discussions initiated by the *Woreda* IADP experts at *kebele* level are barely insignificant. There is no provision of rewarding the IDAs/DAs and remuneration for good work. During our interaction with IDAs/DAs, we realized the proportion of their routine work that they carry out on weekly basis for irrigation extension. The results indicate that their actual performance/contribution in irrigation extension in three schemes is on average 12 percent and the rest assumes community extension service which is also a part of their general extension, particularly the item number 2 of the following table shows that IDAs/DAs are hugely involved in *Woreda/kebele* campaigns (35%) which is also an ancillary task to irrigation activities and is important. The following table shows the activities and IDAs/DAs work performance in various fields.

Table 1. Performance of irrigation extension officials at woreda/kebele

No.	Performance of IDA/DAs work in various field	%
1	Participation in recovery of loan or rural credits	8
2	Participation in Woreda/kebele campaigns such as; road construction, soil conservation, river diversion, pond construction, etc	35
3	Rainfed extension – advising farmers	27
4	Irrigation extension – advising water users	12
5	Community motivation – registration of school children	8
6	Participation in health campaign – malaria, family planning	5
7	Collection of land rental tax	5
	Total	**100**

Source: Assessment survey result, October 2010

Planning of irrigation extension programs

The study team assessed the present annual work plan (June 2010–July 2011) of *Woreda* IADP, has weaknesses and does not substantiate farmers' responsiveness since these plans are not formulated through a participatory approaches that involves water users and other key stakeholders. Consequently, water users' views and concerns are not reflected in the irrigation extension program. In general, the planning activities are pre-determined since *Woreda* IADP receives planning formats and annual activity directives from regional IADP through zonal IADP. The formats are forwarded to *kebeles* where IDAs/DAs organize informal meetings with the *kebele* administration and fill the formats without consultation with the relevant stakeholders including water users. These plans are submitted back to *Woreda* IADP. After compilation of the entire *kebeles* plan, IADP develops the compiled version (*Woreda* plan) and transmits to Zone IADP for approval. In the work plan, IDAs/DAs include some form of irrigation extension activities such as compost preparation, construction of bunds, cleaning and maintenance of canals, livestock fattening, supports in establishing and managing WUA/IC and little on farmers' training. The assessment team found out that although some of these activities are related to irrigation extension, they do not adequately boost effective participatory irrigation extension since essential irrigation extension ingredients like participation are missing. In the course of implementation, some of these planned activities were dropped due to budget shortage or lack of capacity to implement. IDAs/DAs have no extension diaries to keep record of day-to-day irrigation extension events and farmers' problems. Although, SWHISA has provided support for three years in the production of extension diaries but these were not scaled up by the BoARD. Such dairy would have served as an important tool for planning of irrigation extension activities on annual basis.

Capacity development/training

The BPR has emphasized on capacity development and training for the staffs and experts but in reality there is no training/capacity development plan both at *Woreda* and *kebele* levels that can address the training needs of IADP experts, IDAs/DAs and water users. Although, BoARD has produced farmers training centre (FTC) with training guidelines, it is barely seen in *Woreda* and *kebele* offices. Currently, IDAs/DAs and even the experts are not familiar with FTC guidelines and modular courses as a result most FTCs are under utilized as it was noticed in Azwari small-scale irrigation scheme, Gazaman *kebele* of Goncha sissoenesse *Woreda*. The Gazaman FTC was supported by SWHISA about two years ago, since then it has been used.

IADP experts and IDAs have no practical training skills especially in participatory irrigation extension approaches that would enable them translate their skills to the water users. Since the experts are unable to provide routine training to IDAs/DAs and the same with IDAs/DAs, it has negatively impacted on water users' capacity development at large. The water users are left with their traditional knowledge and coping mechanism and have no access to on-the-job training, extension services, irrigation inputs and market opportunities. They barely see IDAs/DAs assisting water users in their irrigation practices. In Ambomask *kebele* of Mecha *Woreda*, the water users in Koga irrigation scheme have undertaken potato and shallot cultivation using local cultivars since they couldn't get improved seeds. These water users have no skills and knowledge about improved practices, pest control and post-harvest technologies but are enthusiastic to follow trial and error methods until they reach at expected levels. Such trial and error methods with knowledge/skill gaps are detrimental for technology adoption which may not be successful at the end**.**

Extension demonstration and communication methods

The study team was able to assess and analyze the skill gaps of IDA/DAs and experts in terms of conducting irrigation demonstrations such as demonstration of high-value crops and other irrigation technologies like drip systems and siphons. The results indicate that extension officers have no practical knowledge on crop technology demonstrations and use of other irrigation devices since they have neither practical knowledge nor training. Also, they lack extension communication campaigns such as awareness raising, field days, group contacts, etc. However, with SWHISA's support in Azwari irrigation scheme some IDAs/DAs and experts were able to receive and undertake practical crop demonstration training for improved potato cultivar and construction of diffused light storage system. Such practical demonstrations either quantify the impact or avoid the use of such qualifiers to learning about the improved seed production, improved practices, irrigation water scheduling and storage of tubers. As a result of these demonstrations the neighbouring farmers in the scheme were motivated for technology adoption, which they are currently following but are lacking improved seed tubers. On the other hand, due to budget constraints it is difficult for *Woreda* IADP to establish and manage irrigation crop demonstrations in the other irrigation scheme of the woreda. Water users in all three schemes have strongly demanded for demonstrations, training and inputs.

Extension program budget

There is no requisite for the allocation of budget for *Woreda* IADP as per their annual budget plan. It was assessed that big chunk (about 69%) of *Woreda* IADP budget is curtailed that affects the continuity of the irrigation program and commitment to the water users. Meagre budget allocation for capacity development, logistics support and routine extension services such as training and demonstration, extension campaigns, and transport cost for IDAs/DAs with perdiem jeopardizing planned activities. Usually, less attention is given to budget allocation for IADP, as a result, good intentioned extension efforts remains unimplemented.

Performance of water user organization

In most cases, water user organization does not exist in many irrigation schemes or their existence is barely minimal. Their institutional set-up is also very weak with no clear roles and accountabilities. The water users are not aware of IADP and improved irrigation technologies. The Azwari modern small-scale irrigation scheme in Goncha *Woreda* has 600 water user beneficiaries, out of which 220 are members of irrigation cooperative and rest are non-members. The respondent-water users confirmed the role of irrigation cooperative in the scheme while some irrigation blocks are managed by the traditional water groups. The Kalai traditional irrigation scheme in West Belessa *Woreda* has three diversions (size of main diversion is 25 ha with total 70 beneficiaries), and these diversions are not systematically managed by the users since they lack skills in group formation and water management. As a result, conflicts in water distribution remain a common phenomenon, and the *Woreda* administration is seen often resolving conflicts. The Koga large-scale irrigation scheme in Mecha *Woreda* is currently having command area of 720 ha (actual target is 7,000 ha over 4 years) and it has irrigation cooperative operating for the scheme. Some irrigation blocks are managed by the traditional water groups with their own by-laws but are mostly disorganized with no clear responsibilities.

Capacity Gaps

This section broadly presents the analysis of the key capacity gaps of individuals (IDAs/DAs, IADP irrigation experts and water users) after summing up their level of current capacities in irrigation extension taking into account their involvement in the three irrigation schemes, which are traditional, modern both small-scale and large-scale. To this effect, the team also proposes suitable skills required for capacity development of these individuals to promote improved irrigation technologies.

Table 2. Capacity gaps and skills required for irrigation extension in Amhara region

Experts	Area of work	Skill gaps	Skill required
1. Woreda IADP experts of at least 5 years experience	**Irrigation extension planning and implementation**	▪ Inadequate skills on participatory irrigation extension planning ▪ Inadequate knowledge on irrigation extension approaches	▪ Ability to undertake farmers' information needs assessment or PRA for participatory planning ▪ Sufficient knowledge on irrigation extension approaches, methods and

Experts	Area of work	Skill gaps	Skill required
(agronomy, horticulture, O&M, water harvesting, post-harvest). **2. Experts of ADMU of Koga Irrigation project of at least 5 years experience** (O&M, water management, agronomy, cooperative extension).		and methods ▪ Poor extension resource prioritization skills to promote irrigation technologies ▪ Insufficient orientation towards IADP implementation strategies ▪ Inadequate practical skills on operation & maintenance of schemes ▪ Lack of skills on monitoring & evaluation of irrigation extension programs ▪ Insufficient ability to guide and mentor IDAs/DAs and resolve water conflicts ▪ Lack of communication and team building skills ▪ Lack of skills to establish coordination link with irrigation service providers ▪ Poor time management skills ▪ Inadequate practical extension exposure ▪ Inadequate networking skills ▪ Lack of skills on extension-research-farmer linkage ▪ Limited skills on developing extension proposals and report writing ▪ Inadequate familiar with improved irrigation technologies including irrigation equipments ▪ Cannot develop impact points for irrigation extension	communication campaigns to transfer skills to the clients ▪ Basic understanding on how to prioritize extension resources ▪ Ability to highlight issues, if any, to the management and ensure their resolution so as not to compromise on water disputes, quality and time ▪ Sufficient knowledge of IADP program implementation strategies so as to communicate easily with the IDAs/DAs and water users ▪ Ability to organize and maintain documents and timely reporting ▪ Ability to effectively manage IDAs/DAs and ensure that they comply with irrigation extension guidelines ▪ Ability to understand monitoring & evaluation of irrigation extension ▪ Strong task orientation, trouble shooting to resolve issues, high integrity and energy levels ▪ Basic computer skills and ability to work on MS Excel ▪ Strong networking and coordination skills ▪ Ability to plan and effectively deploy the available resources (pumps, inputs, and other material) ▪ Strong extension communication skills to be able to communicate effectively with IDAs/DAs, water users, etc. ▪ Ability to articulate IADP objectives to team members, coordinate and mentor IDAs/DAs and farmers ▪ Strong skills to handle irrigation

Experts	Area of work	Skill gaps	Skill required
			equipment
1. Woreda IADP experts of at least 5 years experience (agronomy, horticulture, O&M, water harvesting, post-harvest). **2. Project Experts of ADMU of Koga Irrigation project of at least 5 years experience** (O&M, water management, agronomy, cooperative extension).	**Training and demonstration**	▪ Lack of skills to conduct training needs assessment for irrigation DAs ▪ Lack of skills on planning of training for IDAs/DAs ▪ Difficult to identify and prepare training lesson plans (training modules) ▪ Lack of skills on selection of suitable training methods ▪ Inadequate training skills to perform as a good resource trainer ▪ No skills on post-training evaluation ▪ Inadequate skills to plan and conduct crop demonstrations ▪ Insufficient skills to identify and manage pest and diseases ▪ Poor skills on managing water ▪ Poor skills in post-harvest technologies such as storage, markets, quality control, etc. ▪ Lack of skills to organize field days	▪ Ability to effectively conduct training needs assessment ▪ Ability to plan training programs for IDAs/DAs and farmers including budget and other cost ▪ Basic understanding of identification and preparation of training modules ▪ Strong ability to effectively choose suitable training methods ▪ Training techniques, skills to perform as effective resource trainer ▪ Knowledge of irrigation equipment such as drip system, siphons, pumps, geo-membrane and their functions and the ability to ensure its maintenance ▪ Good written/oral communication skills ▪ Understanding of issues associated with equitable water distribution ▪ Water application planning and management ▪ Planning and organization of field days, awareness and group discussion ▪ Knowledge and ability to undertake demonstration planning, selection of plots, crop cultivars ▪ Ability to demonstrate storage system particularly for tubers and explore market opportunities
3. IDA/ DAs	**Irrigation extension planning, implementation and communication methods**	▪ No orientation on IADP program implementation strategies is given by Woreda ▪ Lack of accountabilities since duties and responsibilities are not determined ▪ Lack of skills on participatory	▪ Ability to define IADP goal and key features, perceive its mission, design program keeping in mind functionality, targets and aesthetic aspects of irrigation extension ▪ Ability to undertake farmers' information needs assessment or

Experts	Area of work	Skill gaps	Skill required
		planning of annual irrigation work plan with water users and other stakeholders ▪ Cannot identify farmers' problems and undertake analysis for planning purpose ▪ Cannot perform participatory technology development trials with farmers and researchers ▪ Lack of knowledge to identify irrigation extension approaches and methods for technology adoption	PRA for participatory planning ▪ Sufficient knowledge on irrigation extension approaches and methods to transfer skills to water users ▪ Basic understanding on farmers' problem identification ▪ Ability to organize and maintain documents and timely reporting ▪ Ability to effectively deliver extension services commensurate with irrigation extension guidelines
		▪ Inadequate skills to initiate group approach or strengthen water users associations ▪ Inadequate practical skills on operation & maintenance of schemes ▪ Lack of skills on monitoring & evaluation of irrigation extension programs ▪ Insufficient ability to mentor water user groups ▪ Inadequate skills to resolve water conflicts ▪ Lack of skills to mobilize water user communities for catchment treatment and maintenance ▪ Lack of skills to establish coordination link with irrigation service providers (inputs dealers and markets) ▪ Poor time management skills ▪ Inadequate practical extension exposure ▪ Inadequate skills to determine actual requirement of inputs and	▪ Ability to understand monitoring & evaluation of irrigation extension ▪ Strong task orientation, trouble shooting to resolve issues, high integrity and energy levels ▪ Basic computer skills and ability to work on MS Excel. Ability to plan and effectively deploy the available resources (pumps, inputs, and other material) in command area ▪ Strong communication skills to communicate effectively with water users for technology adoption ▪ Strong skills to operate irrigation equipment and other devices ▪ Ability to manage water users and resolve water disputes as and when they arise ▪ Ability to create a sense of trust among the water users ▪ Ability to understand and take instructions from Woreda IADP experts ▪ Ability to undertake operations and maintenance activities

Experts	Area of work	Skill gaps	Skill required
		credits for water users ▪ Poor skills to undertake surveys or crop assessment or problem analysis	▪ Coordination with multiple irrigation service agencies and vendors ▪ Ability to mobilize resources as and when required ▪ Ability to handle complaints from water users, ensure timely resolution and keep track of the complaints
	Training and demonstration	▪ Cannot undertake training needs assessment for water users ▪ Lack of skills on planning of on-the-job farmers training ▪ Cannot undertake to run modular courses in FTC ▪ Difficult to identify and prepare training lesson plans (training modules) ▪ Lack of skills on selection of suitable training methods ▪ Inadequate training skills to perform as a good trainer ▪ No skills on how to conduct post-training evaluation ▪ Inadequate skills on establishing crop	▪ Ability to effectively conduct training needs assessment ▪ Ability to plan training programs for water users including budget ▪ FTC training techniques skills to run modular courses ▪ Basic understanding of identification and preparation of training lesson plans (modules) ▪ Strong ability to effectively choose suitable training methods ▪ Training techniques skills to perform as effective resource trainer ▪ Knowledge of irrigation equipment such as drip system, siphons, pumps, geo-membrane and their functions and the ability to ensure that the equipment are properly maintained as

Experts	Area of work	Skill gaps	Skill required
		demonstrations, irrigation equipment, etc ▪ Lack of aptitude to develop irrigation demonstration planning and layout and its management ▪ Insufficient skills in pest and disease identification and control measure ▪ Poor skills in post-harvest technologies such as storage, markets, quality control, etc. ▪ No knowledge on crop-water requirement ▪ Lack of skill in organizing field days	per standards ▪ Good written/ oral communication skills ▪ Understanding of legal issues associated with the equitable water distribution ▪ Knowledge and ability to undertake demonstration planning, selection of demo plots, crop cultivars, model farmers and its implementation strategies ▪ Ability to demonstrate storage system particularly for tubers and explore market opportunities ▪ Ability to identify pest and diseases and their control measure ▪ Planning and organization of field days
4. Water users	**Routine activities**	▪ Insufficient skills in the selection of irrigated crops ▪ Inadequate understanding of roles and responsibilities in scheme management ▪ Little experience on catchment treatment and protection ▪ Lack of training on improved irrigation practices ▪ Lack of knowledge on pest and disease identification and their control measure ▪ Little skills on equitable sharing of water ▪ Lack of skills on headwork and irrigation canal cleaning and maintenance ▪ Lack of knowledge on post-harvest such as storage of tubers and onions under farm	▪ Ability to select high-value crops ▪ Coordinate with IDAs and other water users for water sharing ▪ Knowledge and ability to undertake catchment treatment, drainage and canal maintenance, bund repairs, etc ▪ Ability to work in a group for problem solving ▪ Ability to understand improved cultivation practices ▪ Need to understand identification of pest and diseases and their control measure ▪ Understanding equitable water distribution and sharing ▪ Knowledge of headwork and irrigation system cleaning and maintenance ▪ Knowledge on application of suitable fertilizer and dosage

Experts	Area of work	Skill gaps	Skill required
		condition ▪ Lack of skills on application of suitable fertilizer and dosage ▪ Lack of skills to use modern irrigation equipment such as drip system, siphons, treadle ▪ Lack of skill in planning and managing plot water application	▪ Ability to understand post-harvest activities such as storage of seed tubers, onion and quality control of farm products ▪ Ability to use modern irrigation equipment, drip system, geo-membrane, treadle pumps, knapsack sprayers, siphons, etc ▪ Ability to communicate with other water users for technology adoption ▪ Planning and management of irrigation

Conclusions and Recommendations

According to expert opinions, in water resources management there is no single formula for building the necessary capacities to improve irrigation and drainage. The capacities that needs development ranges from effective communication skills, application of advanced techniques, through the development of analytical skills for those who are responsible for promoting improved irrigation technologies. The target groups or individuals for these different skills range from water users, through irrigation support service providers and irrigation technicians, technical experts and researchers, process leaders and policymakers. Capacity development is centred on the individual, which is why education and training tends to be the main focus of attention when the issue of capacity development is discussed. To understand capacity development is to understand that it is as much a process as an end product. It is an approach to development, not something separate from it to bring about a predefined outcome. It transfers the emphasis from the end product to the process of achieving it. While considering the capacity development for IADP experts, irrigation development agents and water users, the following recommendations are suggested.

Provision of operational manual: An operational manual is a guiding tool to achieving organizational objectives and goals within a time-frame. The manual is usually consisted of a compendium of program strategies and approaches, human resources, templates and importantly gives a clear-cut direction of program management and irrigation extension services. It provides information and practical advice helpful for capacity development of IADP experts and IDAs, increasing the efficiency and effectiveness of IADP and solutions to water users' problems. It is strongly recommended to develop three important operational manuals, these are;

- Participatory irrigation extension operational manual,
- Operation & maintenance manual for scheme management,
- Water user organization and management manual.

Budget support: It is imperative that a requisite amount of budget be earmarked for capacity development initiatives to enhance skills of experts, IDAs and water users. As a routine process in IADP's operational system, continued availability of budget is required to cover the costs for staff training including logistics support. At *Woreda* level, the *Woreda* administration needs to be advised for allocation of funds to cater the need for human resource development. Since IADP is a new set-up, therefore, adequate funds are initially required for this purpose in view to keep the momentum of irrigation extension activities.

Motivation of staff: Increasing the capacity of IADP staff to deliver the best services, IDAs and experts need strong motivation and appreciation from their management. The best motivation is the self-motivation of knowing oneself – first and then doing the right thing at the right time. For staff motivation, some of these are:

- Appreciation/recognition letters for good performance,
- Provision of rewards,
- Recommendation for promotion and higher pay scale within IADP,
- Recommendation for higher studies in relation to irrigation

Monitoring and on-the-job guidance: IADP will need to provide close supervision and monitoring of the IDAs regular duties to enhance capacity development opportunities. Routine supervision and monitoring are important and is largely the responsibility of the supervising officer. On-the-job guidance may also include undertaking of joint field assessments, surveys, participatory extension planning, and free discussions with IDAs that can help enhance professional skills of the same. On-the-job guidance is particularly valuable for newly hired woreda experts and IDAs to improve all their abilities, not just manual skills. The following suggestion aims the maximum value in supervisory visits:

- Create opportunities for IDAs to demonstrate his skills, for example, ask the IDAs to show a practical recommended practice that was carried out,
- Avoid making criticism of the skills in front of others, give him/her guidance once they have gone,
- Do not limit guidance to just making comments, show the IDA how things should be done if he/she doesn't know, and
- Give feedback to IDAs, in order to improve his skills and to know how well the IDA is performing.

Imbalance education qualification of IDAs: The newly hired IDAs have education qualifications of 10+ 3 years diploma from TVET compared to the education qualifications of their co-worker DAs who have 12+ 2 years diploma certificate. Such inadequate qualification mires the IDA's to get admission into summer program B.Sc. degree at recognized universities since entry requirement for degree programs is 12+ 2 year diploma certificate. As a result, the IDAs are morally distorted when they witness their co-worker DAs have better scope for knowledge enhancement in the universities. Such B.Sc degrees also boost for future career development and promotion for DAs. It is very important for IADP to review the existing career development plan of IDAs and resolve this issue to create a favorable working environment otherwise this may continue affect the progress of promoting irrigation technologies.

Increasing IDAs work in irrigation extension activities: Currently, IDAs are more involved in community extension (about 60%) compared to their actual performance/contribution (12%) in irrigation extension. Their involvement in community extension is also a part of their general extension and is ancillary to irrigation services as shown in the previous section. It is recommended to increase IDAs involvement more in irrigation extension towards increased food security as well as to promote IADP' mission to the farming communities since IADP is a new organization. Increasing IDAs work in irrigation extension could be initiated through discussions and meetings with *Woreda* administrations demonstrating the importance of irrigation extension and roles and responsibilities of IDAs in irrigation schemes. Such interactions with *Woreda* administration will substantially help IDA's involvement more in irrigation extension activities.

Training to IDAs on irrigation extension activities: Staff in IADP requires information, knowledge, skill, vision, and mission to do their best for the organization, and this is more important for *Woreda* IADP experts and IDAs. In an organization, capacity development initiatives are the processes through which these can be enhanced among the staff forming part of the network of roles in the organization. As a system for the development of personnel in an organization is generally brought about through a bunch of sub-systems all of which are meant to focus on development of the individuals and groups constituting the social system of the organization, one of these sub-systems is training. Over the years, training has been viewed as the active arm of the top management for preparing the personnel to upgrade their capabilities to meet new organizational challenges. Training thus assumed lot of importance in IADP. It is a planned effort to facilitate employees' learning of job-related knowledge and skills for the purpose of improving performance. Efforts needs to be intensified to organize a quarterly training session at IADP *Woreda* offices, particularly during the irrigation season, to train IDAs on irrigation extension activities of the following quarter emphasizing on impact points (extension messages). Since the training venue is in *Woreda*, it will also give opportunity to IDAs to access information, establishing contacts with support service providers. Such opportunity will capacitate IDAs to provide updated information to water users. The purpose of *Woreda* level training is:

- To establish common understanding among *Woreda* IADP of the current situation in the irrigation field,
- To teach the IDAs precise improved agronomic and irrigation practices that will be suitable for water users,

- To provide the IDAs with supporting technical knowledge and skills, which will improve their ability to analyze water users' problems, understand the benefits of recommended practices and demonstrate these practices.
- To discuss the irrigation extension and demonstration programs of IDAs and sort out all administrative matters to enable them to work with water user groups.

Short-term training: Short-term training is usually geared to the acquisition of more immediate skills for well defined tasks, such as managing canals, establishing crop demonstrations, irrigation extension approaches and organizing WUAs. It may be special courses on particular issues for a wide range of experts including IDAs. They may be conducted on-site or more formally at a training centre or FTC. Increasingly short-term training is also seen as a means of changing attitudes as both IDAs and experts take on new roles in the process of irrigation extension management transfer, and there is a change in the objective of training from mere knowledge transfer towards increasing problem solving capacities. Competences are a complex interaction of knowledge, skills and attitudes, and some programs are now using participatory training methods to stimulate a continuing process of participation in subsequent water management practices. It is therefore recommended to conduct such short-term trainings on special courses to address immediate needs of the IADP staff.

Development of higher education training plan and ToT course: There is a need to develop the capacity of IADP experts and IDAs related to irrigation extension service. They also require a thorough understanding of extension communication methods and implementation modalities of IADP. Presently, most experts and IDAs have no extension exposure and practical training on irrigation extension which is a major weakness for program implementation. It is very important for IADP to develop a higher education training plan that can include course curriculum and modules, schedules, training methods and target trainees. This plan will guide the staff in overall planning and execution of variety of training programs for staff and water users. It is also recommended that a short-term ToT course on "participatory irrigation extension implementation skills" for the selected-IADP experts and IDAs/DAs be undertaken. The results of ToT will boost trainees to assist water users to solving their irrigation problems.

On-farm demonstration: On-farm demonstrations serve as one of the most effective extension education tools for promotion of technologies among the end users. Demonstration can effectively showcase the use of appropriate technology and provide a sustainable method of practical training for the adoption of improved irrigation technologies for the water users. The general objective of the demonstration is to expose water users to new productive irrigation technologies resulting in more profitable irrigated farming. This will result in increased production contRibbuting also to increased opportunities for employment and income in the irrigated agricultural sector. It is therefore essential for *Woreda* IADP to undertake demonstrations on improved cultivars, use of irrigation equipments such as drips and siphons, post-harvest storage, water management. Such demonstrations will capacitate the water user skills and knowledge about irrigated agriculture.

Workshop on capacity development: A 2-day workshop on "Capacity development in irrigation extension, drainage and management" is proposed. The workshop needs to be organized by IADP preferably prior to the irrigation season. The workshop goal is to highlight the important role of capacity development in the irrigation extension and drainage sector, and to bring together agencies, institutions and individuals in order to review and address the following issues:

- Why is capacity development important and what are the specific issues and challenges that need to be addressed in a capacity development program?
- What is the present "state of the art" with respect to capacity development for the irrigation extension sector?
- What approaches are currently being used, and what are the issues and challenges arising from them, including more effective tools to assess the needs and impact of capacity development?
- What new approaches in capacity development are needed to address probable changes in the irrigation extension sector in the near future?
- What facilitating and complementary roles can institutional support service providers and IADP play in supporting and promoting effective capacity development within the irrigation sector?

Access to computers: Access to computers, networks and the internet is enabling access to volumes of information. The tools, techniques and technologies available to help in the management of irrigation, drainage and water resources are advancing rapidly. Developing advanced tools and the capability to apply them in the management of water resources will offer IADP experts and IDA's new opportunities to become more responsive to the needs and aspirations of the water user communities they serve. After many years of being promoted as valuable technologies, geographical information systems (GISs) and soil testing kits are now viable tools for use in the routine management of irrigation systems. It is therefore suggested that provision of computers and other necessary kits be provided to Woreda IADP.

Developing coordination: It is recognized that the greater cooperation between IADP and other irrigation support services, the greater will be the accessibility of water users to extension services. To ensure the maximum utilization of its scarce resources in a cost-effective way, IADP will need to develop effective/enhanced coordination with the support services such as inputs dealers, credit institutions, researchers, extension agencies, markets so that flow of irrigation services are effectively channeled to water users for increased irrigated production. Therefore, *Woreda* IADP needs to identify these service providers, develop working mechanism to ensure supply chain of irrigation equipment, delivery of services to water users and other inputs. Such coordination linkage will capacitate the IDAs to deliver tangible inputs to water users.

Establishment of water user association: WUA is of paramount importance for promoting improved irrigation technologies. WUA plays a key role in every sphere of water resources management for increased irrigated crop production. Formation of WUAs that represent the users at all levels of decision-making in planning, management, and operation has been a key step involving water users in this process. The development of these associations helped promote a socially cohesive behaviour in irrigation. User managed schemes should be encouraged along with the decentralization of operational management to the *Woreda* level. It is worth mentioning here that IADP take necessary steps for the establishment of new WUAs or strengthen the existing WUAs with necessary trainings and institutional support. In this way the capacity of water users will be enhanced and they will be able to identify and decide their roles in smooth water management in line with their expectations.

Ways Forward

Participatory irrigation extension operational manual: As a top priority, development of "Participatory irrigation extension operational manual" is necessary for IADP that can serve as guiding tools for the experts and irrigation technicians to achieve organizational objectives and goals within a time-frame. The manual will usually consist of a compendium of irrigation extension approaches, training needs assessment, extension communication methods, irrigation extension planning, monitoring & evaluation, roles and responsibilities of experts and IDAs, coordination mechanism, templates, etc. and importantly will give a clear-cut direction of irrigation extension delivery system. The manual developed jointly by SWHISA and IADP has been provided to IADP in November, 2010.

Training of Trainers (ToT) course for experts and IDAs: A 2-week ToT course on "participatory irrigation extension implementation skills" for selected-IADP experts and IDAs/DAs is strongly recommended for implementation. The course includes modules with practical exercises on training needs assessment, use of irrigation extension approaches, communication methods, establishing coordination linkages, participatory planning for annual work plan, techniques of irrigation demonstrations, techniques of farmers' problems identification, monitoring and evaluation of extension programs, mentoring and irrigation advisory, techniques of formation of water groups, operation and maintenance of irrigation systems, role of experts and IDAs/DAs in irrigation scheme, role of support services and their linkage…etc. The results of the ToT will boost trainees to replicate the skills gains to IDAs and water users. Though SWHISA and IADP prepared the course in January 2011, since then implementation is not possible due to workload of woreda experts and IDAs/DAs.

Tomato Value Chain Analysis: The Case of Kobo District

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Abstract

Tomato is one of the most perishable types of vegetables dominantly produced by small scale producers that require careful attention along its value chains. This paper presents major findings of tomato value chain analysis, in the case of Kobo district. The objective of the study was to identify the major value reducing and value adding activities of tomato value chain under irrigation based production in Kobo area. Survey was employed to collect data in a cross sectional basis in 2010. Finally, the collected data were analyzed in descriptive statistical tools, content analysis and interpretation methods, under the guideline of Michel Porter's qualitative value chain model using SPSS 16 software.

Tomato producers have two major marketing places, farm gate and weekly open markets at Kobo town. Out of the total tomato sold by producers, 93.4, 5.28 and 1.45% were sold to whole sellers, retailers and consumers respectively. Sixty four tomato whole sale buyers were identified as the major buyers of tomato in 2009/10 production, out of them 14.06% were Mekele whole sellers. Out of the total whole sale volume, 76.74 and 23.37% were sold through dealers and directly to whole sellers, respectively. Mekele whole sellers commonly use dealers to buy tomato at farm gate market. They absorbed 69.63% of the total whole sale shares which is equivalent to 65% of the total supply in 2009/10. Moreover, 72.33% of the total supply which is equivalent to 76.74% of the total whole sale shares was sold through dealers at farm gate market. Farm gate prices of tomatoes varied between 0.36 and 1.33 birr/kg in April and August of 2009/10, respectively. Producers incurred 0.67 birr to produce and sell a single kilogram of marketable fresh tomatoes to Mekele whole sellers. This production cost covered 17.40% of the total costs required to produce and distribute one kg of tomatoes to Mekele consumers. Producers obtained a net of 0.21 birr out of a single kilogram of marketed fresh tomatoes to Mekele whole sellers, this benefit covered 13.29 % of the total net benefits of a kilogram of tomatoes obtained after it is sold to Mekele consumers. Much of the benefits accrued to Mekele whole sellers, but farmers deserved the least benefit out of the total benefits distributed. In the absence of effective market linkages, encouraging farmers to produce perishable vegetables become futile effort for subsistence farmers. Therefore, regulating market of vegetables is critically important to minimize the burdens of imperfect markets from the shoulders of the poor producers.

Key words: Value chain, Producer, Whole seller, Dealer, Imperfect market, Tomato, Kobo

Introduction

The overall performance of Ethiopia's economy is highly influenced by the performance of the agricultural sector which itself is subject to vagaries of weather and related natural and synthetic factors. On the face of unreliable and inconsistent nature of rain dependent Ethiopian agriculture, expansion of irrigation facilities and development of vegetable production provide multiple advantages in creating both backward and forward employment opportunities across value chain actors, and improving farmers' income, supporting local economies and national economies. Ethiopia has untapped potentials of vegetable production and marketing (MOA, 2006, 2007; WB, 2005). Amhara National Regional State is one of the regions having good potentials of irrigation and market opportunities for vegetable production (CSA, 1994). Despite rapidly increasing trends of domestic and international market demands for tomato, its contribution for Ethiopia in general (WB, 2005), and Kobo district in particular (SWHISA, 2007; WoARD, 2009) is still insignificant. Kobo district is one of the districts of Amhara region that have high irrigation potential to produce vegetables like tomato with better market advantages, however, the district is still characterized by one of the most drought prone area.

Farmers in Kobo area produced three times in a year using irrigation in Golina irrigation scheme for instance, cereal production is dominantly covering the largest area followed by vegetables in all the three production seasons. In 2009/10, out of the total land cultivated in the first and second irrigation season and supplementary production 9.8, 17.57, and 7.77% of land was covered by tomato production respectively. Productivity of tomato during supplementary, first and second irrigation production seasons were estimated at 12.0, 10.15 and 9.78 tons/ha respectively. As a result of seasonal price fluctuation, market imperfections and sometimes surplus production farmers claimed that they have experienced dumping of tomatoes in the market, feeding for cattle and sell with minimum price.

Monitoring market performance and creating effective coordination between producers, local dealers and large traders through forums and discussions is essential to develop common understanding between chain actors for their mutual benefits. Market is the central element of development in the agricultural development. Hence, thinking beyond productivity, and incorporating themes of profitability and competitiveness is an option less intervened for the benefits of major value chain actors. The value chain concept has proven particularly useful for the identification and formulation of development of strategies for improved agricultural and rural development (ECA, 2009). Hence, value chain analysis help to find leverage point to uplift a maximum load of value reducing elements that hinder the performances of tomato chain actors with minimum effort in the case study area, Kobo district.

The general objective of the study was to identify the major value reducing and value adding activities of tomato value chain. There were three specific objectives in the study; 1) to identify major actors, their roles and relationships in the tomato value chain, 2) to assess cost-benefit distributions among major market actors in tomato value chain, and 3) finally to assess constrains and opportunities faced by the tomato value chain actors.

Materials and Methods

Survey research design was employed in a cross sectional basis in 2010. The study area Golina modern irrigation scheme was selected purposefully for two major reasons: for its high irrigation potential and large vegetable production coverage in general and tomato in particular. The selected scheme has irrigated 400ha that serves 1375 households (HHs) through surface irrigation methods using Golina River. Following the scheme selection, a total of 106 respondents were selected. About 60 vegetable producer households were selected by simple random sampling and 46 traders were selected purposively for their participation in tomato trading, degree of participation, distance factors and accessibility/availability. Besides, focus group discussions, observations and key informant interviews were used to collect the relevant primary data from dealers, key informants, major whole sellers, retailers, agricultural officers and other relevant information sources. Finally, the collected data were analyzed in descriptive statistical tools, simple cost benefit analysis, content analysis and interpretation methods using SPSS 16 software. For the analysis, Michel Porter's qualitative value chain model (Raphael K. and Mike M, 2000) was applied as a guideline. The model is a simple cause and effect relationship that helps to identify both value reducing and value adding activities across value chains.

Results and Discussion

Characteristics of Households and their Production

Table 1 presents sample households' characteristics and their tomato production system. Out of the total respondents, 50% produced tomato, 83.33% were male and 17.67 % were female. From the total sampled producers, 85 % of the household heads were male while the rest 15 % were female (Table 1). From the total annual cultivated land in 2009/10 in the study area, 4.84 ha (11.66%), 8.78 ha (21.15%), 2.72 ha (6.55%), and 25.18 ha (60.64%) were covered by tomato, onion, pepper, and cereals respectively (Figure 1). The study showed that more land was allocated to cereals than vegetables across all the three production seasons.

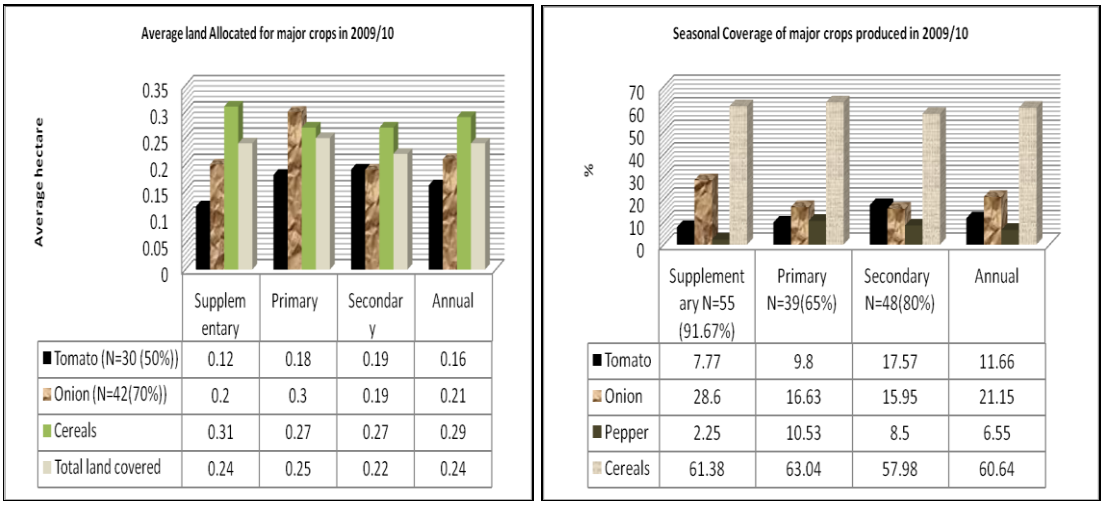


Figure 1. Land allocation and coverage in Golina irrigation scheme (Source: Own field survey, 2010)

Tomato Production in Golina Irrigation Scheme

Tomato is produced three times in a year in Kobo-Golina modern irrigation scheme, constituting supplementary, first and second irrigation production periods from July to October, October to end of January and February to May, respectively. Out of the total land cultivated in first, second, and supplementary irrigation production periods in 2009/10, 9.8%, 17.57% and 7.77% of land was allocated for tomato production, respectively. Productivity of tomato during supplementary, first and second irrigation production seasons were estimated to be 12.0, 10.15, and 13.6 tons/ha respectively (Table 2). All tomato producers do not use tomato staking/bedding methods due to lack of awareness, lack of access of bed making materials, and labor shortage.

If tomato fruits are not handled carefully and marketed timely; they decay easily, which affects their taste, flavor, nutritional and economical values. About 33, 17 and 47% of the respondents indicated that tomato is harvested at the start of ripening, when the fruit color looks red or orange, and when the fruit color looks mixed green and red (Table 1). Farmers usually adjust harvesting days to gain better advantages of higher prices through strategies of waiting for some days and harvest on the coming market days. Hence, the average number of days to store tomatoes during supplementary, first and second irrigation production periods were, 1.64, 1.17, and 1.23 days respectively (Table 2). It was indicated that producers did not store tomato for longer periods; the average number of storage days was 1.37 days (range from 1-2 days).

Materials like wooden crate, plastic cart, and locally made bamboo basket were used to collect tomato product. About 86.7% of tomato producers used wooden box to collect tomato fruits, however, only 50% of the total producers had wooden box to collect tomatoes (Table 1). Producers indicated that traders from Mekele provide them with wooden crates to harvest and collect their products at the time of harvest. The average weight of wooden cart ranges from 5-7 kg and its total capacity ranges from 50-60 kg tomato on average. Traders usually pay farmers only for a 50kg tomato. Most of the farmers transport their product from field to the main road side by using either their own cart or rented one, and others use vehicles, pack animals and human transport. From the total multiple responses of 133.3% given by producers, 86.7% showed that cart is commonly used to transport produces to Kobo markets while the rest 46.7 % used vehicles (Table 1). The total average loss of tomato during supplementary, first and second irrigation periods were 42.76%, 29.97% and 25.43% of the products respectively (Table 4). According to Girma Abera, the loss of vegetables between production and consumption is estimated to be 25-35%. He indicated that, the purpose of packing, transport and storage is to mitigate post harvest losses in the chain through producer to consumer. However, surplus product and market imperfection were deep-rooted challenges that farmers faced both pre- and post-harvest losses. One of the interviewed farmer, Abera, said *"If you have the patience to wait in Kobo market until lunch time, the majority of the product are either transported back home, or dump in the market not to incur transportation cost while our cattle lack forage to feed, or some fortunate producers may sell with a very low prices (one cart of volume 50kg at 4 to 5 Birr price).* This implies that farmers faced challenges of market which may affect their income and livelihood. In Kobo open markets, farmers have experienced in dumping tomatoes in open markets, feeding tomatoes for cattle, selling tomatoes at very low prices. According to tomato producers, the order of rank of problems from 1 to 5 was: market insecurity, low output prices, moisture stress, input scarcity and disease and insect problems (Table 3). Bezabih Emana and Hadera Gebremedhin, (2007) also indicated that market is the major constraints of vegetable production in Ethiopia.

Table 1. Characteristics of households and tomato production

Characteristics	**Cases**	**Total Respondents**		**Tomato Producers**	
		N	**%**	**N**	**%**
HH sex	Male	51	85.0	25	83.33
	Female	9	15.0	5	16.67
	Total	60	100.0	30	50
Tomato seed used (N=30)	Improved seed	-	-	25	75
	Local	-	-	5	25
Plough (N=60)	Own	38	63.3	-	-
Pest control (N=30)	Chemical	-	-	22	73.3
Soil fertility (N=30)	Fertilizer	-	-	8	26.7
	Manure	-	-	15	50
	Compost	-	-	3	10
Bedding (N=30)	Staking	-	-	0	0
Watering (N=60)	Furrowing	45	75	-	-
	Flooding	15	25	-	-
Harvesting stage (N=30)	Start of ripping	-	-	10	33.3
	Orange color	-	-	5	16.7
	Mixed of green and red	-	-	14	46.7
	Missed data	-	-	1	3.3
	Total	-	-	30	100
Collecting materials used (N=30)	Wooden cart	-	-	26	86.7
	Plastic cart	-	-	2	6.7
	Basket and cartoon	-	-	4	13.3
Wooden cart ownership (N=30)	None	-	-	15	50
	Who own 1-2	-	-	25	83.33
	Who own 3	-	-	25	83.33
Transportation	Cart	-	-	26	86.7 (65)
	Vehicles and others	-	-	14	46.7 (35)
	Total	-	-	40	133.3 (100)

Table 2. Tomato productivity and harvest losses (Source: Own field survey, 2010)

Season loss	Production and loss	N	Min.	Max.	Mean	Std. Dev	%
Supplementary	Productivity, t/ha	11	4.0	33.3	12.0	8.2	
	Pre harvest loss, t/ha	11	1.0	4.3	2.5	1.2	21.02
	Post harvest loss, t/ha	11	1.0	6.0	2.6	1.68	21.74
	Total loss, t/ha	11	2.0	10.3	5.1	2.29	42.76
First irrigation	Productivity, t/ha	6	1.67	24.6	10.1	10.2	
	Pre harvest loss, t/ha	6	1.0	1.7	1.2	0.33	11.91
	Post harvest loss, t/ha	6	1.0	2.67	1.8	0.87	18.06
	Total loss, t/ha	6	2.1	3.67	3.0	0.67	29.97
Second irrigation	Productivity, t/ha	13	2.5	25.0	13.6.6	8.5	
	Pre harvest loss, t/ha	13	1.0	4.3	1.8	0.98	13.19
	Post harvest loss, t/ha	13	1.0	4.3	1.67	0.91	12.24
	Total loss, t/ha	13	2.0	8.67	3.47	1.8	25.43
Annual	Productivity, t/ha	30	2.5	33.3	12.35	8.5	
	Pre harvest loss, t/ha	30	1.0	4.3	1.9	1.1	15.78
	Post harvest loss, t/ha	30	1.0	6.0	2.0	1.3	16.61
	Total loss, t/ha	30	2.0	10.3	4.0	2.0	32.38
Storage life	Storage life in days	30	1	2	1.37	0.49	

Table 3. Problem ranking of tomato production and marketing (Source: Own survey, 2010)

Problems	Not a problem		Low		Medium		High		
	N	%	N	%	N	%	N	%	Rank
Insect	2	6.67	7	23.33	9	30	12	40	5
Diseases	2	6.67	7	23.33	11	36.67	10	33.33	8
Low output price	2	6.67	2	6.67	4	13.33	22	73.33	2
Market insecurity	1	3.33	2	6.67	3	10	24	80	1
High input price	9	30	5	16.67	6	20	10	33.33	8
Input scarcity	4	13.33	1	3.33	9	30	16	53.33	4
Canal damage	5	16.67	7	23.33	5	16.67	13	43.33	7
Moisture stress	2	6.67	4	13.33	7	23.33	17	56.67	3
Labor shortage	10	33.33	6	20	7	23.33	7	23.33	9
Poor service delivery	13	43.33	6	20	5	16.67	6	20	10
Capital shortage	14	46.67	6	20	5	16.67	5	16.67	11
Transport shortage	5	16.67	4	13.33	7	23.33	14	46.67	6
Storage	6	20	7	23.33	2	6.67	15	50	5

The Role of Input and Extension Services in Tomato Value Chain

The role of input providers

There are two major categories of input channels in the study area, namely, informal and formal input sources. The identified formal input sources include; cooperatives, NGOs, Woreda Office of Agriculture (WoA) while informal sources include local chemical suppliers, open markets, and major tomato buyers of Mekele whole sellers. Out of the total tomato producers, 26.7%, 50%, 10%, 73.3% and 75% used fertilizer, manure, compost, chemicals and improved varieties. . Formal input sources supplied fertilizer, fungicide chemical, and improved seed for 85%, 31.9% and 48.9% of the users while the rest of the users are supplied with the informal sources. Formal input sources have small share in supplying certified seeds and chemicals to farmers. Out of the total fertilizer users, 45%, 40%, and 15 % had access chemical through WoA, Cooperatives and open markets, respectively. While, 17.02 %, 14.9%, 36.17%, 25.53%, and 6.38% of fungicide chemical users access from WoA, cooperative, Mekele traders, open markets, and other sources, respectively. Out of the total improved seed users, 35%, 19.05%, 28.87%, 23.81%, 19.05 %, 4.76%, 4.76% access from WoA, cooperatives, Mekele traders, open markets, NGOs and others respectively. Currently, farmers has already built a circular type of relationships through inflow of input and output flows of out puts with some Mekele traveler traders who have shaped and developed the interest of farmers to maintain and sustain their relations. From the analysis group discussion made with producers, and survey results, most farmers prefer informal channels for various reasons: affordability of inputs; ease of timely access; space; input choices; presence of dual relationships with vegetable traders that supply input and collect produces, and divisibility of input amount.

However, out of the total 1375 HH beneficiaries of the scheme, only 270 are members of Golina multipurpose cooperative, majority of the beneficiaries use informal input system. The cooperative runs without having legal entity and enough capital. Hence, unlike the other legalized cooperatives, it does not have any guarantee to buy inputs in credit from other high-level cooperatives and sell produces accordingly.

The role of extension service providers

Out of the total respondents, 81.7, 33.3, 45, 11.7, 78.3, and 11.7 % were adopters of improved seed, fertilizer, manure, compost, pesticide, and credit respectively. About 75% used furrow method of irrigation while the rest 25% used simple flooding techniques. Water committee is less capable and empowered to plan and executes effective crop production and water management. Out of the total respondents, 83.3%, 65%, 60%, 51.7%, 38.3% and 75% indicated that they have poor awareness and knowledge level on areas of market information, fertilizer application, chemical application, improved seed application, vegetable production, and post- harvest handling. Among the major agricultural extension support needs, market information was the major problems of farmers followed by post harvest handling and input uses. Training is other major critical intervention to support producers in pre cultivation, pre-harvest, harvest, and post- harvest practices. However, 8.33%, 13.335 and 78.3% of total respondents indicated that, training was given frequently, rarely, and nothing, respectively. Field visit participation is one of extension approach to create mutual learning opportunities within and between farmers and experts. The study showed that 75 % of the respondents did not participate in field days in 2009/10. Only 45% of producers indicated that Development Agent (DA) assisted them on frequent field visits while 36.5% of the respondents complained that no service was given on field level. The rest 16.67 % indicated that field assistance had been given rarely.

Tomato Market Value Chain Actors and their Roles and Shares

From the analysis of discussions, field visits and surveys it was indicated that, there are different major actors involved in tomato marketing having various roles in moving products from points of production to final consumption. These actors are producers, rural dealers, wholesalers, retailers and consumers (see Figure 2).

Tomato Marketing Structure and the Roles of Producers

Tomato producers have two major marketing options to sell their tomato produces: farm gate market and weekly market centers in Kobo and its surroundings. The buyers at farm gate have large market share but the weekly open markets have many market players but having very small market share. If there might be lack of common agreements in price setting, amount of supplies, quality of supply, types of transactions, or other conflict sources at farm gate market, producers usually may take produces on the next market days to Kobo open market after a day. Producer farmers are merely participating only in production function having limited bargaining powers at farm gate market. Farmers usually mix poor qualities with good qualities, matured with immature, thick flesh with thin flesh products, processing types with non processing types when they supply to markets. Out of the total tomato sold by producers, 93.4, 5.28 and 1.45% were sold to whole sellers, retailers and consumers respectively. Out of the total whole sale volume, 76.74 and 23.37% were sold through dealers to whole sellers and directly to whole sellers respectively (Figure 2).

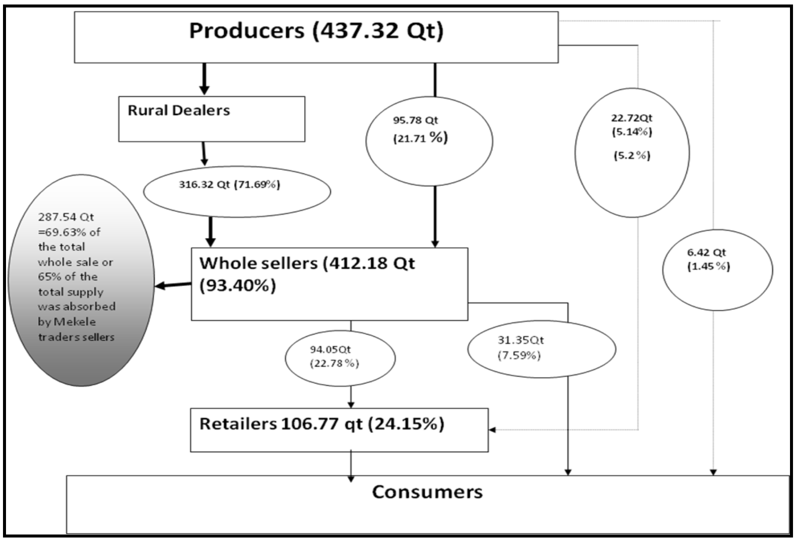


Fig. 2. Tomato product flow and share of actors (Source: Own construction, 2010)

There are an estimated number of 10-15 local dealers engaged themselves in linking producers and Mekele whole sellers at farm gate market. After price agreement made between traders and farmers, farmers usually harvest, collect and transport to main roadside then local dealers sort, grade, pack, weigh and load to lorries. About 72.33% of the total supply which is equivalent to 76.74% of the total whole sale shares was sold through dealers at farm gate market. Out of the total whole sale arranged through dealers, 90.90% were for Mekele buyers. Traders pay dealers at a rate of 0.1 Birr/kg for dealing and 0.15 Birr/kg for grading, packaging and loading activities. Dealers have important role in communicating the buyers and sellers by implementing traders' interest along the process of price setting and transaction processes.

Through the focus group discussion made with eight local dealers, information triangulation made with some whole sellers and local tax collectors, and from producers, there were about 64 whole sellers participating in tomato market in 2009/10 production period with various market shares. Out of them, 14.06% were Mekele whole sellers which are equivalent to 6.20 % of major vegetable traders of Mekele. Mekele whole sellers commonly use dealers to buy tomato at farm gate market. They absorbed 69.63% of the total whole sale shares which is equivalent to 65% of the total supply of the studied scheme in 2009/10. Markets of Kobo and its surrounding has small share of the total demand that absorbed only 35% of the total supply in the same year. The local market has small shares due to the presence of various nods of supply both in Kobo and outside. According to the group discussions made with dealers, tomato buyers bought 2-3 lorries of tomato per day (each with 4.2 tons capacity) in low production periods and 4-7 in good production period. Tomato business has been running in well organized manners by 126 member traders and 15-20 non-member traders. To meet high demand of tomato in Tigrai region, Mekele traders indicated that 5-15 Lorries of tomato/day and 7-20 Lorries of onion/day have been brought from various potential producing areas throughout the year. Kobo, Kombolicha, Shewarobit and Wereta are the major sources from Amhara while Meki is from Oromia.

Retailers are the final link in the chain that delivered tomato to consumers. They are very numerous as compared to wholesalers and their functions were to sell to consumer in pieces after receiving from wholesalers or farmers. Generally, retailers can be divided into two major categories, namely seasonal type and permanent type retailers. The first type of retailers run a risky type of business, they are large in number who are women and female children at Kobo and its surroundings but do not stay for long in retailing activities. They usually buy a package of 50kg tomato early in the morning and retail up to mid day only at the same market center. They are forced either to pay 5 Birr tax for each package of tomato to be retailed or they usually prefer to dump tomato in the market and run away from tax collectors. Unlike, the first type of retailers, permanent

/experienced type of retailers was relatively small in numbers. They usually have legal guarantee and pay tax.

The Tradeoff between Farm Gate Market and Weekly Kobo Markets

Most commonly, majority of producer farmers prefer to sell bulk volume tomato at farm gate with any prices than to take their all produces to other marketing options. After a bulk sale made with any fixed prices arranged by Mekele large buyers at farm gate market, unsold tomato which is usually poor in quality and small in quantity sold at weekly markets of Kobo. In turn, this leads high probability of selling tomato with better price despite any quality issues. This may be due to the low supply and high demand created in weekly markets of Kobo. Unsurprisingly, variation of price margins between the two marketing nodes bring critical distortion of market information both within and between sellers and buyers in both marketing places, that in turn affect marketing decisions of potential buyers and sellers to the next marketing days. Failures of farm gate markets may aggravate problems on the system of local market operations. Because, producers may supply high volume of product at a time to local markets unexpectedly, where there might be small demands that may absorb only small part of the total supply. Comparatively, such contradictory experiences of marketing challenges may lead farmers to regret and divert their interest toward farm gate buyers as choice-one option. The price of tomato at Kobo markets may go high when they predict low, and the reverse. Sadly, marketing decisions of traders work to the opposite scenario of farmers' conditions that in turn keep away both sellers and buyers. Producing tomato without secured market is the strange alchemy of farmers' decisions. The sad fact implies that, market challenges work their own vicious circle, then add, and pack huge problems over the shoulder of poor producers. These limitations made smallholders economically disempowered and exploited too much not to benefit out of their effort (Lemma Desalegn, 2000; Demelash Seifu, 2003).

Tomato Value Chain Governances

Reliability: Despite the complex natures of trapping market challenges, 83.3% of tomato producers indicated that Mekele whole sellers were the most reliable actors in tomato value chain. Farmers showed that these traders were the only traders who periodically visit them and absorb the lion's share of their products. However, 60% and 33.33% of the producers complained that dealers were non-reliable and unknown to predict their roles, respectively (Table 4). On the other hand, comparatively, the rest of local traders were less reliable and less capable to absorb the bulk products produced over different production periods. Evidently, only 23.3 % of the total respondents indicated that local traders were reliable, while the rest did not. Similarly, 20%, 36.67%, and 43.3% of the respondents indicated that consumers were reliable, non-reliable and unknown, respectively.

Trust: As the degree of social relations between dealers and experienced traders increase via tomato market, dealers usually may work toward the benefit of traders, hopping to get additional benefit from such traders through pre- calculated and hidden common agreements. If farmers might have relationship with traders, it is based on suspicion rather than trust. Though 70% of the producers implied that Mekele traders were trustful buyers comparatively, most traders deal through dealers in arrangements of lower prices, informal and illegal actions in grading and valuation, delay of transactions and payments, incorrect weighing tools. Out of the total producers, 53.33% indicated that local dealers were low trusted while 43.33 were unable to know dealers action with concrete evidence (Table 4).

Dealers usually try to settle disagreements between buyers and sellers in price setting and transaction scenario through continuing convincing mechanisms and simply making producers as mere price takers. Key informants indicated that, if some dealers accomplish their mission over producers successfully, then they would have additional awards given by buyers without the knowledge of sellers. This implies that, consciously, local dealers play tricky gambling games over producers. Generally, the price and quality regulations were absent in the tomato sub sector. Seasonal price variations of tomato were marked throughout the whole production seasons. Farm gate prices of tomatoes varied between 0.36 and 1.33 Birr/kg in April and August of 2009/10 respectively (Figure 3). The price of tomato increased sharply from April to August and slightly declined back from September to mid November then slightly stable from mid November to mid December. The prices highly fluctuate from mid December on wards up to May, during which high volume of the product was sold to Mekele buyers. Tomato prices in open markets of Kobo is found to be equal to farm gate price during September to mid December, and then increased from mid December to April. Then both farm gate price and the price at open market highly increased up to August and farm gate prices take over the slightly higher selling price. At farm gate market, traders only paid competitive prices in the time of deficit supply that usually occurred during May to August (Figure 3).

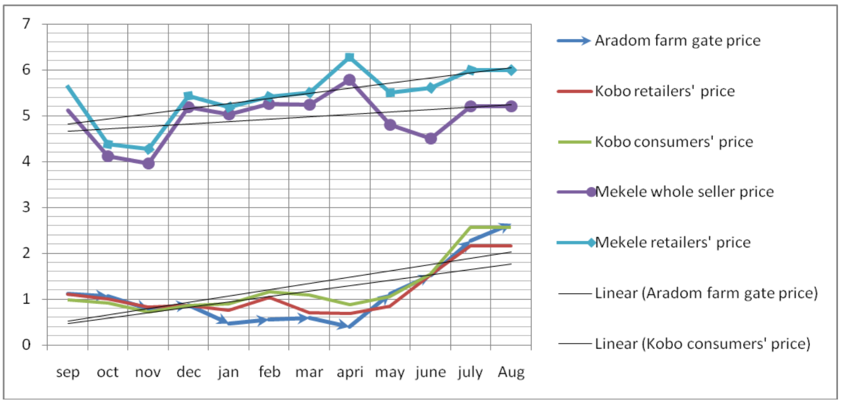


Fig. 3. Tomato price trend in 2009/10 (Source: Own field survey, 2010)

Table 4. Farmers' perceptions on behaviors of buyers and dealers **(Source:** Own field survey, 2010)

Indicators	**Major market actors**	**Response**	**Good**		**Bad**		**I don't Know**		**Rank**
			N	**%**	**N**	**%**	**N**	**%**	
Fair price arrangement, governance	Mekele Whole seller	30	10	33.3	9	30	11	36.7	2
	Local Retailers	30	8	26.7	7	23.33	15	50	3
	Dealers	30	4	13.3	16	53.33	10	33.3	4
	Consumer	30	12	40	4	13.33	14	46.7	1
Reliability	Whole	30	25	83.3	3	10	2	6.67	1
	Retailer	30	7	23.3	13	43.33	10	33.3	2
	Dealer	30	2	6.67	18	60	10	33.3	4
	Consumer	30	6	20	11	36.67	13	43.3	3
Trust	Whole	30	21	70	6	20	3	10	1
	Retailer	30	8	26.7	11	36.67	11	36.7	3
	Dealer	30	1	3.33	16	53.33	13	43.3	4
	Consumer	30	14	46.7	9	30	7	23.3	2
Summed values (indicator of goodness)	Whole	90	56	62.2	18	20	16	17.8	1
	Retailer	90	23	25.6	31	34.44	36	40	3
	Dealer	90	7	7.78	50	55.56	33	36.7	4
	Consumer	90	32	35.6	24	26.67	34	37.8	2
	Total responses	**360**	**118**	**32.8**	**123**	**34.17**	**119**	**33.1**	

Marketing and Price Strategies of Tomato Buyers

Out of the total wholesale respondents, 45.5 and 54.5 % indicated that quality parameters and expected profit margins were the major criteria used to set prices, respectively (Figure 4). Out of the total retailers, 46.4, 14.3 and 39.3% indicated that quality parameters, market prices and profit margins were the determinant factors to buy tomatoes from wholesale traders, respectively. On the other hand, 27.3, 4.5 and 68.2% of the total wholesale traders implied that quality parameters, market prices and profit margin were the major criteria considered to set selling prices. Unlike the buying price criteria, quality parameters become less considered in setting selling prices. For whole sellers, the major criteria considered to set selling prices was profit margins. To the contrary, quality parameter was considered by 57.1% of the total retailer respondents as the major factor to set selling prices while 35.7 and 7.1 % of retailers considered profit margin and market price. Out of the total wholesale respondents, 77.3 and 22.7% indicated that fluctuations of tomato buying price were moderate and very instable respectively (Figure 4). And 75, 14.3 and 10.7% of retailer respondents indicated that tomato-buying price was very instable, instable and moderate, respectively. On the other hand, out of the total whole sale respondents, 50, 36.4 and 13.6 % indicated that fluctuations of tomato selling price was very instable, instable and moderate respectively (Figure 4). Out of the total whole sale respondents, 72.7% of the wholesale and 57.2% of the retailers indicated that there was an imperfect price trend across towns at a particular time. Out of the total respondents whole sellers, 81.8% indicated that supply and demand variations was causes of price fluctuations while the rest implied that market imperfection and information collision were the factors of price fluctuation.

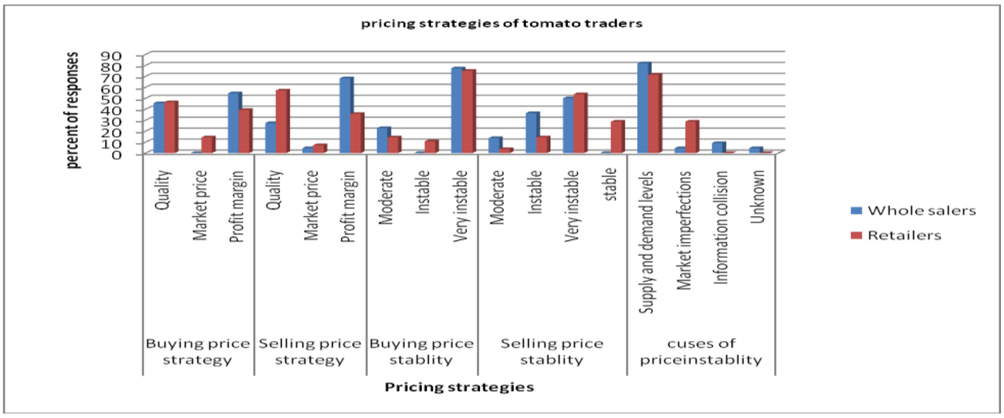
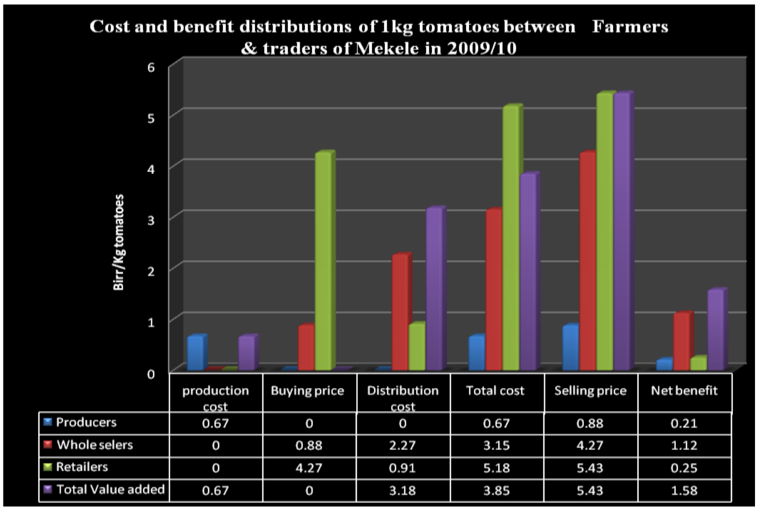


Fig. 4: Buying and selling price of whole sellers and retailers (Own field survey, 2010)

Cost and Benefit Distributions among Tomato Value Chain Actors

For the analysis of cost benefit distribution among actors, the major output channel was considered. Producer-dealer-Mekele large buyers-Retailers. This section focuses the distributions of costs and benefits among the major value chain actors of tomato. Average costs of product loss, labor, inputs, and others constituted 39.84%, 35.15%, 18.71%, 3.35% of the total cost required, respectively. Out of the total costs, product loss was the major cost incurred followed by labor costs (Figure 5). Producers incurred 0.67 Birr to produce and sell a single kilogram of marketable fresh tomatoes to Mekele whole sellers. Production cost covered 17.40% of the total costs required to produce and distRibbute one kilogram of tomatoes to Mekele consumers. As we can see in Figure 5, the remaining 83.60 % (3.18 Birr) of the total cost was costs of distribution, of which 58.96% (2.27 Birr) covered by whole sellers and 23.64 % (0.91 Birr) covered by retailers. This implies a single kilogram of tomatoes took 3.18 Birr to produce and distRibbute to Mekele consumers. On the other hand, a single kilogram of tomatoes gave a net benefit of 1.58 birr, in its path from producers to consumers. Producers obtained a net benefit of 0.21 Birr out of a single kilogram of marketed fresh tomatoes to Mekele whole sellers, this benefit covered 13.29 % of the total net benefits of a kilogram of tomatoes obtained after sold to Mekele consumers. Mekele traders shared the remaining 86.71% (1.37 Birr) of the total net benefit, of which 70.87% (1.12 Birr) and 15.82% (0.25 Birr) of the total net benefits shared by whole sellers and retailers respectively. Much of the benefits accrued to Mekele traders, producers obtained the least benefit out of the total benefits distributed (Figure 5).



	production cost	Buying price	Distribution cost	Total cost	Selling price	Net benefit
Producers	0.67	0	0	0.67	0.88	0.21
Whole selers	0	0.88	2.27	3.15	4.27	1.12
Retailers	0	4.27	0.91	5.18	5.43	0.25
Total Value added	0.67	0	3.18	3.85	5.43	1.58

Fig. 5. Cost and benefit distribution (Source: Own field survey, 2010)

Conclusion and Recommendations

Tomato producers have experienced ‘menu of market challenges’ both at farm gate and local markets of Kobo town in tomato value chain. Tomato has no organized market structure. Consequently, farmers are forced to sell their product at farm gate to limited major buyers of Mekele traders with little share of local buyers of Kobo. Lack of reliability of local traders may associate with inconsistencies of supply and demand that frequently occurred in local markets of Kobo. Producers obtained a net benefit of 0.21 Birr out of a single kilogram of marketable fresh tomatoes to Mekele whole sellers, while Mekele traders shared the remaining 86.71% (1.37 Birr) of the total net benefit. Absence of effective input and service provision, production planning, lack of markets, low output prices, poor market information management systems made farmers the victims of mono channel marketing system and kept them risk takers of tomato value chain.

The following actions are recommended for effective tomato value chain.

- Improving input and service provision systems both in pre- and post- harvest handling of tomato. Formal input channels should be strengthened by solving problems of delays of delivery, promotion of credit awareness, seed and chemical quality control and granting cooperatives with legal entity. Moreover, inputs introduced by illegal traders and informal sources need to be monitored.
- Encouraging and empowering farmers to help them integrate both to vertical and horizontal activities of production and marketing processes.
- Searching potential markets and strengthening market linkages may improve the market performance and its competences. Creating coordination between producers, local dealers and large traders through forums and discussions is essential to develop common understanding between chain actors for fruitful coordination in the value chain system.

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Irrigation Water Management Practices and Challenges in Amhara Region

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Introduction

The importance of irrigated agriculture is increasing in the world from time to time. Over 270 million hectares of land is currently irrigated worldwide. About two-thirds of this area is irrigated by surface water delivery through canal irrigation systems. Nearly 40% of the crop production in the world comes from the irrigated lands that accounts for only 17 percent of the cultivated lands and 60% of the fertilizer from the total consumption for cultivated lands is used for irrigated lands. In Ethiopia, traditional irrigation has been in practice for many years. It is rooted far back in history. By considering availability of water and land resources, technology and economics, the current irrigation potential of the Ethiopia is estimated to be about 3.5- 5.0 million hectares.

TheAmhara region has abundant Water Resource: (1) 40% of Abay with a catchments area of 201,346ha, (2) 60% flow of Tekeze- Angereb with a total catchments area of 90,000 ha, and (3) About 30% flow of Awash basin, and (4) The whole of Tana basin flows are the major potentials of surface water in the region (source: Abay and Tekeze Basin Master Plan Study). There are also numerous seasonal and perennial springs and sub surface water potentials. By considering availability of water and land resources, technology and economics, the irrigation potential of the region is estimated to be 650,000- 700,000 ha out of which 250,000 ha is estimated to be suitable for small scale irrigation and more than 400,000 ha is for medium to large scale irrigation.

The area coverage of traditional irrigation is increasing from time to time in Amhara region. Even in difficult terrains, traditional irrigation is practiced by small holder farmers. However, it is difficult to exactly estimate the area coverage of traditional irrigation in the region. The development of modern irrigation infrastructure development is also getting more emphasis in the region. Large storage dam irrigation infrastructures like Koga irrigation and other medium scale intake weirs have been constructed. However, following poor water management practices, low input use (improved seeds and fertilizers) crop productivity per unit area in the command areas of both traditional and modern irrigation schemes is very low. During this field observation which is part of the regular irrigation extension activity, several traditional and modern irrigation schemes performances in the region were assessed and reported. This paper is therefore a field irrigation water management assessment report of which it may contribute to identify the gaps for better extension and research support in the development efforts of irrigated agriculture in the region.

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Methodology

The methodology used includs field observation, discussion with farmers, experts and development agents. The observation has been made to identify gaps in the areas of irrigation water management and input use both in traditional and modern irrigation schemes as part of regular field supervision.

Traditional Irrigation Management Practices in Amhara Region

Irrigation water is delivered to the command area through traditionally constructed temporary diversion canals. Traditional temporary diversion structures serve only for one dry season. During the rainy season temporary diversion materials are usually taken away by the river or flood. Therefore, after the rainy season, the re-construction of temporary diversions every irrigation season is a must. This requires large amount of local diversion materials and labor. In some places local diversion materials, like stones, sodden earth, wood, etc. are not easily available. In such cases farmers are obliged to carry local materials from distant places every year.

Diversion canals are commonly made from earthen materials. Due to financial problems concrete lining is not a common practice in traditional irrigation schemes. Depending on the soil type, slope, length of canal, canal bed uniformity, etc, in traditional earthen canal irrigation schemes water losses through deep percolation is common phenomenon (Figure 1). Such losses may contribute to scarcity of irrigation water resulting competitions and conflicts over water use. At the same time within the same command area, some members may be more affected by the shortage or benefit from the abundance of water based on the location (upstream or downstream), slope, soil type, and crop type they grow.

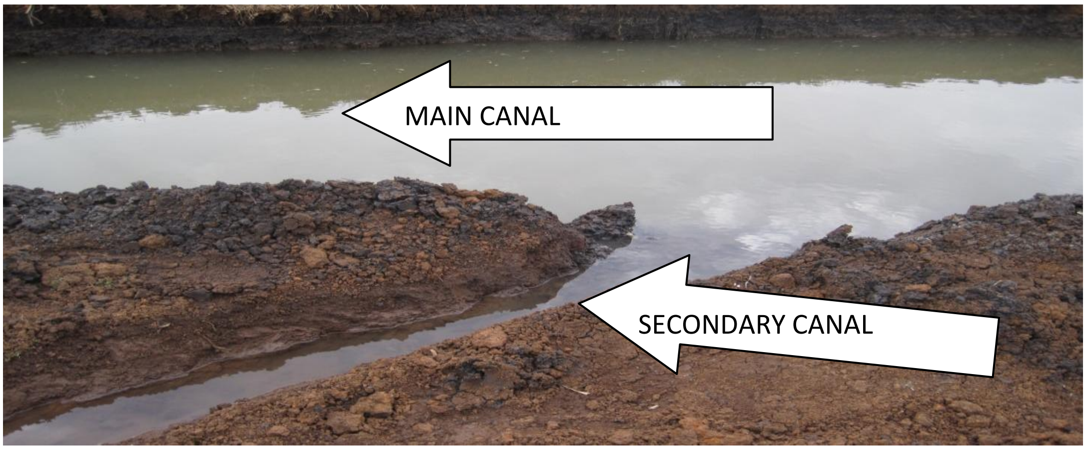

Fig. 1. Andas traditional diversion without flow control measurements

All traditional irrigation schemes in the region do not have water distribution controlling and measuring devices. The most commonly used technique of water distribution in traditional irrigation systems is water supply by rotation. In some traditional irrigation schemes, wherever or whenever water supplies are abundant, farmers are free to use water at will. In some cases farmers adopt continuous or intermittent irrigation depending on their crop type and stage of growth. The irrigator therefore has the freedom to match irrigation to soil and crop needs and to coordinate irrigation with other farming activities.

The commonest methods of irrigation are wild flooding and furrow irrigation. Leveling of irrigation land is not at all practiced. Due to differences in land leveling, method of irrigation, time of irrigation and water application is found to be non uniform. These lead to over irrigation causing deep percolation or under irrigation causing moisture stress. Farmers along the same canal take water on rotation basis. Each farmer can take water as long as he needs once it is his turn. Frequency is therefore unscheduled because the duration of irrigation is at the freedom of the individual farmer. Once water is delivered to their fields during their turns, most farmers keep on irrigating until their turn is over no matter how deep the water is applied to their fields. In most cases, this situation causes water loss due to deep percolation and runoff (Fig. 2 and 3). Erosion is also a common phenomenon. However, in some places there are better traditional irrigation management practices which could be up scaled (Fig.4).

Fig. 2. Over flooded furrow irrigation, Fogera

Fig. 3. Flooding with non uniform water application

Fig. 4. Best traditional irrigation practice, Fogera

Low input use is another problematic area observed. In most irrigation schemes of both traditional and modern, input use is very low. Crop productivity under traditional irrigation is therefore very low. In some pocket areas where there are alluvial deposits, the productivity of irrigated agriculture without the use of fertilizers is observed to be much better due to its good soil fertility. In spite of the fact that traditional irrigation has much management limitation, it has significant contribution to the household incomes of small holder farmers.

Fig. 5. Good harvests from irrigated agriculture, Fogera and Kewot

Major Problems of Traditional Irrigation Management Practices

- High labor and local material requirement for the temporary intakes and canals

Fig. 6. Labor and material intensive traditional diversion, Fetam River

- River diversion is based on indigenous knowledge. Intake discharge does not consider canal carrying capacity and crop water requirement. Uncontrolled discharge was observed.

Fig. 7. Traditional diversion, Andas river diversion, Burie

- Irrigation water is unregulated, lacks water controlling and measuring devices in that case there is high water loses (conveyance and application), erosion, and low irrigation scheme efficiency
- Accidental and frequent collapse of temporary intakes during the dry season and complete collapse in the rainy season.
- Sever erosion or collapse of the river embankment at the point of the temporary intake

Fig. 8. Uncontrolled water distribution, Silala river diversion, Burie

Modern (Medium to Large Scale) Irrigation Management Practices

The introduction of large scale irrigation infrastructure with central water distribution systems requires significant management skills, institutional capacity building and operational rules, both at the level of the government and water users. Modern irrigation systems include small to large scale irrigation infrastructures. According to Ethiopian context the size of small scale irrigation is up to 200ha, medium scale 2,000ha, and large scale more than 3,000 ha. For example, Koga is one operational large scale irrigation scheme in the region. The government is operating and maintaining the dam and the main canal, while farmers through water user groups elected by irrigation beneficiaries manage from the secondary canal down to the field level. There are water measuring devices and control structures for water management.

The designed water delivery system of Koga irrigation project is continuous flow. Currently, water distribution is not based on crop water requirements. Water is delivered by considering the size of the irrigable area in each irrigation block. Irrigation blocks are not planted and harvested at the same time and the crops are not the same except some coincidence. Some fields may be planted, others are under seed bed preparation and others unploughed while water is running through the canals. Crop water planning is not considering crop water needs. For this purpose, planning should be done for every dry season based on the available water stored in the reservoir. Planning based on the reduced available stored water may include area reduction, increased in irrigation efficiency, selection of crops which are less water requiring and short growing crops. Generally, available stored water and crop water needs should be the center of planning, which is not currently practiced in Koga irrigation.

Irrigation methods and water application uniformity are more or less similar to that of traditional irrigation except medium to large scale irrigation systems have lined canal systems. Input use in modern irrigation schemes is like that of traditional irrigation. Inequity in the pattern of water allocation/distribution is common both in traditional and modern irrigation water management, causing excess water in some places and deficits in others. Head reach farmers often take advantage of their location and take an unfair share of water when the service is not reliable and water is scarce. For example in Koga irrigation project, at the given moment, it is not meeting high irrigation scheme efficiency, equitable and timely water distribution, skilled and knowledgeable operations, etc.

Generally, because of the severe deficiencies in irrigation water management, benefits derived from many irrigation projects (both traditional and modern) are far short of expectations in the region. Some small to medium sized modern irrigation schemes in the region are poorly designed, constructed or managed by the beneficiaries. As a result, there are several irrigation schemes which have been completely collapsed while others suffer from significant seepage losses. In such schemes, irrigated areas in the dry season's production are reduced from the expected at the irrigation development planning stage. This situation has led to:

1. Decrease in volume of flow through the canal and cause water shortages to the designed area. This happens following seasonal discharge decrease of annual and perennial rivers
2. Less probability of double cropping either by time factor or shortage of water. This occurs as a result of improper planning.

Major Problems of Modern Irrigation Schemes

Major problems of modern irrigation management practices could be categorized as technical, financial and social problems. Details could be described as follows:

A. **Technical problems:** Technical problems include: (1) Study, design and construction problems, (2) Overall operation and maintenance problems - lack simple and replicable technologies for operation and maintenance, (3) Scheme water management problems -inequitable, untimely, insufficient water supply, over irrigation, uneven distribution, etc, and (4) Watershed management problems -siltation in most cases and salanization in few cases especially in the Kobo-Borkena valleys, like Beteho irrigation scheme in oromia zone of Amhara region, collapse of modern irrigation schemes by boulders or flooded.

Fig. 9. Field level water application and distribution problems of Koga irrigation

Fig. 10. Collapse of Gotu scheme by flood from the untreated catchment, North wollo

B. **Financial problems:** Financial problems include (1) lack of sufficient budget for Study, Design and Construction, (2) insufficient budget for operation and maintenance, and (3) budget for rehabilitation including redesigning

C. **Social problems:** Major social problems include (1) low beneficiary participation in scheme management, (2) Conflict over water use, conflicts among irrigation water users within the same irrigation scheme and conflict between upstream and downstream users, (3) Land reallocation and compensation, (4) Problems of market access, (5) problems of access roads from the command area to the main road.

Recommendations

- Upgrade traditional irrigation schemes and improve traditional water management practices.
- Introduce/develop simplified irrigation techniques and technologies that can be used and operated with limited budget and skill by smallholder farmers.
- Recognize the decisive role of beneficiaries in irrigation water management and involve them in all decision making processes in irrigation water management.
- Produce field guide operational manuals.
- Introduce effective water application techniques and proper input use for smallholder farmer managed irrigation schemes in the region.
- Develop capacity (knowledge and skills) for irrigation operation and maintenance
- Introduce improved and high value crops that are best responsive to irrigation
- Introduce integrated catchment treatment program to minimize the risk of reservoir siltation and collapse of irrigation schemes by flood
- Allocate sufficient budget for operation and maintenance.
- Conduct scheduled participatory monitoring and evolution of the performance of irrigation schemes in the region.

Assessing Irrigation Performance of Smallscale Irrigation Schemes in North Gondar, Amhara Region

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Abstract
In Ethiopia, capital is a constraint to incur huge investment for irrigation despite small scale irrigation can be an alternative solution to enhance food production. To evaluate existing performance whether small scale irrigation schemes developed by the government and NGOs are working efficiently or not, study was carried out in North Gondar Zone,Gondar Zuria district, Arno and Fana irrigation schemes. Primary data using observation, measurement, and user interview; and secondary data using external sources have been collected from each scheme and calculation was done based on indicators to evaluate performance of Arno and Fana irrigation schemes. The major data inputs were discharge, climatic data, major crops grown in each scheme, production and production cost. The schemes were evaluated against performance indicators' set by IWMI. It was observed that both schemes have poor practices to be improved and good practices to be promoted. According to the t-test analysis, highly significant difference was observed between the means of output per irrigation supply and relative irrigation supply. But there was no significant difference in output per cropped area, output per command area and output per consumed ETO. Fana irrigation scheme was better in terms of output per irrigation supply and return on investment, with mean values of 2.48 Birr/$m^3$and 1280.82%, respectively. In numeric value, Arno is better in relative water supply and relative irrigation supply, 1.99 and 2.04 respectively. Relative water supply and relative irrigation supply nearest to the value of 1 implies no water and irrigation wastage which is the case for Fana irrigation scheme with the mean values of 0.925 and 1.275 respectively.

Key words: Small irrigation schemes, Performance indicators, Arno, Fana

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increased food demand. To maintain self-sufficiency in food supply, one viable option is to raise the productivity per unit water use. A favorable method for raising yield per unit of water use is through irrigation. The question, how is irrigated agriculture performing with limited water and land resources, however, has not been satisfactorily answered. This is because of that we are not able to compare irrigated land and water use to learn how irrigation systems are performing relative to each other and what the appropriate achievement targets are (David, et al, 1998).

In Ethiopia, where the principal component of project development (i.e., finance) is a constraint to incur huge investment for irrigation, small scale irrigation can be an alternative solution to enhance food production. Small scale irrigation structures, owing to their relatively small investment cost, ease of construction, simplicity of operation and maintenance have been a strategic target of the country for achieving sustainable food security and self-sufficiency (IFPRI, 2009). A number of such schemes have been designed and constructed in the previous years. However, while some schemes are performing successfully, others have failed to serve the intended purpose. Frequent operation and maintenance needed so as to sustain the schemes (FAO, 1986).

The variables that influence performance of irrigated agriculture are infrastructural design, management, climatic conditions, price and availability of inputs, and socioeconomic settings. International Water Management Institute (IWMI) has prepared different "comparative" indicators that are helpful for comparing irrigated agriculture between countries and regions, between different infrastructures and management types, and between different environments and for assessment over time of the trend in performance of specific project. According to David et al. (1998), the indicators have the following features:

- The indicators are based on relative comparison of absolute values, rather than being referenced to standards or targets

- The indicators relate the phenomena that are common to irrigation and irrigated agricultural systems
- Data collection procedures are not too complicated or expensive
- These set of indicators are designed to show gross relationship and trends and should be useful in indicating where more detailed study should take place, for example where a project has done extremely well, or where dramatic changes take place

This study has covered the comparative performance of two selected irrigation schemes in north Gondar zone. An attempt was made to see the causes and effects of the variation in these schemes. Frequent monitoring of the performance of irrigation systems assists to distinguish whether the targets and objectives are being met or not; provides system managers, farmers, policy makers a better understanding of how a system operates; helps to identify the strengths and weaknesses, consequently alternatives that may be both effective and feasible in improving system performance to achieve maximum efficiency. Hence, the study was carried out with the objective of evaluation of the performances of selected small scale irrigation schemes in North Gondar Zone.

Materials and Methods

Description of Study Area

The study area is located within the Lake Tana sub-basin, Gondar Zuria Wereda of North Gondar Zone in Amhara Region. The rivers, Fana and Arno, used as irrigation source, drain into Lake Tana. Both schemes show almost similar climate since they are found in the same basin. They have a mono- modal rainfall pattern and the humid period for Arno and Fana consists 131 days (1 June – 9 Oct.) and 106 days (6 June -19 Sept.) respectively. The mean annual rainfall of Arno and Fana is 1099 mm and 1008 mm and mean monthly temperature is 19.8 and 20.9 $^{o}{}_{C}$ respectively.

Fana with potential irrigable area of 31 ha is found in *Fana* gott, *Das-Dinzaz kebele*. Fana was constructed in 2007. It is located at about 45 km southwest of Gondar town.

Its altitude also ranges from 2040 to 2458 m a.s.l. The topography of the area covers from gentle slope to steep. The type of diversion is traditional canal intake. Most of the cultivated area's soil type is clay loam. Garlic, potato, maize and perennial fruits are dominant irrigated crops in the area. The farmers have competitive use towards scarce water and exercise both crop and livestock production to improve their livelihood. Similarly, Arno River is found in *Arno gott Sendaba kebele* with the potential irrigable area of 61 ha and is at a distance of 50 km to the south east of Gondar. Its altitude also ranges from 2010 to 2315m a.s.l. The topography of the area covers from gentle to steep slope. It has broad crested diversion weir and its water source is a perennial river. It was constructed in 2000 and all its main canal length is lined. Most of the cultivated area's soil type is silt loam. Garlic, potato, maize and onion are dominant irrigated crops in the area. Farmers practice both crop and livestock production.

Data collection method

Discharge rate was measured on spatial and temporal basis i.e. following the production season on the field canal outlets. The recorded discharge values have established a linear equation which relates time versus discharge and time versus the distance from field canal outlet to intake canal using the JMP-5 statistical software. This could enable to estimate the amount of water that actually arrived on the field. The agronomic practice was surveyed using actual measurements. The existing crop spacing was measured for fruit crops. In addition, farmers and Development Agents in the kebele were interviewed to put standards that estimate variables like farm gate prices of irrigated crops, cost of production, area irrigated per crop per season and per year, crop types, major crops frequently produced, etc.

Estimated values

These values are calculated through known parameters. Irrigation and water demand have been calculated using CROPWAT for window version 4.2 software (Clarke, 1998). Peak consumptive use of crop has been calculated by selecting a crop that needs highest water supply (l/s/ha) in the CROPWAT model and assuming all the irrigated area to be covered by this crop which has high atmospheric demand in the season. To calculate scheme relative irrigation supply, relative water supply and output per unit water consumed, one should determine the estimated total net irrigation requirement, total net water requirement and total water consumed by ET_0 respectively. The input data for determination of estimated crop water requirement, irrigation water requirement and water consumed by ET_0 for CROPWAT model are climatic, rainfall, soil, crop data and cropping pattern. These data values which represent for each irrigation scheme were added to the model and the scheduling criterion was adjusted using optimal irrigation scheduling. The results are listed in the table below. Secondary data like cost of infrastructure and number of beneficiaries were collected from Gondar Zuria Wereda Bureau of Agriculture. Climate data such as temperature (mean maximum and mean minimum), sunshine hours, humidity, wind speed and rainfall was collected from the Regional Meteorological Agency. These data are further used for estimation of real water and irrigation requirement with the assumption of irrigation efficiency of 70%.

Measured values

All calculations of standard indicators (Table. 1) were carried out based on collected data during one year for both irrigation schemes. To collect discharge data, velocity-area method and flow measuring devices were used (Figure 1). The flow measuring devices were cutthroat flume and partial flume. The data values that were found using the above methods were averaged. Discharge diverted from the source was calculated by Velocity-Area method i.e., measuring the mean flow velocity across a cross section and multiplying it by the area where flow measurement was undertaken. Crop rotation (Table. 2) was developed for six rounds for both schemes by using crop family rotation system so as to avoid nutrient depletion and disease infestation referred from Marshall Bradey (1997). In Fana irrigation scheme majority of the crops are perennials, which cannot allow crop rotation.

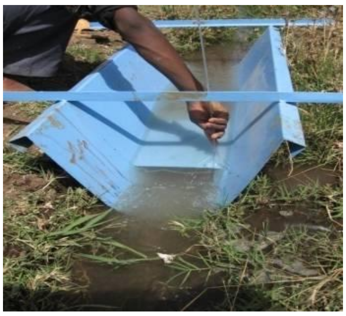

Fig.1. Devices used to measure discharge: cutthroat flume (left) and partial flume (right)

Table 1. List of IWMI's Standard Comparative Indicators used to evaluate the performance of Arno and Fana irrigation schemes and their description

Performance Indicator	Description
Output per cropped area (birr/ha)	Production/irrigated area
Output per unit command area (birr/ha)	production/production command area
Output per irrigation supply (birr/m^3)	Production/ Diverted irrigation supply
Output per unit water consumed (birr/m^3)	Production/ Volume of water consumed by ET
Relative water supply	Total water supply/ Crop demand
Relative irrigation supply	Irrigation supply/ Irrigation demand
Water delivery capacity	Canal capacity at the system head/ Peak consumptive demand
Gross return on investment (%)	Production/ Cost of infrastructure
Financial self sufficiency (%)	Revenue from irrigation/Total O&M expenditure
Conveyance efficiency (%)	Discharge at canal outlet/discharge diverted from the source

Table 2. Rotation system used for irrigated crops in Fana and Arno irrigation schemes

Round1	Round 2	Round 3	Round 4	Round 5	Round 6
Garlic	barely	Potato	onion	maize	tomato
Fenugreek	garlic	Barley	potato	apish	maize
Potato	Maize	Garlic	tomato	barley	onion
Onion	barley	Potato	garlic	maize	tomato
Tomato	onion	Maize	potato	garlic	barley
Maize	garlic	Tomato	barley	onion	potato
Barley	potato	Onion	maize	tomato	garlic

Results and Discussion

The water delivery capacity, financial self sufficiency and conveyance efficiency of Arno scheme is better than that of Fana (Table 3). As shown in Table 4, output per cropped area of Arno is greater than Fana but, in terms of area coverage, Arno produces less than half of its potential. The mean value of relative irrigation supply is 2.04 and 1.275 for Arno and Fana irrigation schemes, respectively. This implies Arno supplies more water (i.e. double of the irrigation demand that is estimated by CROPWAT model) while, in Fana it is equivalent to its irrigation demand. This occurrence is due to the reason that, Arno scheme has less competition for irrigation water than Fana. In terms of relative water supply, Arno (1.99) has lower mean value than Fana (0.925) irrigation scheme. Water delivery capacity of the schemes is 0.96 and 0 .32 for Arno and Fana, respectively. This implies that, Arno can meet the irrigation demand of the crops even if all the area of the irrigation scheme is covered by a single crop having high water consumptive use.

Table 3. Summary of comparative analysis results for Arno and Fana irrigation schemes

No	Indicators	Unit	Arno irrigation scheme	Fana irrigation scheme
1	Water delivery capacity	-	0.96	0.32
2	Financial self sufficiency	(%)	100	-
3	Conveyance efficiency	(%)	58	48.43

The financial performance shows that, financial self sufficiency for Arno is 100% which implies that the entire collected water fee is allocated for operation and maintenance. But this does not mean that the operation and maintenance demand of this scheme is fulfilled. On the other hand, water users in Fana irrigation scheme doesn't contribute water fee that is why this indicator equals to zero. The Gross returns on investment of Arno and Fana irrigation schemes are 51.927 and 1280.817% respectively. The gross return for Fana irrigation scheme was higher due to low investment cost.

Conclusion

Despite the fact that every scheme has a contribution towards food production, the degree of its contribution vary from scheme to scheme since crop production is affected by multiple factors. So, the comparison of irrigation schemes helps to point out the weaknesses and strengths of irrigation practice in the region, and is helpful for managerial decision and technical measures to be taken for their future improvement.

Fana irrigation scheme have more constrained supply of irrigation water as compared to Arno irrigation scheme due to the competitive use of scarce resources among farmers. Moreover, productivity per unit of water is 2.477 and 1.38 for Fana and Arno respectively. Hence it calls for management intervention for wise use of irrigation water in the Arno scheme. Through wise use of water its actual water supply can be minimized and used for irrigating additional land and increased production per unit of water. On the other hand, higher return on investment of Fana irrigation scheme implies that its irrigation scheme is constructed with low investment cost and produces more production per year. T-test analysis revealed that, output per irrigation supply and relative irrigation supply showed highly significant difference (at 5%).The lower relative water supply and relative irrigation supply of Fana irrigation scheme is due to the fact that most of the area is covered by perennial fruits and the application of water is at longer intervals. Regardless of its longer canal length, Arno has better conveyance efficiency due to its lined canal system.

In general, the comparison of the performance of irrigation systems will help to know the present status of irrigation schemes. It helps to point out the strengths and weaknesses of existing practice and search for possible interventions in time. Therefore, for scheme level irrigation water management and irrigation system improvement, conducting frequent performance evaluation on selected schemes is imperative. The limitation of this paper is that the research work was done for one year. Due to this, it couldn't be possible to see the trend of the indicators' over time.

Table 4. Results of T-test analysis for Arno and Fana small scale irrigation schemes using IWMI's comparative indicators

Rotation No	Output per cropped area		Output per unit command area		Output per consumed (ETo)		Output per irrigation supply		Relative irrigation supply		Relative water supply		Return on investment	
	Fana	Arno	Fana	Arno	Fana	Arno	Fana	Arno	Fana	Arno	Fana	Arno	Fana	Arno
1	9255.2	20089.3	34264.0	39581.3	5.06	9.26	2.87	2.27	1.09	2.33	1.17	2.22	1487.5	85.5
2	7174.0	5211.9	26559.5	10268.9	2.89	2.03	2.23	0.59	1.16	1.97	0.87	1.96	1152.6	22.2
3	9206.8	11961.6	34085.2	23567.5	8.40	3.89	2.86	1.35	1.35	1.80	0.97	1.77	1479.2	50.9
4	7654.5	19528.7	28338.5	38476.8	3.25	9.12	2.38	2.21	1.35	2.37	0.84	2.26	1229.8	83.1
5	6469.7	4833.2	23952.2	9522.7	3.85	1.88	2.01	0.55	1.35	1.97	0.87	1.96	1039.4	20.6
6	8070.0	11606.9	29876.7	22868.8	3.42	3.77	2.51	1.31	1.35	1.80	0.83	1.77	1296.5	49.4
Mean	7971.7	12205.3	29512.7	24047.6	4.48	4.99	2.48	1.38	1.275	2.04	0.925	1.99	1280.8	51.9
Lsd (5%)	**0.271**		**0.142**		**0.760**		**0.006**		**0.002**		**0.000**		**0.000**	

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The Paradox of Water Distribution in Tuweir Minor Canal: Lessons Learned from Gezira Scheme, Sudan

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Abstract

Gezira Scheme was designed for cotton production. It was designed to serve water to 50% of its gross command area in two consecutive growing seasons (summer and winter). But later, in the 1960s, a crop diversification and intensification policy was implemented in the Scheme. That results to operate the system over its capacity; together with an increment of the actual sedimentation rate from the Blue Nile's catchment, silt to enter the canal system has increased. Consequently, operation and maintenance costs have risen to a point that is beyond the capacity of the government. This in turn could affect water distribution. However, it was not clear, where and how the water distribution change in the scheme. This paper investigates the water distribution on a minor canal called Tuweir which is a part of a big project, the Blue Nile programme, implemented to analyse the situations on operation and maintenance in depth. Both socio-economic and bio-physical data were collected through interviewing, field observations, and measurements. The result implies, though it is difficult to claim that water distribution in the past was well planned and optimal, there was at least relatively formal, predictable and specified water indenting system that roughly corresponding with estimated crop water requirements and the canal capacity. However, currently neither scientific approach of crop water requirement calculation takes place nor does the canal capacity feature in the balance at all. Factors like the operation of the Field Outlet Pipes (FOPs) by farmers themselves as well as their irrigation perceptions negatively affected the water supply security. The interplay of these factors has created unequal, unreliable and unscheduled water distribution between numbers of the Tuweir minor canal. The impacts of the water distribution changes produce both long term (out migration of farmers, cropping pattern changes and deterioration of the system); and short term effects (yield reduction, conflict between farmers, additional costs for water pumping...) on the water users.

Key words: Water distribution, Operation, Maintenance, Minor canal, Gezira, Sudan

Introduction

The Gezira Irrigation Scheme reclines south of Khartoum between the Blue and White Nile Rivers. The scheme is one of the largest and oldest irrigation schemes **(880,000 ha)** on the African continent. The Gezira Scheme gets its irrigation water from the Sennar and Roseires Dams on the Blue Nile River. The irrigation system comprises two main canals (Managil and Gezira) running from the head-works at Sennar Dam to a common pool at the cross-regulator at 57 km. At this junction, the Managil canal divides into 4 branches, to divert water to the Managil extension; while, the Gezira main canal flows an additional 137 km northwards.

The annual water discharge of the Blue Nile is estimated on average to be 50 billion cubic meters measured at Roseires (Ahmed 2000-cited by Eldaw 2004). Based on the Nile water agreement between Sudan and Egypt in 1959, the allocated water for Sudan was 18.5 billion cubic meters (37% of the Blue Nile). The Gezira Scheme is entitled to approximately 35 % of this share, which is 6.5 billion cubic meters (Eldaw, 2004). This has been used to irrigate 50% of the gross area in a season. The scheme was established by the British purposely for the cotton production before 1925 (Sennar Dam was completed in 1925). But in the 1960s with the diversification and intensification policy of the government, other crops like groundnuts, wheat, and vegetables had been introduced in the scheme.

Water distribution is ‘the process of actual water proportioning in practice - ‘the concrete distribution of wet water’- it is about water scheduling that is a certain amount of water per a certain area for certain time duration (Boelens, 2008) and (Uphoff, 1986). The relation between ‘hydraulic laws’, the ‘control infrastructures’ in use and the socio-technical linkages between techniques (design, operation, maintenance), ‘users’ and ‘providers’ often lead to typical patterns of distribution (Treffner et al., 2010). Users and Providers refer both technical and social actors (operators, irrigation engineers and management bodies at different levels of the network). The typical patterns of distribution are proportional flow, rotational system, request or supply system, and head-end or tail-end control, along the command of irrigation canal.

The water distribution in the GS is the Gezira main canal conveys water to branches. From branch water flows to major canals as a continuous flow during the irrigation seasons (from July to April). From the major water is delivered to minor canals. The water distribution principle was at the beginning of the cropping season, the water requirement of the different crops in the minor first had to be calculated and transmitted to the engineer who would determine the amount of water that would be discharged to each reach of the minor canals. Accordingly, the required water from the higher levels to the minor had to be conveyed. From the minor canals water flows to Abu-Ishreens (Abu XX)-a small field ditch (tertiary channel) and from Abu XX to the field through Abu Sittas (Abu VI) - the smallest field channel. The Abu XX is designed to serve the 'Number' or tertiary unit (1,350m x 280m=37.8 hectare land) at fixed intervals of 292 m along the minor canal (Abu XX's take off perpendicular of the minor canal). Field Outlet Pipes (FOPs) take-off the water at right angles (12 meters long with a 0.35 m diameter).

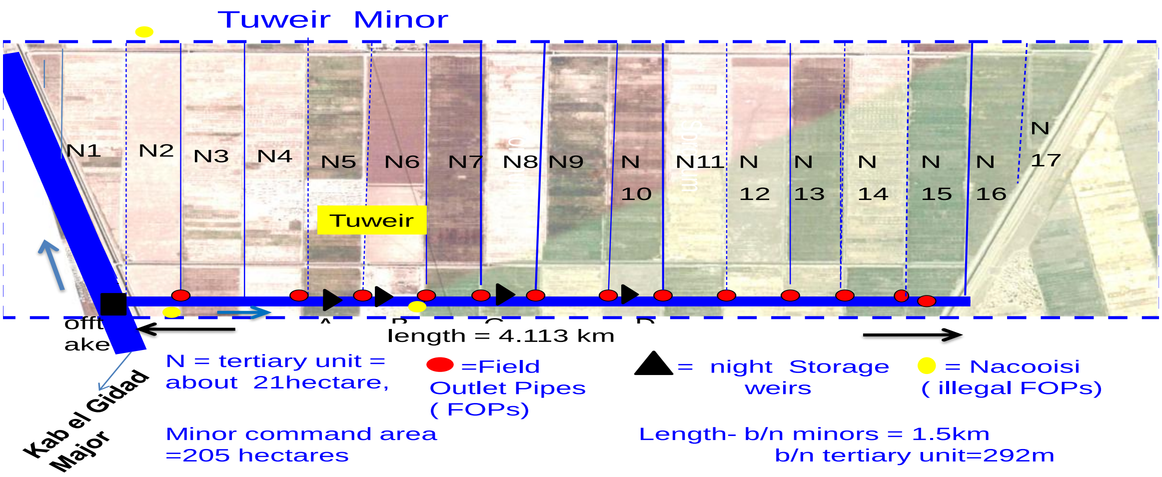

Figure 1: Tuweir minor canalization system

Generally the Scheme has played a significant role in the country's economic development. According to the World Bank (2000) report, the scheme has a long history of satisfactory performance, to the extent that it has been used as a model for designing and developing all other major irrigation systems in Sudan, especially up to the 1960s, when the scheme was operated at its designed capacity. However, in contrast to this historical appreciation before the 1960s, recently many studies showed that the scheme has deteriorated due to high siltation problems. This resulted in high sediment accumulation problems in the scheme, and there is a need for high levels of financial capital to overcome this problem. However, the government supplied budget for O&M is insufficient to cover the capital outlay required to cope with the sedimentation problem. Consequently, there is a lack of 'equity and reliability' of water supply to tenants (World Bank, 2000). Therefore, this research was implemented to analyse what water distribution changes and impacts have taken place in the scheme.

Methodology

The study was conducted in 2010. The study area located 194 kilometer to the North from sennar dam, which is called Tuweir tertiary canal at the 'Kab El Gidad' major canal at the tail of the Gezira irrigation scheme. The geographical location of the area is 14^o38^1 longitude and 33^o34^1 latitude; and altitude is 431m above sea level. The study area principal features are a level and nearly uniform topography of water retentive clay soils which keeps down losses from seepage. This soil slopes away from the Blue Nile and water therefore naturally runs through the irrigation canals by gravity. The annual rainfall is about 308 mm. The maximum mean temperature is 38^oc while the minimum temperature is about 22^oc. The main cash crops in the area include cotton and groundnut while sorghum is stable crop in the area.

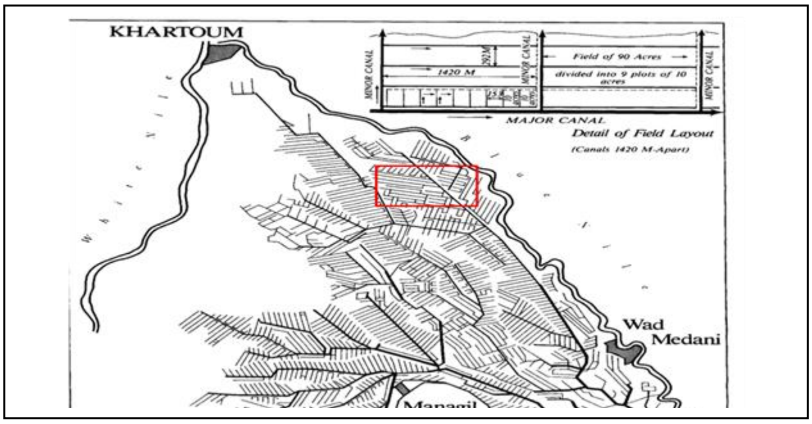

Figure 2: The Gezira Scheme (Source: 'Agriculture in Sudan' in Wallach, 1988)**,** *the box in upper corner is the study site of the Kab El Gidad major*

The study was carried out between July and October of which six weeks were assigned to intensive fieldwork in the case study tertiary canal. Data were collected through interviewing, field observations, and simple flow and water level measurements using float method. Three control points for flow (discharge) measurements are selected at Tuweir minor canal (minor 3); at the head, middle and tail. Design of the research and data cross-checking was done through a wide range of scientific literature and (local) policy documents.

Results and Discussion

The result will be discussed below on the basis of water distribution in theory (that is how water was intended to be distRibbuted among users in the scheme); and water distribution in practice (based on practical observations and interviews in Tuweir minor canal in 2010). The effects of water distribution changes on users, conclusions and recommendations will be also presented precisely.

Water Distribution in Theory

Indenting (Required water requesting)

As mentioned above, the principle of water distribution at each level up to the minor canals was based on the block inspector (BIs) request to the Sub Division Engineer (SDE). The request is made before the coming planting season; on the basis of the crop water requirements which are calculated by BIs. Actual distribution is done by considering the canal water carrying capacity (table 1) which is checked by the respective Engineers at each level. So, if too much irrigation water is requested by the BIs over the canal capacity which is checked by the engineers, the two actors need to negotiate to reach consensus.

During the planting seasons the request from BI to SDE occurs on weekly basis, i.e. every Tuesday as early as possible before 1:00 pm, but not later than 2:00 pm. After 2:00 pm indenting will not be considered for the afternoon change, it would only be implemented in the next morning’s alteration. This procedure helped to maintain a steady uniform flow throughout the week in all the canals; and the indent is expressed in cubic meter per day (MOIHP, 1934). If a need arise to adjust the indents, it will be sent to the Division Engineer on Saturdays. The adjustment should balance changes on different area within a major. So in this way farmers can irrigate according to their schedule.

Table 1. Gezira Scheme irrigation system components and their capacity

Canals	Number	Capacity(m^3/sec)	Length (km)	Av. width(m)
Main	2	354	261	50
Branches	11	25 to 120	651	30
Majors	107	1.2 to 15	1,652	20
Minors	1,500	0.5 to 1.5	8,119	6.0
Subtotal	**1068**	- - - - - - - -	**10,683**	- - - - - - -
Abu XXs	29,000	0.116	40,000	1.0
Abu VIs	350,000	0.05	100,000	0.5
Total	**380,068**	- - - - - - - - - -	**150,683**	- - - - - -

Source: Ahmed, 2009

Normally the above described indenting has become the norm with a long time history. Reports show that it has not been practised accurately since 20 years ago (Ahmed, et al, 1988). The researchers found many unclear indenting records, such as high peak indenting in October regardless of small area coverage for wheat during this time; peak crop water requirement records during the peak rain period of August. Water distribution in the scheme is continuously altered from time to time (Wallingford, 1991) due to different reasons. HRS and Wallingford (1988) reported that the indenting was not perfect- for instance without any change effected in the case of rain. It was reported in Tuweir minor, Kab El Gidad major, a severe reduction to less than 50% of the indent that lasted for over seven weeks in the 1987/88 season. World Bank also reported that ‘usually claims of inequity caused by siltation and weed infestation are frequently being made by farmers’ (World Bank, 1990, p. 4).

Water Distribution in Practice

Nowadays, the above theoretically set indents are totally gone. WUAs have replaced the previous BI, but they are not functional. At present, WUAs may communicate the respective engineers just to give an overview of the type of crops that will grow in the coming season based on their expectation. How much land will be covered and the actual crops to be grown in that particular season is not known to decide on the amount of water to be released from the dam and division box. Hence, the water distribution to each level could not consider the actual crop water needs or the canal capacity. No adjustment indenting in case of rain or peak crop water demands (interviews and observations). The operator at the off take of the minor responded that he will make a request to the respective engineer when he faces a serious problem like a canal breakout flow. But he will not make any request to facilitate a reliable, equal, on time water distribution according to the crops' need or no call for adjustments to have healthy and productive plant growth.

Water Distribution between Minors, in Kab El Gida Major

Without going through further analysis, the above explanation of ineffective indenting can create unequal water distribution between minors. Currently the water discharge which is released to each minor is based on a rough estimation instead of the theoretically restricting indents according to the crops need and canal capacity. Most of the minor off take operators were new employees who have no experience on fair water distribution to users. They were also influenced by some powerful farmers. For instance, the off takes of Tuweir and Kersh El Fil minors were operated by one operator, who has no experience on canal operation (new employed and he is a farmer). Simply from the observed gate opening of the two minors in the field one can see the difference of water distribution between these two minors (Figure 3). It shows, on the observed dates, mostly the Kersh El Fil minor gate was *fully opened* while, the Tuweir minor gate was opened partially. The difference was not originated from the actual share of water allocation for each minor, but simply from Kersh El Fil farmers' influence made on the operator. Because, the operator admitted that, the Kersh El Fil minor farmers come to him more frequently than the Tuweir minor farmers, to convince him to open their minor fully. This kind of water distribution is also practiced in other upstream and downstream minors of the Tuweir minor within the Kab El Gidad major. Evidently in some minors, it was observed that farmers themselves opened minor off take that can upset equal water distribution among water users.

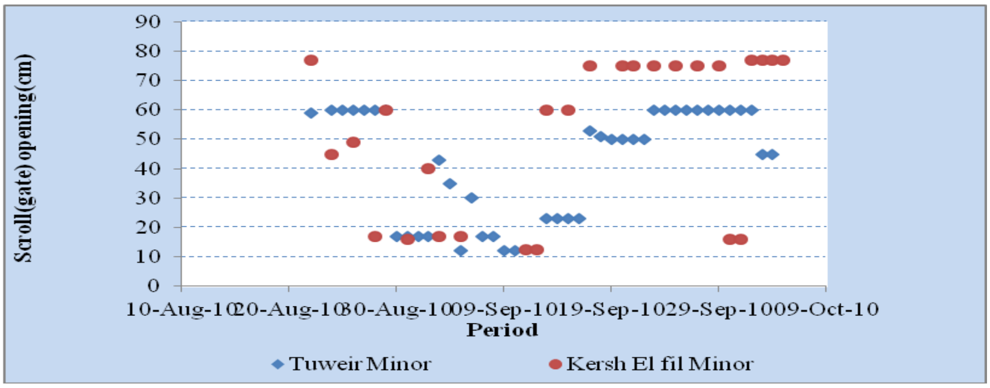

Figure 3. Gate opening of Tuweir and Kersh El Fil Minors showing poor irrigation water distribution in Gezira Scheme

Water Distribution between Numbers (tertiary units)

During the study, water distribution differences between tertiary units were realized. Some of the practical reasons for the water distribution difference that we understood during this assessment are presented below. These practices were important factors for water distribution differences among users not only between or within numbers but also between minors and majors.

Farmers Operation of Field Outlet Pipes

As mentioned above since there is no planned water distribution among users, farmers irrigate by their own perception about their crop water satisfaction. In this regard, one may irrigate his crop with too much or too little water. In Tuweir minor canal farmers were complaining about this situation as ‘one takes more water than his crops need while others are suffering from water shortage within the minor/number’. Figure 4 show that two farmers in this minor were irrigating their crops fully. Yet it was not observed that all of the farmers in Tuweir minor were irrigating their crops like what these farmers did. Hence, the farmers’ actions can affect water availability and equal water distribution for downstream users.

Differentiated management concerns amongst various types of farmers

There are different groups of farmers in the Scheme such as owners, sharecroppers, labourers and renters. These groups have their own sense of ownership and responsibility in managing the system. They also have different irrigation water management experiences. In this scenario unequal water distribution between them is almost inevitable through one may leave the gate open to acquire more irrigation water than others; another one may not care about what will happen to others in the next day due to his action. Many owners in Tuweir argued that water management failures are experienced in the area, because most of the sharecroppers have insufficient experience to manage the water.


FOP1 **FOP6**

Figure 4: Two examples of excessively irrigated farmer fields while others are suffering from water shortage in Gezira Scheme

However, we argue that, rather than experience, as many sharecroppers do not own land, they want to maximize their yield as much as possible in a season. To do so, they operate the system in any way that helps to satisfy their crops' need according to their perception. In addition this group of farmers have not been working in a fixed hawasha, number or minor. Instead they may move to another hawasha, number or minor every season. Hence, they may not care for what problem will occur next in one specific area as far as no rules have been developed to control their irrigating behaviour. Moreover, this group is not the only hoarder of water. The other groups (renters, owners or labourers) also displayed the same behaviour of carelessness/selfishness. As an example, Figure 5 below shows some farmers' actions on the minor and Abu XX section to irrigate their farms, which affect water distribution patterns for downstream users. Moreover, farmers are practising additional income generating activities outside the village. Usually, land owners give their land to the other groups of farmers when they are gainfully employed outside the scheme.

Nakoosi

'Nakoosies' are FOPs/Abu VI which farmers employ to irrigate by diverting water from downstream minor or Abu XX to upstream numbers or hawashas. These practices are illegal and beyond the minor or Abu XX canals' designed capacity though it is one of strategies farmers use to irrigate their higher level lands almost at the tail of every hawasha. There are two nakoosies FOPs from the Tuweir minor that have been used to irrigate the upstream minor command numbers. Within Tuweir minor there are many Abu VI from downstream Abu XX to irrigate upstream 'number'. Such practices have been observed frequently in all numbers of Abu XXes of the Tuweir canal during our field work. Certainly these practices have significant impacts on water distribution differences between users of different minors and within the same minor.

Other practices

Other practices comprise of water use making a sudd- mud across the minor or Abu XX sections to back up the water levels and the closing of night storage weirs (NSWs), to push more water through the upstream FOPs or field inlet. These are also sources of water distribution differences among the farmers (figure 5). These practices are sources of conflict between farmers.

Using the canal water for household purposes is another practice in Tuweir minor (see Figure 5b below). Since, Tuweir villagers have no access to tap water; they use water from the minor canal for domestic purposes. One day we observed that villagers opened a fallowed FOP to divert water to their village, to irrigate ornamental trees inside the village and to serve other purpose like house building, while the downstream farmers in the same minor were suffering from water shortages. These practices may seem simple or normal in other places but they have significant effects on decreasing the level of water in the minor and creating inequitable water distribution between users.

Maintenance induced effects on water distribution

In many ways (lack of) maintenance can produce water distribution differences among numbers/minors. In Tuweir minor, silt removal was not taken place after the middle of the minor since three years ago. This affected the reliability/equity or on time distribution of water for downstream farmers.

(a) (b)

Figure 5: Nakoosi and different farmers' in Gezira Scheme illegally use irrigation water on a minor and Abu XX channel for multiple purposes

On the other hand, though it is an indicator of the poor water management, in the upstream parts accumulated silt raises the water level. That pushes more water into upstream FOP than downstream. Evidently, canal excavation was done in Tuweir minor on Sep 21-25/2010. Before the excavation was done, the upstream users were accessing excess water, due to the accumulated silt that raised the head and helped ease discharge of water into upstream FOPs. But after the silt removal, the water level in the upstream section of the minor canal decreased dramatically. As a result the amounts of water delivered to these upstream FOPs decreased, and relatively the discharge into downstream FOPs improved (Table 2). Though it cannot be generalized for other places as well, it was a problem for upstream users at that moment.

However, in general except for the above exceptional case as figures 4; 5 and 6 indicate, from the available water in the canal, the upstream users enjoy the lion's share of the water at the expense of downstream users, because of poor management. In addition it was obvious to observe that after any irrigation of upstream users, there was excess water flowing to the road or to the fallowed land while the downstream farmers are not able to irrigate their crops. All in all, this results into unequal water distribution among users.

Figure 6. Water distribution difference because of absence of sediment management practice - on FOP 1 at Gezira Scheme. *N.B.* The first plate (a) shows in FOP1 water was flowing out over the suck-mud and this was most often the case before canal excavation. Plate (b) shows, after canal excavation, the amount of water discharging into this Abu XX decreased dramatically, so that farmers create a head across the minor.

Table 2. Water distribution estimation between FOPs of Tuweir minor canal at Gezira

Hydr-aulic level	**Field Outlet Pipe (FOPs) from the head to tail**	**Area / feddan**	**Date of Observation (2010)**							**Average**	**-(+) 30% correction Factor**
			03-Sep	**12-Sep**	**17-Sep**	**21-Sep**	**25-Sep**	**29-Sep**	**02-Oct**		
			Estimated Discharge (at the head of each Abu XX) in liters/second								
Up stream FOPs	FOP1	60	26	32	0	0		10.2	25	15	11-20
	FOP2	90	0	51	116	56	25	60	44	50	35-65
	FOP3	83	48	0	68	53	45	100	19	48	33-62
	FOP6	90	0	0	54	40	0	0	0	16	11-20
	FOP7	90	111	11	94	82	11	43	45	57	40-74
	Average		**37**	**19**	**66**	**46**	**20**	**43**	**27**	**37**	36
Down stream FOPs	FOP9	90	27	0	12	6	44	96	68	36	25-47
	FOP10	90	16	0	13	26	61	83	100	42	29 -54
	FOP12	90	0	0	10	0	23	0	0	5	3-6
	FOP13	90	15	0	69	0	58	50	74	38	27-49
	Average		**15**	**0**	**26**	**8**	**47**	**57**	**61**	**30**	

Source: Round trip assessment of the Minor during the field work,

The above Table (2) is a rough estimation of discharges in operated (cultivated land) FOPs in 2010 season in Tuweir minor during round trip observations of the specified FOPs on the specified dates. The estimation was supported by simple flow measurements using orange method. The unmentioned FOPs in the above Table are left fallowed or winter crop numbers' FOPs (i.e. there is no water flow into these FOPs during study time). Generally the Table shows water supply at downstream FOPs was less than that of upstream FOPs before excavation was done. But after the excavation (after Sep 21-2010), the discharge to downstream FOPs (FOP 9 and FOP 10) was better than upstream FOPs (FOP 1) because of reduction of sedimentation effect (Figure 7).

The values in the 'average column' of Table 2 indicate that FOP 1 and FOP 6 in the upstream part have less discharge than downstream FOPs except for FOP 12. But the case especially which pronounced in FOP1 before the minor silt removal was always much water flow into FOP1. Evidently, excess water from FOP1 over flooded to the adjacent tertiary unit while FOP1's gate was partially or fully closed. In the Table, there is area size difference between the cultivated FOPs. However, there are no functional discharge controlling structures that help water to deliver according to the area coverage of each FOP. For instance FOP 1 and FOP 3 have no pipe at all; the water runs into their Abu XX without control only controlled with mud filled-sack. In addition, there was also a case though FOPs were observed closed, after a moment these FOPs would be opened. So in reality there was no water shortage in these upstream parts. However, in downstream FOPs such as FOP 9, 10, 12 and 13 zero refers to the fact that the FOP was already opened, but there was no water that can be delivered to these FOPs. Especially FOP 9 and 12 face a problem of water to discharge into their Abu XX. As a result, many 'nakoosies' channels from FOP 10 and FOP 13 to FOP 9 and FOP 12 respectively have been observed. Also during these round trip assessments, it was found that there are differences in water distribution between upstream and downstream parts of an Abu XX.

Figure 7. Grass cover difference between FOPs because of water distribution difference at Gezira Scheme

Moreover, photos in Figure 8 below show that water distribution differences between upstream and downstream parts along the Tuweir minor section. That means if the upstream FOPs are opened then the downstream FOPs cannot get enough water to irrigate their fields. This situation has been aggravated because there is no water distribution schedule among users. Consequently water distribution inequity can always be observed between upstream and downstream parts of Tuweir minor.

Figure 8: Water distribution difference in Tuweir minor Section (Plates were taken on September -17-2010)

Water distribution differences within a number

This is also a significant issue in the area. Farmers who have hawasha (farm) at the head of an Abu XX received water relatively more reliably and on time than the downstream farmers. During the study it was clear that downstream farmers can get water only after the upstream farmers have finished their irrigation (Figure 8). As a result many downstream farmers have been forced to irrigate their crops too lately or insufficiently. For instance, more than one week delay was observed in number 11. Table 3 below shows interview results from some farmers according to their perception i.e., here irrigation delay refers the time from which farmers want to irrigate yet they could not able to irrigate because of water shortages in the area.

Table 3. Farmers claim of irrigation delayed due to water distribution in Tuweir minor

Farmers	**Farm Location**	**Irrigation delay (days)**	**Date of interview**
1	Number 11	4	06 Sep-10
2	Number 14	7	06-Sep-10
3	Number 10	5	26 Sep-10
4	Number 11	16	24-Sep-10
5	Number 14	30	27-Sep-10
4	Number 11	9	22-Sep-10
5	Number 3	6	28-Sep-10
6	Number 10& 11	5	26-Sep-10
7	Number 11	15	30-Sep-10
8	Number10 & 11	4	24-Sep-10

This result was confirmed through observations in the two numbers - number 3 (upstream) and number 11 (downstream). Of course relative to the downstream number, the upstream number farmers can irrigate when they want to irrigate. Only some downstream farmers' hawasha of number 3 faced some problem, but the problem was not serious like number 11 (downstream farmers). At least there was water in number three Abu XX up to the tail, while number 11 Abu XX dried completely after the middle. In number 11 it was observed that, starting from 12 September 2010, water flow to its Abu XX was limited and many farmers were complaining about it frequently, because their irrigation was delayed from a few days to more than 15 days as the above Table shows.

The reason for this difference might be socioeconomic or power. Most owners were working at the head while, the number of sharecroppers is more significant in downstream. On the other hand head- tail issues of water distribution are significant. Obviously, at the head farmer can capture the amount of water available regardless of power /socioeconomic factor. Here, with different scales there is a difference in accessing irrigation water at each level of the number between upstream and downstream hawashas.

This is because, as one can imagine that as there is no plan for irrigation scheduling between farmers to irrigate turn by turn, the head farmer might even be irrigating twice before the tail farmer does not irrigate even once. There are no working rules to govern each farmer to irrigate fairly. The problem is more severe for downstream farmers than upstream farmers within the minor. Thus the effect clearly results unequal water distribution between farmers.

Impacts of Water Distribution Pattern

Yield reduction

Though it is difficult to justify yield reduction due to water distribution (since, other factors like agronomic management may also affect it), many farmers in Tuweir canal claim that the yield reduction from time to time is mainly because of poor water distribution between upstream and downstream at each level of the minor. So, even if it is not easy to quantify the reduction without detailed research, Table 4 provides insights of yield reduction which was deducted from farmers' interviews in the area. Most farmers stated that, last year most of them did not get yield at all in the area. Indeed, without farmers claim, from the above observed water distribution difference between users, yield reduction is expected. Omer Elwaded (1986, who sited Hamid Fakki et al, 1984) stated that clear yield reduction originates from inequitable water distribution for cotton plants within the scheme depending upon the location and the level of major, minor and Abu XX field channel.

Table 4. Yield difference between the past and last year (2009/2010)

Farmer	**Farmers location in the minor**	**Crop type**	**Previous seasons Average Yield**		**Average Current yield/2009**		**Average Yield Reduction**	
			Suck/ feddan	Kg/ ha	suck/ feddan	Kg/ ha	suck/ feddan	Kg/ ha
1	FOP 9&10	Sorghum	13	3095	4	952	9	2143
2		Sorghum	10	2381	2	476	8	1905
3	FOP7	Sorghum	13	3095	2	476	10	2381
4		Sorghum	10	2381	2	476	7	1667
	Average		**11**	**2619**	**3**	**714**	**9**	**2143**
5	FOP 1	Groundnut	27	6429	18	4286	20	4762
6	FOP 10	Groundnut	20	4762	8	1905	13	3095
7	FOP 2	Groundnut	30	7143	25	5952	5	1190
	Average		**26**	**6190**	**13**	**3095**	**9**	**2143**
9	FOP 2	Wheat	14	3333	4	952	10	2381
10		Wheat	13	3095	1	238	12	2857
	Average		**13**	**3095**	**3**	**714**	**11**	**2619**
1 feddan=0.42 hectare			1 suck=100 kg					

Source: Interviews with farmers

Conflict between farmers

Unequal water distribution creates frictions between upstream and downstream farmers in a minor or number. Some farmers argued that they have found their Abu VI closed. Otherwise they should watch their Abu VI in the evening or they should look for other options, like pumping. In addition conflict is obvious between who are using nakoosi and other practices like creating a head/close NSWs and the impacted downstream users by these practices. It was realised that usually at the tail end of the minor, most of the farmers are sharecroppers while at the head end of the minor, most of them are owners. This exposes that tail end farmers not to equally negotiate on water right or other management claims like maintenance as the head end farmers (owners).

Unequal water distribution has also forced farmers to spent additional costs such as for pumping and labour. Farmers in Tuweir minor said, downstream farmers always use pumps particularly for the winter season crops. This costs them a lot of money, renting a pump is about 42 US $ at last year currency per one and half days pumping. In addition when the amount of water decreases in the Abu XX farmers need a longer time to irrigate than with a normal flow. In this way they incur additional labour costs.

Conclusion and Recommendations

The past relatively formal and restricted water indenting according to the crops need and the canal capacity estimation has become a theory rather than a practice. Nowadays, water is released to each level jus as a habit, no scientific approach crop water calculation over canal capacity balance at all. As a consequence of unequal, unreliable and unscheduled water distribution to users has become a practice.

Factors such as operation of the FOPs by every farmers and their irrigation perceptions, lack of concern /sense of ownership while managing the system and their different practices to cope up water distribution changes; mismanagements of the system by officials like poor operation and maintenance; and absences of working water management rules for users are aggravating the situation of unequal water distribution within a major/minor/number.

In Tuweir minor, there are water distribution differences between numbers. Usually upstream farmers get relatively good amount of water than downstream farmers. Such variation was also observed within a number (between farms). The way of excavation has also impact on water distribution. After the minor excavation the downstream farmers got relatively good amount of water. However, some upstream numbers get limited amount since the water level in the minor drops down when the sediment removed.

The impacts of unequal, unreliable, or unscheduled water distribution have long term and short term effects on users. In a short term effects it can clearly reduce yields; arise conflicts between farmers or expose farmers to additional costs, like renting/buying pump to get irrigation water, then finally deterioration of the irrigation infrastructures as a whole. Further more in a long term effects of water distribution changes, farmers have been leaving their villages to seek a job outside the scheme; the remaining farmers are changing their cropping patterns- focusing on less risk bearing crops (sorghum).

The existing water distribution should be improved. Irrigation scheduling among users based on the growing crop is necessary. This can be achieved if hydraulic property is created by each farmer. This can be achieved through farmers training and participation how to manage their irrigation system.

Lessons learned

Some lessons that can be drawn from the paradox of water distribution in the Tuweir minor are:

- From the past well organized system: water distribution based on the crops need and the canal capacity balance, as well as; the experience of crop rotation and uniformity throughout a tertiary unit are very important to equal water distribution among users.
- We have seen how sever silt load and poor maintenance can deteriorate even if a well established large scale schemes like Gezira. So that, continues follow up of a system; employ soil conservation measures on upstream parts; and continuous maintenance of irrigation canals as well as, creation of hydraulic property concept to farmers (through full participation and cost recovery) are important lessons that need actions on the existing and future schemes that we are going to develop in our country.

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Diseases, Insect Pests and Parasitic Weeds of Common Crops and their Importance under Irrigation Conditions of Ribb River, South Gondar

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Abstract

Diseases, insect pests and parasitic weeds of crops at Ribb were surveyed under irrigation condition from 2010 to 2011 fiscal year. During the survey periods different horticultural, cereal and pulse and oil crops were inspected. Onion, potato, tomato, pepper, cabbage, garlic and shallot were among horticultural crops where as wheat, barley and maize were from cereals crops and safflower, rapeseed and lentil were from pulse and oil crops. Dozens of diseases and insect pests were recorded and identified in the surveyed area. Powdery mildew, purple blotch, yellow rust and virus were the most important disease of onion, shallot, wheat and pepper respectivelly. Thrips, cutworm, boll worm, and aphids were important insect pest on onion, potato, tomato, barley and wheat respectively. Porcupines (jart), birds and mole rat were vertebrate pests where as orobanchea was the single important parasitic weed on tomato. Generally, diseases and insect pest recorded as a major pest needs research and development intervention towards in designing and adopting control strategies. Moreover, regular monitering stratagy has to be designed since one minor pest at a time became major pest on other time.

Key words: Diseases, Insect Pests, Parasitic Weeds, Irrigation, Ribb

Introduction

In general irrigation enables cultivation of wide range of crop production. Different types of crops that range from vegetables to cereals produced in Ribb catchment area. According to Crow (1989) the most important widely grown crops are onion (*Alluim cepa*), potato (*Solanium tubersum*), tomato (*Lycopersicum esculantium*), pepper (C*apsicum spp.*), cabbage (*Brasiica olerceae)*, garlic (*Alluim sativim*), shallot (*Allium* *cepa*) and rapeseeds (*Brasica napus*) are among vegetables and wheat (*Triticum astivium*), barley (*Hordeum vulgar*), maize (*Zea maiz*) and faba bean (*Fasiolus vulgaris*) are among cereals and pulses, respectively.

Irrigated agriculture is characterized by intensive land use and substantial use of external inputs. The trend enables year round growing of crops to smallholder farmers as a means of enhanced income generation. Such an overlap in crops enhances pests to continuously multiply, resulting in intensive and year-round induction of the continuous build up of pests and diseases (Tindall,1983). The pests and diseases of an irrigated crop includes those living below the soil surface (e.g., termites, cutworms), foliage feeders (e.g., beetles, caterpillars), miners/borers (e.g., fruit borers, stem miners, leaf miners) and sucking pests (e.g., aphids, thrips, white flies, spider mites and bugs). Diseases of importance on these crops range from soil-borne pathogens (damping off, root rot, wilts) to leaf diseases (blast blight, rust) and those causing rotting of vegetative parts (stem rot, sheath rot) and parts (e.g., black rot, fruit rot). Nematodes often constitute an important biotic constraint to irrigated crop production (Tesfaye, 1995).

Quantitative and qualitative data on the extent of occurrence and distribution based on the intensity and damage caused by pests and diseases are scanty in Ribb irrigation area. It is important to assemble baseline information on the relative economic importance of the commonly occurring pests and diseases in the representative production ecologies of the area. Therefore, the objective of this study was to identify the importance and spatial and temporal distribution of diseases, insect pests and parasitic weeds of different crops in the command area.

Materials and Methods

Site Description

Ribb irrigation command area is located in Libo Kemkem and Fogera woreda in South Gondar zone. It is situated at $11^{0}46$ to $11^{0}59$ latitude north and $37^{0}33$to $37^{0}52$ longitude east. Altitude ranges from 1774 to 2410 meters above sea level and predominantly classified as Woina-Dega. Mean annual rainfall is 1216 mm occurred during June to September.

Survey Procedures

The survey was conducted in the two consecutive years of 2009/10 and 2010/11 irrigation period at Ribb irrigation command area. The target crops were different horticultural, cereal and pulse crops that were grown in the command area. Onion, potato, tomato, pepper, cabbage, garlic and shallot were among horticultural crops; wheat, barley and maize were among cereals and safflower, rape seed and lentil were among pulse and oil crops.

Periodic field visits at seedling, heading and maturity stages of the crop were conducted to generate comprehensive information for every 1 to 2 kilometers interval (17 fields). Leaves, roots and stem of the plant were inspected thoroughly across each field diagonally in an X- fashion usually with the help of 50*50m quadrant (Thomas, 1985). The intensity of the diseases was recorded as low (x), intermediate (xx), and high (xxx) depending on the load of infection. Low intensity means below five percent, intermediate means below 25%, and high means above 25% percent of infection (Crew, 1984). Most of the fungal, bacterial and viral diseases were identified by field symptoms following procedures indicated in Crew (1984). Further conformations were made in plant pathology laboratory found at Adet Agricultural Research Center.

Similarly, necessary insect pest data were recorded depending on the kind of pest damaging important crops. Generally, the kinds of host infested, part of plant affected, symptom observed, stage of the insects, and percent of infestation and status of insect were recorded. Moreover, as usual, insect pests were categorized as major and minor pests to understand its status for further research intervention. The severity of damage was recorded from 0 to 9 scales. Identification of most insect pests was made under field condition with the help of field guide books and other references. In addition to diseases and insect pests, fields were assessed for existence of parasitic weed. Data of host crop, weed count and distribution of parasitic weeds were recorded during the survey periods.

Results and Discussion

Diseases

During the survey periods different horticultural, cereal and pulse crops were grown in the command area. Onion, potato, tomato, pepper, cabbage, garlic and shallot were among horticultural crops, wheat, barley and maize were among cereals and safflower, rapeseed and lentil were among pulse and oil crops. However, most of the land was covered with horticultural crops especially with onion, tomato, shallot and pepper. Wheat also currently progressively increased in area of coverage. However, the crops were affected with different diseases and insect pests. Hot pepper was majorly affected with powdery mildew and the incidence was recorded to 100 percent. Mancozeb 2 to3 kg/ha is effective against this disease. Virus, bacterial leaf spot and fusarium wilt also recorded on hot pepper. But currently these diseases are not recorded as production constraint. Onion is highly affected with powdery mildew and purple blotch. According to Bekele (1985) both are major diseases of onion and shallot. The incidence of powdery mildew and purple blotch was 100 and 60 percent respectively. Redomile 2 to 3 kg/ha is effective to control. Currently bulb rot diseases were less important and the incidence is less than 1 percent. Viruses were recorded as major diseases of tomato. Disease incidence of 10 percent was recorded in the irrigable area. The infestation was severe across all *kebeles* and locality which needs research intervention. Rust was one of the major constraints for garlic production in the area. The intensity is above 50% in all assessed areas. Tilt fungicide usually recommended means of control for rust infestation. Root rot diseases caused by fusarium were less frequent on garlic fields. Use of proper irrigation interval and crop rotation are advised to control soil inhibiting pathogens (Table 1).

The identified cereals were also affected with different diseases. Yellow rust was recorded a destructive disease on wheat fields. The incidence of the diseases was as high as to 100 percent compared to the other diseases. Tilt 0.5-1kg/ha usually recommended means of control for rust infestation (Zillinsky, 1983). Barley and maize also affected with head smut and maize strike virus respectively. However, both diseases were minor at the time of assessment (Table 1).

Lentil and safflower is the dominant pulse crop and oil crop in the surveyed area. Fusarium wilt affect lentil even though the incidence was not serious but safflower were found healthy (Table 1). In general, in the present survey more fungal diseases were encountered as compared to the other disease causing agents. Virus and bacterial diseases were less important except viruses on tomato and bacterial leaf spot on pepper (Table 1). Despite many major diseases appear during the survey periods farmers do practically nothing to control. Most farmers consider the diseases as normal feature of the crops. Awareness creation could be given to farmers as priority option in a controlling program.

Insect Pests

Lists of various insect pests were identified during the period of assessment. Tomato fields were highly affected with African boll worm (*Helicoverpa armigera*) and found as the major insect pest on tomato. The incidence of the pest was nearly 50 percent. Insecticides like Decamethrin and Cypermethrin have been recommended as a means of control. According to Gashaw and Lemma (2002), there are also some tolerant varieties like Melkaselsa (Serio), Pusa Early Dwarf', 'Pusa Ruby' and Seedathing, have been recommended to reduce the bollworm damage on tomato (Table 2).

Thrips on onion and garlic, aphides on wheat and barley, cutworm on potato, pepper, onion, tomato, snap bean and haricot bean were important insect pests (Christopher 2002). The incidence of onion thrips was 100 percent in all onion growing fields. This pest is most important for smallholder farmers. According to Dennis Hill (1993), Dimethoate and Selicron insecticide has largely utilized as means of control (Table 2). Maize Thrips (*Frankiniella spp*) were counted up to 35 on average on single plant leaves at early stages of maize; however this was not seen at mid and late stages of the crop development. Stalk borers were recorded on maize crop. However, the incidence was below two percent and minor during the survey period (Table 2).

Table 1. Status and distribution of diseases of some crops in Ribb irrigable area

Host crop	**Crop Growth Stage**	**Common name**	**Scientific name**	**Intensity**	**Locality**
Hot pepper	Flowering/Maturity	Powdery	*Leveillula*	xxx	A,B
	Flowering	Virus	*virus*	xx	A,B
	Flowering/Seedling	Wilt	*Fusrium*	xx	A
	Flowering	Leaf Spot	*X.*	x	A,B
Tomato	Seedling	Fusariu Wilt	*Fusarium*	x	A
	Flowering	Virus	*virus*	xxx	A,B
	Flowering	Powdery	*Erysiphe*	xx	A,B
Wheat	Booting/Seedling	Yellow Rust	*Pucinia*	xxx	A,B
	Booting	Stem rust	*Puccinia*	x	A,B
Shallot	Bulb Incitation	Purple Blotch	*Alternari*	xxx	A,B
	Maturity	Bulb Rot	*Fusarium*	x	A
	Maturity	White Rot	*Sclerotiu*	x	A
Barley	Maturity	Loose Smut	*Ustilago*	x	A,B
Maize	Tussling/Seedling	Maize Strick	*Virus spp*	x	A,B
Potato	Flowering/Maturity	Bacterial Wilt	*Ralstonia*	x	(-)
	Flowering	Early Blight	*Alternari*	x	A,B
	Seedling/Flowering	PLRV	*Potato*	x	A,B
Garlic	Bulb Incitation	Rust	*Puccnia*	xxx	A,B
	Maturity	White Rot	*Sceleroti*	x	A,B
Cabbag	Heading	Powdery	*Erysiphe*	xxx	A,B
Onion	Maturity	Bulb Rot	*Fusrium*	x	A,B
	Maturity	White Rot	*Sclerotiu*	x	A,B
	Bulb Incitation	Purple Blotch	*Alternari*	xxx	A,B
	Bulb Incitation	Powdery	*Peronosp*	xx	A,B
Emmer	Heading	Yellow Rust	*Pucinia*	xxx	A,B
Rape seed	Flowering	Down Mildew	*Peronosp*	xx	A,B
	Flowering	Whit Rust	*Albigo*	x	A,B

When <5% of plants infested (x), 5-25% of plants infested (xx), >25% of plants infested (xxx), Abua Kokit (A), Shina Tseyon (B)

According to Polaszek (2008), striped rice stalk borer (*Chilo suppersalis Wlk.)* and stalk-eyed fly (*Diopsis thoracica W)* was recorded on rice but currently minor pests. However, their distribution was wide across all trial fields. These are relatively recent pests and had not been correctly identified yet. According to IRRI (1996), literature consulted indicated that these pests were important on rice crop (Table 2). Large areas of wheat crops have been invaded by the Russian wheat aphid (*Duraphis noxia*). The infestation of the pest was 100 percent in all surveyed fields and hence the details should be studied and loss assessments should have to be taken as area of intervention.

Cereal leaf beetles (*Oulema spp.)* were found minor insect pests occurring with numbers less than 5 per meter square. However, they may have the potential to cause damage and loss on wheat and barley at seedling stage when the environment favors. Cutworms (*Agrotis spp.)* were found most important pests on pepper, potato and snap bean at seedling stages (Table 2).

Table 2. Status and distribution of insect pests of some crops in Ribb irrigable area

Crop	Growth stage	Pest common name	Insect stage	Scientificna	Status	Locality
Tomat o	Fruiting	Boll worm	larva	*Helicoverpa*	major	A,B
	Fruiting	Cut worm	larva	*Agrotis* spp.	major	A,B
	Fruiting	Leaf minor	larva	*Liriomyza*	miner	A,B
Pepper	Seedling	Cut worm	larva	*Agrotis* spp.	major	A,B
	Flowering	White fly	Nymph/adul	*Bemisia*	major	A
	Flowering	Leaf minor	larva	*Liriomyza*	major	A
	Pod Setting	Boll Warm	larva	*Helicoverpa*	major	A
Potato	Rhizome	Cut worm	larva	*Agrotis* spp.	major	A,B
Onion	Bulb Incitation	Thrips	Nymph/adul	*Thrips tabaci*	major	A,B
	Seedling	Cut worm	larva	*Agrotis* spp.	major	A,B
Garlic	Bulb Formation	Thrips	Nymph/adul	*Thrips*	major	A,B
Saff	Flowering	Aphids	Nymph/adul	*Aphis* spp.	major	A,B
Rice	Heading	Striped rice stalk	larva	*Chilo*	minor	A
	Heading	Stalk-eyed fly	unknown	*Diopsis*	minor	A
Maize	Tussling	Thrips	Nymph/adul	*Frankiniella*	minor	A,B
	Silking	Stalk borer	Nymph/adul	*Busseola*	minor	A,B
	Tussling	Aphids	Nymph/adul	*Rhopalosiphu*	minor	A,B
	Heading	Lady bird beetle	unknowen	*Epilachena*	minor	AB
Wheat	Heading	Russian wheat aphid	Nymph/adul	*Diuraphis*	major	A,B
	Heading	Cereal leaf beetle	Nymph/adul	*Nematocerus*	minor	A,B
	Heading	Stem borer	larvae	*Chilo* spp.	minor	A
Barley	Heading	Russian wheat aphid	Nymph/adul	*Diuraphis*	minor	A
	Heading	Cereal leaf beetle	unknowen	*Nematocerus*	minor	A
	Heading	Aphids	Nymph/adul	*Rhopalosiphu*	major	A
Snap	Pod Setting	Cutworm	larva	*Agrotis* spp.	major	A

**Abua Koki (A), Shina Tseyon (B)

Parasitic weed

The only parasitic weed found in the command area was orobanchea. It parasitizes especially tomato during the irrigation season. The intensity of the weed was more at Shina Tseyon kebele than other kebeles. However, the practice of farmers growing tomato year after year will favor in the near future to cover large geographical area. Orobanchea can be effectively controlled with rotation of non-host crops.

Vertebrate pests

Different vertebrate pests were recorded on tomato, potato, pepper and wheat during the survey periods. The pests were porcupines, birds and mole rat. However, their status was minor to be distructive in the command area (Table 3).

Table 3. Status and distribution of vertebrate pests in Ribb irrigable area

Host	**Common name**	**Scientific name**	**Locality**	**Status**
Potato	Porcupines	*Hystrix cristate*	Shina tseyon	Minor
Pepper	Birds	*Unknowen spp*	Shina tseyon	Minor
Wheat	Mole rat	*Tachyoryctes spp*	Shina tseyon	Minor
Rice	Birds	*Unknown spp*	Abua kokit	Minor

Conclusion and Recommendations

Dozens of diseases and insect pests were recorded and identified in the surveyed area. Powdery mildew, purple blotch and rust were the most important diseases. Thrips, cutworm, boll worm and aphids were important insect pests. Porcupines, birds and mole rat were vertebrate pests where as orobanchea was the single important parasitic weed. Hence, immediate control measure has to be suggested and practiced especially for major pests and diseases.

Few crops such as rice, tomato and onion dominate the surveyed areas. This leads to the existence of aggressive pests to have more generations without breaking the life cycle. Hence, diversification and introduction of additional adaptive crops will be required. In most farmers’ field, onion is planted year after year without any viable crop rotation. Therefore, strong extension service has to be suggested about the importance of crop rotation in breaking the life cycle of diseases, insect pests and weeds. In general, many kind of insect pests and diseases were recorded in the surveyed area. Some of the pests were found major, which needs to take action and some others were minor during the periods of surveying. Hence, periodic monitoring strategies should be designed in the study area.

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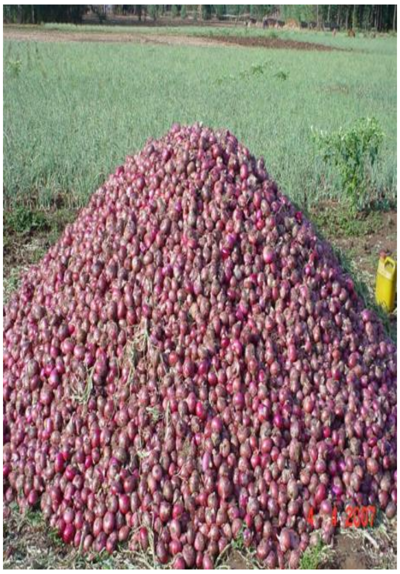
PART 2

WATER PRODUCTIVITY IN SMALLHOLDER IRRIGATION



Performance of Potato Varieties under Irrigation Production System in the Mid and High Altitude Areas of Northwestern Amhara Region

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Abstract

Potato (Solanum tuberosum L.) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia. Farmers produce potato both in rain fed and irrigation production systems. Despite the variation in climatic conditions and production problems between the two production systems, potato breeders release improved potato varieties by only evaluating under rainfed production season. Therefore, the objective of this study was to evaluate the performance of improved varieties under irrigation production in the mid and high altitude areas of Amhara region. The experiment was conducted at Adet, Koga and Debark in 2010 and 2011. Six and seven improved potato varieties at Adet and Koga, and at Debark are tested against the local variety using randomized complete block design with three replications. Belete and Guassa gave the highest marketable and total tuber yields at Adet and Koga. On the other hand, Gera and Zengena gave the highest marketable and total tuber yield at Debark. Therefore, Belete and Guassa, and Gera and Zengena are recommended respectively for mid and high altitude areas of Amhara region under irrigation production system.

Key words: Potato, Irrigation production, Mid- and high altitude areas, Ethiopia

Introduction

Potato (*Solanumtuberosum* L.) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia. It is one of the most productive and widely grown food crops in the world and produces approximately twice as many calories per hectare as rice or wheat (Poehlman and Sleper, 1995). It is adapted to a wide range of climates and can be grown in both tropical and temperate environments and at elevations from sea level to 4000m (Bradshaw and Bonierbale, 2010). This indicates potato's inherent nature to grow under wider agro-ecological conditions. The crop serves as food and cash crop for farmers in Ethiopia and occupies the 3rd largest area compared to other root and tuber crops (CSA, 2010). Potato holds a huge promise for improving the livelihoods of hundreds-of-thousands of smallholder farmers in Ethiopia’s risk-prone highlands.

The productive nature of potato has a special place of contribution to address food security issues of the mid and high altitude areas of the Amhara region where farm lands are decreasing due to high population. Potato’s short crop cycle also adds its value too. The high potential of potato for improving food security, increasing household income and consequent poverty reduction is a consequence of: the crop’s high relative yield and output of carbohydrates, proteins and essential minerals (even under current inadequate management), increased urban demand for highly valued potato (for fresh consumption and processing) and dynamic demographics including increased population size, subsequent decline in average farm size and consequent agricultural intensification for high per-area output. The rapid increase in potato production area and a trend that is autonomously fuelled by farmers without major outside incentives, reaffirms the promise of potato.

In Ethiopia potato is produced in the rainy season under rain fed condition and dry season using irrigation. In 2002, the irrigated potato production system contributed 58.7% of the annual potato tuber produced and 76.8% of the total area of land planted with potato in the country (CSA, 2003). Likewise, in the Amhara Region irrigated potato production system contributed 84.2% of the area and 65.5% of the annual potato production (CSA, 2003). Although irrigated potato production system contributed the lion’s share both in the country and in the region, its productivity (3.7 t/ha) is lower than the rain fed (10.5 t/ha) system (CSA, 2003). This may be due to differences to climatic conditions and production constraints (Yigzaw *et al*, 2008).

Although a number of varieties were released and recommended for the user in the main rainy season, potato varieties for irrigated farming are limiting. In the near decade, the production of potato also expanded to irrigation systems. Some of the reasons for the expansion of potato production to irrigated production in the region are: increment impact of the crop (as a food and income generating crop), expansion of irrigation infrastructure, incidence of disease especially late blight in the main season and the emerging market for processed products in most towns are cited.

The prevailing maximum temperature is higher in the irrigated potato production system than in the rain fed. In addition, the average monthly minimum temperature is low and causes frost injury to the plant during the irrigation season. Therefore, at higher temperatures the plant fails to initiate tubers and at low temperatures vegetative growth is restricted by frost (Horton, 1987). Despite significant climatic variations between the two production systems, potato breeders in Ethiopia select and release potato varieties only based on the performance under rain fed condition. Thus this experiment was conducted to assess the adaptability and performance of potato varieties, released for rain fed production system, for irrigated production system in mid and high altitude areas of Amhara region.

Materials and Methods

The experiment was conducted using a Randomized Complete Block Design with three replications under irrigation condition for two consecutive years (2010 and 2011). At Adet six improved potato varieties (Zengena, Jalenie, Gudenie, Gera, Belete and Guassa,) and at Debark seven varieties (Zengena, Jalenie, Gudenie, Gera, Belete, Gorbella and Shonkola) were evaluated against the local check. The description of test sites was presented in Table 1.

Plot size was $9m^2$ with spacing of 75cm between rows and 30cm between plants. Undamaged, reasonably uniform, healthy and sprouted tubers were selected and planted on well prepared plots. Nitrogen and P_2O_5 were applied at the rate of 81 and 69 kg ha^{-1} respectively for all sites. Fertilizer was applied at the rate of urea 117 kg ha^{-1} and DAP 150 kg ha^{-1}.The whole P_2O_5 was applied at planting whereas nitrogen was applied in three splits at planting, first cultivation and flowering stages of the crop. It was irrigated once in a week using furrow irrigation method. Healing was done twice throughout the growing period.

Table 1. Description of study areas for potato adaptation under irrigation, 2010 & 2011

Study Areas	Altitude (m asl)	Temperature (^{0}C)		Soil PH	Remarks
		Maximum	Minimum		
Adet	2240	27.68	6.95	5.43	Research site
Koga	1960	27.86	8.18	4.5	Research site
Debark	2800	19.16	8.2	-	Farmers' field

Note: the mean temperature shown above is only the average of the growing months from Dec. - April

Days to emergence was recorded when 50 percent of the plants emerged. Plant height was measured as the distance from the base of the stem to the tip of five randomly selected matured plants of the central rows. Days to flowering was recorded as the number of days from emergence to 50 percent of flowering. Days to maturity were recorded when the haulms of 50 percent of the plants in each plot turned yellowish. The actual number of main stems per hill was recorded from five sampled plants at physiological maturity. Marketable and unmarketable yields (kg) were recorded from two central rows of plants that resulted in total yield per net plot. Diseased, insect pest attacked and tubers less than 20 mm in diameter were classified as unmarketable. Statistical analysis was done using SAS version 9.0 software (SAS institute, 2002). Mean comparison were made using LSD at 5% probability level.

Results and Discussion

The combined analysis of variance over locations and years for total tuber yield showed the presence of significant differences among varieties(V), test locations(L) and years(Y) while non significant difference for interactions of LV,VY and VLY (Table 2). The presence of non-significance of interactions indicates consistent performance of varieties under consideration over locations and years.

Performance of Varieties at Adet

Analysis of two years data indicated that there was statistically significant variation among varieties tested in terms of tuber yield and agronomic parameters (Table 3). Accordingly, Belete produced the maximum total tuber yield (23.66 ton/ha) followed by Guasa (21.37 ton/ha) and the lowest yield (19.21 ton/ha) was obtained from Local variety. Actually the yield obtained was much lower than what has been obtained in the main rainy season. This could be due to the prevailing maximum temperature, which was higher in irrigation season than the main season. Mondal and Chatterjee (1993) reported that lower potato tuber yields in warm conditions than cool because of higher temperature that delays tuber initiation.

Table 2. Combined ANOVA of over locations and years for tuber yield and agronomic performance of seven potato varieties under irrigation at Adet and Koga in 2010 and 2011

Sources	DF	DTE	DTF	PH	DTM	NMS/p	MTY	TTY
Location	1	**	**	*	**	*	**	**
Year	1	**	**	*	*	NS	**	**
Variety	6	NS	*	*	**	**	*	*
Variety x Location	6	NS	*	NS	**	**	NS	NS
Variety x Year	6	NS	*	NS	NS	NS	NS	NS
Variety x Year x Location	7	*	*	**	*	NS	NS	NS

DF- degree of freedom, Interaction, **, * =Significant at1% and 5% respectively and NS=Non Significant. DTE- days to emergency, DTF- days to flowering , PH-plant height(cm) , DTM- days to maturity, NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY- unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

Table 3. Mean tuber yield and agronomic performance of potato varieties under irrigation combined over years (2010 and 2011) at Adet

Varieties	DTE	DTF	PH (cm)	DTM	NMS/ p	MTY (t/ha)	UMTY (t/ha)	TTY t/ha)
Belete	21.00	59.00	49.53	118.00	3.87	21.749	1.917	23.666
Guassa	20.67	69.33	57.53	120.33	3.60	20.287	1.083	21.370
Zengena	21.33	70.67	72.63	119.67	2.63	18.778	1.713	20.491
Jalenie	22.67	63.33	61.33	119.67	3.13	21.139	0.704	21.843
Gudenie	21.67	70.33	62.83	118.67	5.87	18.88	2.907	21.787
Gera	24.00	69.00	59.37	119.67	3.60	17.952	2.270	20.222
Local	20.00	64.00	55.20	116.00	6.57	17.713	1.500	19.213
Mean	21.62	66.52	59.78	118.86	4.18	18.213	1.486	20.799
CV (%)	6.34	5.28	68.2	1.56	18.41	20.40	50.60	20.01
LSD (5%)	2.44	6.25	7.04	3.29	1.37	3.04	NS	3.09

NS= Non Significant, DTE- days to emergency, DTF- days to flowering , Ph-plant height (cm) , DTM- days to maturity ,NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY- unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

Performance of Varieties at Koga

At Koga, the combined data over seasons indicated that Belete and Guasa performed better than others. However, at Koga tested varieties showed less mean performance than varieties tested at Adet (Table 4). This is mainly because of low pH value and high soil temperature that hinders tuber formation and enlargement at Koga (Table 1). Soil pH is one of important factor contributing to overall potato yield reduction and marketable tuber grades. According to Havlin *et al*. (1999), the optimum pH for potato production is about 5-5.5.

Table 4. Mean tuber yield and agronomic performance of potato varieties under irrigation combined over years (2010 and 2011) at Koga

Varieties	DTE	DTF	PH (cm)	DTM	NM S/p	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
Belete	17.00	58.66	48.99	115.00	3.62	21.207	1.732	22.939
Guassa	18.00	58.66	51.95	118.66	3.62	22.144	1.589	23.733
Zengena	22.00	66.00	55.79	122.00	3.54	14.295	1.304	15.599
Jalenie	17.67	63.00	47.83	119.00	3.20	16.454	2.505	18.959
Gudenie	16.33	56.33	48.53	113.00	4.16	21.569	1.623	20.133
Gera	16.67	58.00	52.45	109.33	3.33	18.516	1.947	20.463
Local	16.67	60.00	46.20	108.66	3.45	18.600	1.814	14.400
Mean	16.59	60.09	50.25	115.09	3.56	20.397	1.787	19.183
CV (%)	4.07	1.04	7.12	2.15	5.69	24.00	30.45	21.86
LSD (5%)	1.28	1.12	6.36	4.41	NS	NS	1.401	NS

NS= Non Significant, DTE- days to emergency, DTF- days to flowering , Ph-plant height (cm) , DTM-days to maturity ,NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY-unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

Combined across locations (Adet and Koga) and season's average performance, varieties were significantly different in plant height, days to maturity, number of stems per plant, marketable and total tuber yields (Table 5). Belete and Local variety gave the highest (22.89 ton/ha) and the lowest (16.23 ton/ha) total marketable tuber yield respectively. However, varieties were not significantly different in days to emergence, days to flowering and unmarketable tuber yield (Table 5). The local variety was the shortest and the earliest maturing variety. According to skin color, tuber size and uniformity and test, farmers preferred Guassa and Jalenie respectively.

Table 5. Mean tuber yield and agronomic performance of potato varieties under irrigation combined over locations (Adet and Koga) and years (2010 and 2011)

Varieties	DTE	DTF	PH (cm)	DTM	NMS/p	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
Belete	25.66	63.08	52.30	110.33	3.85	19.269	3.620	22.890
Guassa	25.66	65.33	56.52	112.75	3.71	19.131	2.966	22.098
Zengena	24.66	66.91	66.29	114.25	2.42	15.958	2.224	18.182
Jalenie	25.50	65.00	55.87	112.50	3.10	17.976	2.911	20.897
Gudenie	23.41	66.92	57.17	110.00	3.60	15.723	2.935	18.658
Gera	24.33	64.92	57.66	109.08	3.42	16.569	2.813	19.463
Local	22.58	62.58	50.00	106.25	3.26	14.604	1.715	16.232
Mean	24.54	64.96	56.54	110.73	3.76	17.034	2.745	19.774
CV (%)	14.32	6.38	11.45	2.54	25.33	26.90	56.54	23.99
LSD (5%)	NS	NS	5.27	2.29	0.77	3.74	NS	3.860

NS= Non Significant, DTE- days to emergency, DTF- days to flowering , Ph-plant height (cm) , DTM- days to maturity ,NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY- unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

Performance of Varieties at Debark

The result of combined analysis of variance in Debark indicated that year by variety interaction was not significantly ($p<0.05$) different (Table 6). This implies that varieties performed across the two years uniformly. The main effect of test year and variety were significant ($p<0.05$) for total and marketable tuber yield which means that there was performance difference between varieties and test years.

Table 6. Mean square and F-test values of total and marketable tuber yield of tested potato varieties at Debark under irrigation condition combined over two years (2010-2011)

Source	DF	Means Squares		F-test	
		TTY	MTY	TTY	MTY
Replication	2	10.22	6.57	0.55NS	0.36NS
Year	1	414.01	739.47	22.21**	4.74**
Variety	7	91.41	58.23	4.9**	3.21*
Variety*Year	7	16.46	6.56	0.88NS	0.36NS
Pooled error	30	18.63	18.15		
Total	47				

DF- degree of freedom *significant at 5%; **significant at 1%; NS=Nnon-significant, DTE- days to emergency, DTF- days to flowering , Ph-plant height (cm) , DTM- days to maturity ,NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY-unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

The combined analysis of variance over the two years (2010 and 2011) at Debark indicated that there was significant difference ($p<0.05$) among the varieties for all parameters. The Varieties Gera and Zengena gave the highest total tuber yield (30.26 ton/ha and 29.16 ton/ha) and marketable tuber yield (26.5 ton/ha and 25.17 ton/ha) respectively (Table 7). Therefore, Gera and Zengena were more adaptable to irrigation production system in both years compared to other varieties. In addition the performance of Gorbella, Belete, and Jalenie were promising and there is no big performance difference among these three varieties (Table 7). On the other hand, Shenkola, Gudine and the local check poorly performed in terms of tuber yield. Jaline (86. 83 days) and local (87.5 days) flowered earlier as compared to the other varieties. The overall performance of improved varieties in terms of total tuber yield was higher than the local check under irrigation condition.

Table 7. Mean tuber yield and tuber yield components of potato varieties tested at Debark under irrigated production system combined over two years in 2010 and 2011.

variety	DTF	PH (cm)	NMS/p	TNPH	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)
Jaline	86.8	36.7	6.1	34.8	24.0	3.18	27.17
Belete	88.8	35.5	5.8	37.2	23.58	3.95	27.53
Zengena	92.5	44.6	4.7	35.5	25.17	3.99	29.16
Gorbela	88.7	39.4	5.3	33.7	24.31	3.42	27.73
Local	87.5	31.3	4.1	34.2	17.60	2.29	19.90
Gudine	88.3	32.2	5.6	38.0	20.08	2.46	22.56
Gera	92.2	36.9	5.1	34.3	26.50	3.74	30.26
Shenkola	93.5	41.9	4.2	35.8	19.62	1.55	21.15
Mean	89.7	37.3	5.1	35.4	22.60	3.07	25.68
CV (%)	4.0	16.3	23.5	10.1	18.8	43.8	16.8
LSD (5%)	4.24	7.2	1.42	4.23	5.02	1.58	5.09

DTE- days to emergency, DTF- days to flowering , Ph-plant height (cm) , DTM- days to maturity ,NMS/p- number of main stem per plant, MTY- marketable tuber yield (t/ha), UMTY-unmarketable tuber yield (t/ha), TTY-total tuber yield (t/ha)

Conclusion and Recommendations

Despite the difference in performance of varieties among the three locations, Belete and Guassa gave consistently higher total tuber yield per hectare. However, according to farmers assessment based on skin color, tuber size and uniformity and test, Guassa and Jalenie were selected first and second respectively. Therefore, Belete, Guasa and Jalenie are recommended for production in the mid altitude areas of northwestern Amhara under irrigation. Even though the overall performance of all improved varieties at Debark was good, Gera and Zengena were better in terms of total and marketable tuber yields. Therefore, these two varieties are recommended for production at Debark and similar high altitude agro-ecology under irrigated production system.

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Performance of Dessert and Cooking Type Banana Varieties at Jari, South Wollo

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Abstract

Banana is one of the important fruit crops in the mid and low altitude areas of Ethiopia. However, its productivity is very low compared to its productivity in other parts of the world. This is partly attributed to lack of adaptable, high yielding and better quality banana varieties to farmers. To solve this problem cooking and desert banana variety trials were carried out at Jari sub-center for four consecutive years (2005 to 2009). These experiments were laid out in randomized complete block design with three replications. Suckers were planted at a spacing of 2.5 m between rows and 2.5 m between plants. Two years consecutive data on yield and yield related parameters were collected and combined analysis of variance was made. Among the dessert type banana varieties Grande Naine (72.39 t ha^{-1}), Williams-I (69.36 t ha^{-1}), Williams-II (68.89 t ha^{-1}) and Poyo (68.29 t ha^{-1}) were high yielder varieties with a yield advantage of 178, 166, 164 and 162%, respectively over the Local (26.08 t ha^{-1}) variety. In addition, Grande Naine, Williams-I and Williams-II showed highest finger weight of 235.83, 205.01 and 191.30 g, respectively. Similarly among the cooking type banana varieties Cardaba (58.82 t ha^{-1}), Kitawara (57.14 t ha^{-1}), Wondo genet-III (52.57 t ha^{-1}), Kibungo-I (52.55 t ha^{-1}) and Chibul Angombe (51.61 t ha^{-1}) were better yielders having a yield advantage of 79, 74, 60, 59 and 57%, respectively over the least yielder variety Wondogenet-IV (32.91 t ha^{-1}). Moreover, the cultivars Grande Naine, Williams-I and Williams-II from dessert and Kitawira and Cardaba from cooking banana possessed the maximum weight of fingers and surpassed all the other varieties. Therefore, varieties Grande Naine, Williams-I and Williams-II, from dessert types and Cardaba and Kitawira from cooking types are recommended for production at Jari and similar areas.

Key words: Banana, Varieties, Dessert, Cooking, Jari

Introduction

Dessert banana and cooking banana (*Musa spp*. AAA and AAB groups) are major starch staple crops of considerable importance in the developing world (Dadzie and Orchard, 1997). Banana (*Musa .Spp*.) is a member of the Musaceace family and native to South East Asia (Robinson, 1996). The plant is herbaceous, fast growing and produces short lived stalk (pesdostems) which arise from underground corm or rhizome.

The main distinction between a dessert banana (AAA) and a cooking banana (AAB) is the type and amount of starch granules in the particular variety. For example, the dessert variety, Gros Michel, has small starch grains and when ripe, has a low percentage of starch; the French Plantain, on the other hand, has large starch granules, and when ripe, contains a high percentage of starch (Morton, 1987). They are consumed both as an energy yielding food and as a dessert (Dadzie and Orchard, 1997). They are giant perennial herbs that originated in Southeast Asia. Bananas and plantains are today grown in every humid tropical region (Picq *et al*., 1998; Arias *et al*., 2003). Bananas are the fourth most important food crop in the world after rice, wheat and maize and are grown in more than 130 countries across the world, in an area of 8.25 million hectares producing 97.38 million tons with productivity of 11.80 t ha^{-1}. Banana ranks third place in world fruit volume production after citrus fruit and grapes and second place in trade after citrus fruit (Balamohan *et al*., 2008).

Moreover, with increasing urbanization, bananas and plantains are becoming more and more important as cash crops, in some cases providing the sole source of income to rural populations. Thus, it is playing an important role in poverty alleviation. Bananas and plantains are one of the cheapest foods to produce. The cost of production of one kg of plantain is less than that for most other staples, including sweet potato, rice, maize and yam. Consequently, bananas and plantains can be a very cheap food to buy and are, hence, an important food for low-income families (Picq *et al.*, 1998). Bananas and plantains also grow in a range of environments and produce fruit year round. Thus, it provides energy during the “hungry-period” between crop harvests.

Banana is just more than a crop. The ripe banana is utilized in a multitude of ways in the human diet from simply being peeled and eaten out of-hand to being sliced and served in fruit cups and salads, sandwiches, custards and gelatins; being mashed and incorporated into ice cream, bread, muffins and cream pies. Ripe bananas are often sliced lengthwise, baked or boiled, and served (perhaps with a garnish of brown sugar or chopped peanuts) as an accompaniment for ham or other meats (Hailu *et al*., 2013).

Ethiopia lies entirely in the tropics where vast areas are suitable for banana growing. Banana production in Ethiopia ranges from homestead to large commercial plantations.

Commercial banana production had been undertaken in the past mainly in the warmer semi-arid river valleys of the country and predominately under irrigation. At present, bananas are the leading fruit crops produced in the country both in terms of area coverage and production where the bulk is produced in traditional agricultural system. Due to its relatively little requirement of land preparation, care, maintenance and a comparatively high yield per given area and time, bananas are well suited to traditional agricultural system. Available statistical data indicate that the average land acreage under banana production in the country in general and in Amahara region in particular is about 2085962 and 13539 hectares and their average yield is 7.09 and 2.16 t ha^{-1}, respectively (CSA, 2010).

This implies that banana varietal development research in the country in general and in Amhara region in particular is at its infant stage and there are no cooking banana varieties disseminated to the farming community. On the other hand, nowadays, there is a production of dessert type banana in small scale with poor quality and low productivity. Edward *et al* (1992) evaluated several cultivars of banana for their yield potential at Melkassa and the result revealed that Giant Cavendish, Gittitay and Poyo cultivars giving yields in the ranges of 21-24 t ha^{-1}. In addition, Seifu (1999) recommended Dwarf Cavendish, Poyo, Giant Cavendish and Ducasse hybrid from introduced and locally collected varieties for production. However, the performance of these varieties in Eastern amhara is unkown and farmers grow low yielding as well as poor quality dessert type banana varieties. Therefore, the objective of this study was to identify adaptable, quality and high yielding cooking and dessert type banana varieties for Jari and similar areas.

Material and Methods

An on-station trial was carried out from July 2005 to September 2009 at Jari research site of the Sirinka Agricultural Research Centre (SARC). Jari is situated at $11^0 21'$ N latitude and $39^0 38'$ E longitude, at 1680 meters above sea level and it receives a mean annual rainfall of 1204.6 mm. The average annual minimum and maximum temperatures were 11.20 ^{0}C and 25.60 ^{0}C, respectively (SARC, 2010). The soil type of the trial site was sandy loam, providing in general very good drainage.

The experimental material consisted of eleven cooking (Kibungo-I, Wondogenet-4, Matoke, Cardaba, Chibul Angombe, Saba, Niju, Ikimaga, Cachaco, Kitawira and Wondogenet-3) and twelve dessert (Dwarf cavandish, Gaint cavandish, Poyo, Lactana, Grande Naine, Butuza, Piang Raja, Williams-I, Williams-II, Robusta, Kamaramasange and Local) banana varieties obtained from Melkassa Agricultural Research Center. On 7 July each sucker planted in a well-prepared hole with a depth, diameter and width of 50 cm, 50 cm and 50 cm, respectively. The experimental design was a randomized complete block with three replications. Four plants were used for each experimental unit. Planting distance was 2.5 x 2.5 m with a plant population density of 1600 plants ha^{-1}. Plants were fertilized with 600 kg N ha^{-1} (0.38 kg N $tree^{-1}$) and 320 kg P kg ha^{-1}(0.20 kg P $tree^{-1}$). Phosphorus fertilizer was applied at planting, while N was applied in split applications (6-10 applications $year^{-1}$) to prevent leaching. In addition, 24-40 t ha^{-1} well decomposed cattle manure was applied at planting. The plants were surface irrigated in every 5-7 days for young seedlings whereas at interval of 10-15 days for older plants. All plots were mulched before the beginning of dry season (in June and January). Three plants were maintained within each banana mat. De-suckering and weeding were done regularly each 1-3 months depending when required. Growth data, expressed as plant height and number of leaves were measured two times in a year, while pomological data such as finger diameter and finger length, the bunch weight, average finger weight, marketable and total finger yield were also collected by taking representative samples. After each data collection, sanitation involving removal of dead leaves and suckers was conducted. Data were analyzed using SAS Release 9.0 software. Differences among individual means were tested using the Least Significant Difference test (LSD) at $P < 0.05$ level.

Results and Discussion

Dessert Banana

Table 1 presents the plant height, number of leaves, finger diameter and finger length. Plant height was highly variable among the cultivars studied, the tallest being recorded for *cvs.* Local and Piang Raja, with 3.40 and 3.34 m, respectively, whereas the lowest (1.71 m) values were recorded for *cvs.* Dwarf Cavendish. In this context, Girma (2013), from Melkassa reported a plant height for banana for *cvs.* Grand Nine and Williams of 3.00 and 2.90 m, respectively. Moreover, the results of the present study for plant height are similar with those reported by Dilip *et al*. (2010) in Canada for *cvs.* Grand Naine and Williams of 2.14 and 2.06 m, respectively. Numbers of leaves was highly variable among the cultivars studied, the maximum number being recorded for *cvs.* Local and Piang Raja, with 15.63 and 15.37, respectively. Whilst the lowest (10.31) number were recorded for *cvs.* Lactana. In addition, a perusal of the finger diameter (Table 1) showed that the varieties under test did not vary statistically in finger diameter. However, it was observed that the longest finger diameter of 4.00 cm was achieved by the cultivar Robusta followed by Local (3.98 cm), whereas the smallest diameter was noted in Lactana (3.35 cm). The cultivars studied differed significantly in finger length, the lengthiest being reported for *cv.* Robusta, Williams-I and Williams-II, with an average finger length of 19.74, 19.68 and 19.35 cm, respectively. The shortest were recorded in *cvs.* Kamaramasange and Local, with length of 12.87 and 14.20 cm, respectively. Regarding finger length, comparable results were reported by Girma (2013) for *cv.* Grand Naine and Willims (15.00 cm each) and by Dilip *et al*. (2010) for *cv.* Grand Naine (14.01 cm) and *cv.* Willims (12.40 cm).

Table 1. Plant height, number of leaves, finger diameter and finger length for the dessert banana cultivars studied

Cultivars	**PH (m)**	**NL**	**FD (cm)**	**FL (cm)**
Dwarf cavandish	1.71^{e}	13.98^{ab}	3.91	16.80^{cd}
Gaint cavandish	2.64^{c}	11.92^{bc}	3.74	17.13^{bcd}
Poyo	2.66^{c}	13.73^{ab}	3.76	18.97^{ab}
Lactana	2.98^{b}	10.31^{c}	3.35	16.68^{cd}
Grande Naine	2.17^{d}	13.13^{ab}	3.87	18.62^{abc}
Butuza	2.74^{bc}	11.79^{bc}	3.82	18.38^{abcd}
Piang Raja	3.34^{a}	15.37^{a}	3.87	16.64^{d}
Williams I	2.26^{d}	13.75^{ab}	3.84	19.68^{a}
Williams II	2.24^{d}	13.17^{ab}	3.81	19.35^{a}
Robusta	2.78^{bc}	14.21^{ab}	4.00	19.74^{a}
Kamaramasange	2.90^{bc}	13.56^{ab}	3.68	12.87^{e}
Local	3.40^{a}	15.63^{a}	3.98	14.20^{e}
LSD (5%)	0.30	2.78	0.40	1.94
F-test	***	**	NS	**
CV (%)	6.59	17.87	8.97	9.59

**PH=Plant height; NL= nnumber of leaves; FD= finger diameter; FL= finger length*

Table 2 presents the bunch weight, average finger weight, marketable and total finger yield for each of the cultivars studied. The heaviest bunch weight was produced from *cvs.* Grande Naine, with an average of 24.16 kg, whilst the smallest values were recorded for *cvs.* Lactana, with 8.54 kg. Regarding bunch weight, comparable results were reported by Balasubrahmanyam *et al*. (2003) in India for *cv*. Grand Naine (26 kg) and by Ana *et al*. (2006) in Brazil with a value of 24.19 kg. Moreover, the results of the present study for bunch weight are in similar with those reported by Dilip *et al*. (2010) in Canada for *cvs.* Grand Naine and Williams of 14.73 and 15.74 kg, respectively. Moreover, average finger weight from *cv*. Grand Naine carried the heaviest average weight (235.83 g) closely followed by Williams I and Williams II with 205.01 and 191.30 g, respectively and were statistically similar. By contrast, *cvs.* Local and Kamaramasange showed the smallest significant average weight of 99.31 and 100.41 g, respectively. Similar finger weights for *cv.* Grand Naine and William fruits (132 and 116 g, respectively) were reported in the experiment by Girma (2013) at Melkassa. MoARD (2009) also made similar observations. Balasubrahmanyam *et al*. (2003), Ana *et al*. (2006) and Dilip *et al.* (2010) reported better performance of Grand Naine and Williams than other varieties. The cultivars studied differed significantly in marketable finger yield, the highest being reported for *cv.* Grande Naine, Williams-I and Williams-II, with an average marketable yield of 69.60, 66.79 and 65.34 t ha^{-1}, respectively. The lowest were found for *cvs.* Local, with 23.73 t ha^{-1}. In relation to the total finger yield, the *cvs.* Grande Naine, Williams-I, Williams-II and Poyo showed the highest value among all the cultivars, with values of 72.39, 69.36, 68.89 and 68.29 t ha^{-1}, respectively. By contrast, the *cv.* local had the lowest significant total finger yield of 26.08 t ha^{-1}. The results of the present study for finger yield are in similar with those reported by Girma (2013) in Melkassa for *cvs.* Grand Naine and Williams of 43.60 and 55.60 t ha^{-1}, respectively. And it has been also reported by Balasubrahmanyam *et al*. (2003), in India with a finger yield of 57.50 t ha^{-1} for *cv*. Grand Naine.

Table 2. Bunch weight, average finger weight, marketable finger yield and total finger yield for dessert banana cultivars studied.

Cultivars	BW (kg)	AFW (g)	MFY (t ha^{-1})	TFY (t ha^{-1})
Dwarf cavandish	15.14^{d}	152.41^{cd}	55.93^{c}	62.62^{b}
Gaint cavandish	14.23^{de}	157.33^{cd}	56.94^{c}	58.31^{b}
Poyo	18.64^{c}	188.64^{abc}	64.93^{b}	68.29^{a}
Lactana	8.54^{g}	136.78^{de}	41.91^{d}	45.85^{c}
Grande Naine	24.16^{a}	235.83^{a}	69.60^{a}	72.39^{a}
Butuza	20.89^{b}	185.51^{bc}	57.42^{c}	61.11^{b}
Piang Raja	12.55^{ef}	123.63^{de}	35.09^{e}	35.88^{d}
Williams I	21.36^{b}	205.01^{ab}	66.79^{ab}	69.36^{a}
Williams II	20.52^{bc}	191.30^{abc}	65.34^{ab}	68.89^{a}
Robusta	20.35^{bc}	129.96^{de}	40.55^{d}	41.87^{c}
Kamaramasange	11.78^{f}	100.41^{e}	30.89^{e}	33.06^{d}
Local	21.65^{b}	99.31^{e}	23.73^{f}	26.08^{e}
LSD (5%)	2.00	47.42	4.49	4.48
F-test	**	**	**	**
CV (%)	9.82	25.66	7.60	7.18

**BW= bunch weight; AFW= average finger weight; MFY= marketable finger yield; TFY=total finger yield*

Cooking Banana

Table 3 presents the plant height, number of leaves, finger diameter and finger length for each of the cultivars studied. The longest plant height (3.20 m) was found in *cv.* Wondogenet-3, while the lowest height for *cvs.* Matoke (2.54 m). In this context, Girma (2013), from Melkassa reported a plant height for banana for *cvs.* Cardaba and Kitawira of 4.08 and 4.00 m, respectively. Moreover, the results of the present study for plant height are in similar with those reported by Dela *et al*. (2007) and Gerard et *al*. (2008) in Philippines and Georgia for *cvs.* Cardaba of 4.01 and 1.25 m, respectively. The data in Table 3 indicated that there were no significance differences among banana varieties in leaf number. However, it was observed that the highest (17.83) number of leaves were achieved by the *cv*. Saba followed by Ikimaga (16.63), whereas the lowest were produced by Kibungo (14.24) and Wondogenet-4 (14.34). Finger diameter was highly variable among the cultivars studied, the longest being recorded for *cvs.* Cardaba and Saba, with 5.11 and 5.07 cm, respectively. Whilst the shortest (4.20 and 4.22 cm) diameter were recorded for *cvs.* Wondogenet-4 and Matoke, respectively. Girma (2013), from Melkassa reported a finger diameter for banana for *cvs.* Cardaba and Kitawira of (4.00 cm each). Moreover, the finger diameter in these cultivars is similar to those reported by Dela *et al*. (2007). The cultivars studied differed significantly in finger length, the highest being reported for *cv*. Kitawira and Cachaco with an average finger length of 17.97 and 17.47 cm, respectively. The shortest were found for *cvs.*Wondogenet-4 and Wondogenet-3, with length of 13.97 and 14.49 cm, respectively. Regarding finger length, comparable results were reported by Girma (2013) for *cv*. Cardaba and Kitawira (14.00 cm each). In addition, Dela *et al*. (2007) reported better performance of Cardaba (11.02 cm) in finger length than other varieties.

Table 3. Plant height, number of leaves, finger diameter and finger length for the cooking banana cultivars studied.

Cultivars	**PH (m)**	**NL**	**FD (cm)**	**FL (cm)**
Kibungo	3.17^{ab}	14.24	4.27^{c}	16.84^{abc}
Wondogenet-4	2.83^{bcd}	14.34	4.20^{c}	13.97^{e}
Matoke	2.54^{d}	15.39	4.22^{c}	16.06^{bcd}
Cardaba	2.88^{abcd}	16.47	5.11^{a}	15.54^{cde}
Chibul Angombe	2.69^{cd}	14.89	4.47^{bc}	16.63^{abc}
Saba	2.80^{cd}	17.83	5.07^{a}	15.64^{cde}
Niju	2.66^{cd}	15.03	4.23^{c}	15.66^{cde}
Ikimaga	2.84^{bcd}	16.63	4.39^{bc}	15.16^{cde}
Cachaco	2.87^{abcd}	14.93	4.91^{ab}	17.47^{ab}
Kitawira	2.98^{abc}	15.68	4.24^{c}	17.97^{a}
Wondogenet-3	3.20^{a}	16.21	4.53^{bc}	14.49^{de}
LSD (5%)	0.35	2.84	0.54	1.71
F-test	*	NS	**	**
CV (%)	7.19	15.65	10.26	9.21

**PH=Plant height; NL= nnumber of leaves; FD= finger diameter; FL= finger length*

Table 4 presents the bunch weight, average finger weight, marketable and total finger yield for each of the cultivars studied. Bunch weight was highly variable among the cultivars studied, the highest being recorded for *cvs.* Wondogenet-3 and Chibul Angombe, with an average weight of 19.02 and 18.26 kg, respectively. Whilst the lowest values were recorded for *cvs.* Wondogenet-4 and Cardaba, with 11.73 and 13.11 kg, respectively. Regarding bunch weight, Dela *et al*. (2007) in Philippines reported comparable results for *cv.* Cardaba (19.50 kg). The cultivars studied differed significantly in average finger weight, the highest being reported for *cv.* Kitawira, with an average weight of 210.22 g, closely followed by Cardaba (191.23 g). The lowest weight was found for *cvs.* Wondogenet-4 and Niju, with 107.79 and 118.06 g, respectively. Similar finger weights for *cv.* Cardaba and Kitawira varieites were reported in the experiment through Girma (2013) (129 and 95 g, respectively) at Melkassa. MoARD (2009) also made similar observations. Dela *et al*. (2007) reported better performance of Cardaba (129.53g) in finger weight than other varieties. In relation to the marketable finger yield, the fingers with the highest yield recorded in *cvs.* Cardaba and Kitawira, with an average yield of 56.93 and 56.55 t ha^{-1}, respectively, whareas lowest values were recorded for *cvs.* Wondogenet-4 and Saba, with 32.04 and 32.55 t ha^{-1}, respectively. In addition, the highest total finger yield was found for *cv.* Cardaba and Kitawira, with a yield of 58.82 and 57.14 t ha^{-1}, respectively. While the lowest yield of 32.91 and 33.88 t ha^{-1} was realized from Wondogenet-4 and Saba, respectively. The results of the present study for finger yield are in similar with those reported by Girma (2013) in Melkassa for *cvs.* Cardaba and Kitawira of 48.00 and 46.30 t ha^{-1}, respectively.

Table 4. Bunch weight, average finger weight, marketable finger yield and total finger yield for cooking banana cultivars studied.

Cultivars	**BW (kg)**	**AFW (g)**	**MFY (t ha^{-1})**	**TFY (t ha^{-1})**
Kibungo	17.88^{ab}	179.38^{bc}	50.60^{ab}	52.55^{ab}
Wondogenet-4	11.73^{e}	107.79^{f}	32.04^{e}	32.91^{d}
Matoke	15.39^{bcd}	143.59^{de}	45.41b^{c}	47.09^{b}
Cardaba	13.11^{de}	**191.23^{ab}**	56.93^{a}	58.82^{a}
Chibul Angombe	18.26^{a}	141.87^{de}	49.90^{abc}	51.61^{ab}
Saba	13.93^{cde}	129.19^{def}	32.55^{e}	33.88^{d}
Niju	14.35^{cde}	118.06^{ef}	41.78^{cd}	44.08^{bc}
Ikimaga	15.26^{bcd}	149.35^{d}	33.75^{de}	36.04^{cd}
Cachaco	14.39^{cde}	155.70^{cd}	34.39^{de}	36.43^{cd}
Kitawira	16.45^{abc}	210.22^{a}	56.55^{a}	57.14^{a}
Wondogenet-3	19.02^{a}	154.14^{cd}	51.91^{ab}	52.57^{ab}
LSD (5%)	2.67	28.80	8.70	8.74
F-test	**	**	**	**
CV (%)	14.83	16.16	16.89	16.38

BW= bunch weight; AFW= average finger weight; MFY= marketable finger yield; TFY=total finger yield

Conclusion and Recommendations

Grande Naine, Williams-I and Williams-II from dessert gave a marketable fruit yield above 65.00 t ha^{-1}. These varieties are top yielder and supposed to be new introduction to the eastern Amhara. Cardaba and Kitawira from cooking types produced better yield above 55.00 t ha^{-1} in marketable fruit yield. Therefore, Grande Naine, Williams-I and Williams-II from dessert types and Cardaba and Kitawira from cooking types are recommended for production at Jari and other areas with similar agro-ecologies.

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Adaptation of Mungbean Genotypes under Irrigation Production at Kobo District, North Wollo

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Abstract

Mungbean (Vigna radiata) has been grown in India since ancient times. It is still widely grown in Southeast Asia, Africa, South America and Australia. Mungbean is a warm season annual crop requiring 90-120 days of frost-free conditions from planting to maturity. It does best on fertile sandy loam soils with good internal drainage. In spite of its importance and merits mentioned above, Mungbean is not well-studied and known in Ethiopia especially in eastern Amhara under irrigation. Kobo woreda lies in warm temperature zone, it has hot to warm sub-moist agro-ecology. The objective of this study was to evaluate the adaptability and yield potential of different cultivated varieties and introduced mungbean genotypes under irrigation. The trial was conducted in RCB design with three replications in 2010 and 2011 irrigation seasons. The tested varieties/genotypes were N-26, VC6173-B-33, Kenya, Shewarobit local 1 and Shewarobit local 2. The result indicated that variety N-26 and Shewarobit local 2 had produced significantly higher yield of 1600 kg ha^{-1} and 1534 kg ha^{-1}, respectively. Moreover, they require short maturity period,65-70 days, than the others. In addition N-26 had shiny and bold seed which is an important quality criterion for export. It was slightly determinant in nature than the others which is suitable for mechanization and efficient utilization of labor. The overall performance of N-26 and Shewarobit local 2 was better than the other varieties. Therefore, these two varieties were recommended to be demonstrated and popularized under irrigation condition of Kobo and similar agro ecologies.

Key words: Mungbean, Vigna radiata, Kobo

Introduction

Endowed with varied agro ecological zones and diversified natural resources, Ethiopia has been known as the home land and domestication of several crop plants. Pulses have been cultivated and consumed in large quantities in Ethiopia for many years. As an important component of crop production in Ethiopia's smallholder’s agriculture, oulses are providing an economic advantage to small farm holdings as an alternative source of protein, cash income, and food security. The crops have been used for many years in crop rotation practices. Some of them have also played an important role in the export sector generating foreign currency for the country. Although the availability of pulses have never been in surplus in the subsistence farming community, recently it is observed that the production and supply of some pulses is increasing due to increase in demand both in local and international markets (MOA, 2004). Mungbean is early maturing crop, which is also drought resistant. It has great potential for the semi-arid areas; due to its short growing cycle. Special features include high yield, good nutritive value, the earliness and drought resilient features, the reasonable cost of production and the ability to withstand striga without being parasitized.

Mung bean is widely adapted from 1000–1650 m a.s.l under low to medium rainfall conditions (350–750 mm). It is adapted to many areas of short length of growing period such as the Rift Valley, Kobo, Showarobit and other similar areas (Kidane *et al*, 2010). Since the crop is a recent introduction to Ethiopia, unlike other pulses, its consumption is not widespread. Moreover, despite a growing demand in the international market, there is also chronic supply gap in Ethiopia. However, although the production is low and recent, the export market have been grown slightly from 822 tons in 2001 to 1363 tons in 2002 (MOA, 2004)

Mungbean seeds are sprouted for fresh use or canned for shipment to restaurants. It constitutes a substantial portion of easily digestible protein (20-23%) of low flatulence in the cereal-based diet of a majority of people. Its sprouts are consumed as a common vegetable in many countries. Its composition includes 23.86-27% protein, 1.15% fat, 3.32% ash, 62.62% carbohydrates, 16.3% fiber, 6.60% total sugars, 9.05% water (Heather Maskus *et al*, 2010). In addition, mungbean is rich in vitamins A, B1, B2, and C, and niacin as well as minerals such as potassium and calcium, which are necessary for the human body. Because of their major use as sprouts, a high quality seed with excellent germination is required. Larger seed with a glassy, green color seems to be preferred.

Mungbean is a warm season annual crop requiring 90-120 days of frost-free conditions from planting to maturity. Adequate moisture is required from flowering to late pod fill in order to ensure good yield. If proper varieties are used Mungbean are adapted to the same climatic areas as soybean, dry bean and cowpea. Mungbean do best on fertile sandy, loam soils with good internal drainage. They do poorly on heavy clay soils with poor drainage. Performance is best on soils with a pH between 6.7 and 7.2 and plants (Oplinger *et al*, 1990). Mung bean productivity can range from 340 to over 2267.5 kg ha^{-1} (Oplinger *et al*, 1990). In spite of its importance and merits mentioned above, mungbean production was not well-studied and known in Ethiopia especially in eastern Amhara both under rainfed and irrigation conditions.

The low land areas of eastern Amhara fall in rift valley. These areas are characterized by moisture stress having high population pressure. These areas have high potential of pulse production in general and mung bean in particular. However, in the face of unreliable and inconsistent nature of rainfall, production of export or high value commodities like mung bean under irrigation provide multiple benefits. Farmers in Kobo produced three times in a year using rainfall and irrigation, from July to October, October to end of January and February to May, respectively. Hence, irrigation based mungbean production in this area can play vital roles to maintain soil fertility and crop rotation practices. However, given irrigation production potential and market access to the nearby regions, it had never reaped the opportunities of mungbean production, as it would suppose to be. Therefore, the objective of this study was to evaluate different Mungbean varieties or genotypes under irrigation to make mungbean familiar for the area and to increase crop diversity so as to increase the income of farmers.

Materials and Methods

Study area

The experiment was conducted at Kobo which is located 54 km from Woldia in the direction of north. Its altitude ranges from 1000 - 2800 m a.s.l and mean annual rainfall amount of 668 mm. It has an agro-ecology of hot to warm sub-moist valley and escarpment. Its mean daily temperature is usually greater than 21^{o}C. The agro-climatic feature of the woreda is inclined to be tropical with 7.9%, 37.2%, and 54.9% of it is *Dega*, *Woina Dega*, and *Kolla*, respectively (Girma and Samuael *et al*, 2000). Soil type is Euritic Fluvisol lying on low plain on valley floor enclosed by low but steep side hills and drains to rift valley river basin. The soils are deep to very deep, mostly alluvial origin, moderately well to imperfectly drained. The infiltration rate and permeability are low with high runoff generation potential. But due to flat topography it is less susceptible to erosion. The pH of the soil ranges from 6 to 7. The major crops grown in the area are Sorghum, *Teff*, and Maize (Getachew, 1993). The livelihood of the population is depending on mixed farming and crop production, with about 96% of its population engaged in agriculture. Due to various constraints, Kobo woreda is one of the food insecure woredas of the Amhara National Regional State.

Experimental Set up

The trial was conducted for two years during 2010 and 2011 irrigation seasons. Five Mungbean varieties/genotypes were evaluated in randomized complete block design with three replications for their adaptability and yield performance under irrigation. The materials were N-26, VC 6173-B-33, KENYA, Shewarobit local 1 and Shewarobit local 2. Shewarobit local 1 has deep green seed color, 65-75 days length of growing period and 55-65 cm plant length; and Shewarobit local 2 has light green seed color and 60- 70 days length of growing period. In addition, it has smaller seed size than Shewarobit local 1. The varieties/genotypes were planted with 40cm and 5cm between rows and plants, respectively on a plot size of $20m^2$ (4m X5m). Data were collected for number of pods per plant, number of seeds per pod, biomass, 100 seed weight, seed yield, harvest index, days to flowering, days to maturity and plant height. The data were analyzed using GenStat 13^{th} Edition (SP2) statistical software.

Results and Discussion

As it is presented in Table 1, results obtained during first year (2010) showed that there was significant difference in days to flower, number of pods per plant, number of seeds per pod, plant height and 100 seed weight. But there was no significant difference in biomass, seed yield and harvest index among the tested varieties. Even if there was no statistically significant difference in seed yield, N-26 and Shewarobit local 2 showed better performance than the other varieites. The varieties N-26 and Kenya produced the highest

(1332 kg ha^{-1}) and lowest yield (718 kg ha^{-1}) respectively. The respective days to maturity was 62 days and 69 days for variety N-26 and Shewarobit local 1. Nevertheless, the overall performance of N-26 and Shewarobit local 2 was better as compared to other varieties (Table 1). However, due to water scarcity and irrigation water management, the first year yield of all the tested varieties was low as compared to second year (Table 2).

Table 1: Means of Days to Flowering, Days to Maturity, Number of Pods Per Plant, Number of seeds Per pod, plant height, 100 Seed Weight, Biomass, Grain Yield and Harvest index of mungbean, 2010.

	Genotypes	**DF (days)**	**DM (days)**	**NPP**	**NSP**	**PH (cm)**	**Ds**	**100 SW(g)**	**BM (g/plot)**	**GY (kg/ha)**	**HI**
1	**N-26**	**44a**	**62**	**11a**	**9a**	**33.7c**	**1**	**6.1a**	**7814a**	**1332**	**27.3**
2	VC6173-B-33	44a	64	14b	7ab	27.0ab	1	6.4a	7980a	1197	23.9
3	Kenya	46a	66	8a	8ab	24.8a	1	6.7a	5251b	718	17.7
4	Shewarobit local 1	24a	69	20c	5ab	30.3bc	1	4.4b	7584ab	1011	20.9
5	Shewarobit local 2	**37b**	**67**	**15b**	**7a**	**24.8a**	**1**	**4.3b**	**7921a**	**1232**	**24.8**
	GM	39	66	14	7	28.1	1	5.6	7310	1098	22.9
	CV (%0	12.5	3.4	10.7	9.1	6.6	0	6.7	17.6	23.9	18.5
	DMRT(0.05)	*	NS	*	**	*	NS	**	NS	NS	NS

*** Significant at 0.01%, *significant at 0.05%, *** significance at < 0.001, DF=days to flowering, DM=days to maturity, NPP=number of pod per plant NSP=number of seed per pod, Ph= plant height (cm), Ds= disease score, SW=seed weight, BM= biomass, GY=Grain yield, GM=grand mean, DMRT= Duncan multiple range test, CV% =coefficient of variations*

In 2011, maximum yield was produced from variety N-26 (1867 kg ha^{-1}) and Shewarobit local 2 (1530 kg ha^{-1}), respectively. The lowest yield was recorded in variety Shewarobit local 1 (1167 kg ha^{-1}). There was significant difference among the varieties in seed yield, days to flower, days to maturity, plant height, 100 seed weight and harvest index. But there was no statistically significant difference in biomass yield and number of pod per plant among the varieties. The maximum and minimum days to flower was recorded in variety Shewarobit local 1 and Kenya, 57 days and 42 days, respectively. Variety Shewarobit local 1 showed maximum days to mature (97 days) and N-26 showed lowest days (65 days) to mature (Table 2).

The combined analysis showed that significant variation in seed yield was observed due to the main effects of year and genotype and the interaction effect of year by genotypes. The year by variety interaction in seed yield, days to flower, days to mature and plant height were significant (P<0.01). All the varieties performance in seed yield, plant height and other parameters increased during the second year (Table 3). The crop has indeterminate nature that is why the year by Genotype interaction for days to flower and maturity showed significant difference. Higher and lower yields were recorded in variety N-26 and Shewarobit local 2, 1600 and 1534 kg ha-1, respectively. N-26 and Kenya showed better performance in number of seed per plant (i.e., 9.5 and 8, respectively). Shewarobit local 1 was taller than the other varieties with a height of 51.6 cm. In two years period, there was no economical disease infection although halo blight was observed at the seedling stage. Frequent irrigation, hoeing, fertilization and other cultural practices were used to control insect pests. After the implementation of the above cultural practices the plant recovers from insect damages.

Table 2: Means of Days to Flowering, Days to Maturity, Number of Pods per Plant, Number of seeds Per pod, plant height, 100 Seed Weight, Biomass, Grain Yield and Harvest index of Mungbean, 2011.

Genotypes	**DF (days)**	**DM (days)**	**NPP**	**NSP**	**PH (cm)**	**Ds**	**100 SW(g)**	**BM (g/plot)**	**GY (kg/ha)**	**HI**
N-26	**48b**	**65c**	**19**	**9.7**	**44.b**	**1a**	**6.1bc**	**5722**	**1867a**	**31a**
VC6173-B-33	44d	70b	22	8.7	47.3b	2a	6.5ab	4777	1335bc	30.9a
Kenya	42e	71b	16	8.7	49b	1a	6.8a	6754	1366bc	22.7ab
Shewarobit local 1	57a	97a	24	10	73a	1a	5.5c	7507	1167c	16.5b
Shewarobit local 2	**46c**	**70b**	**26**	**7.7**	**45.6b**	**2.6a**	**3.9d**	**6957**	**1530b**	**26.8a**
GM	47.5	74.5	21.6	8.9	51.8	1.6	5.7	6343	1453	25.6
CV (%)	1.6	2.0	19.1	15.9	10.5	61.4	5.1	30.1	9.8	18.4
DMRT(0.05)	***	***	NS		***	NS	***	NS	*	*

*** Significant at 0.01%, *significant at 0.05%, *** significance at < 0.001, DF=days to flowering, DM=days to maturity, NPP=number of pod per plant NSP=number of seed per pod, Ph= plant height, Ds= disease score, SW=100 seed weight, BM= biomass, GY = grain yield in kilo gram per ha GM=grand mean, DMRT= Duncan multiple range test, CV% =coefficient of variations*

Table 3: Combined Means of Days to Flowering, Days to Maturity, Number of Pods Per Plant, Number of seeds Per pod, plant height, 100 Seed Weight, Biomass, Grain Yield and Harvest index of Mungbean, 2010 and 2011

Genotypes	DF	DM	NPP	NSP	PH (cm)	Ds	100 SW (g)	BM (g/plot)	GY (kg/ha)	HI
N-26	46a	63c	15bc	9.5a	39.0b	1	6.1b	5303	1600a	29.1a
VC6173-B-33	44ab	67b	18ab	7.8b	37.1b	1.5	6.5ab	4882	1383bc	28.3a
Kenya	44ab	68b	12c	8ab	36.9b	1	6.7 a	5018	1042d	26a
Shewarobit local 1	40b	83a	22a	7.7b	51.6a	1	5c	6124	1296c	23a
Shewarobit local 2	41ab	69b	20a	7b	35.2b	2	4d	5954	1534ab	28.9a
GM	43.13	70	17.5	8	40.0	1	5.680	5456	1371.	27.2
G	NS	***	*	*	***	NS	***	NS	***	NS
Y	*	**	*	*	**	NS	NS	*	*	NS
G XY	***	***	Ns	*	***	NS	*	NS	***	NS
CV (%)	8.1	2.7	19.8	13.7	10.4	53.3	5.9	26.9	10.5	30.5

*** Significant at 0.01%, *significant at 0.05%, *** significance at < 0.001, DF=days to flowering, DM=days to maturity, NPP=number of pod per plant NSP=number of seed per pod, Ph= plant height, Ds= disease score, SW=seed weight, BM= Biomass, GY = Grain yield in kilo gram per ha GM=grand mean, DMRT= Duncan multiple range test, CV% =coefficient of variations*

Conclusion and Recommendations

Five varieties were tested during irrigation season with the objective of evaluation and adaptation of different varieties/genotypes and introduced mungbean genotypes and to make the area productive in different crops and increase the income of the farmers. High yield, early maturity and disease tolerance were important criteria to select the varieties. N-26 and Shewarobit local 2 were found high yielder and early maturing. Moreover, N-26 was slightly determinant in nature than the others and it had shiny and bold seed which is important quality parameter for export. The determinant nature made it suitable for mechanization and efficient utilization of labor. Therefore, these two varieties were recommended to be demonstrated and popularized under irrigation condition of Kobo and similar agro ecologies. Further agronomic studies on mung bean under irrigation condition should be future focus towards the achievement of maximum yield potential of the varieties.

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Response of Irrigated Onion to Nitrogen and Phosphorus Fertilizers at Ribb, Koga, Megech, and Gurmbaba Irrigation Schemes in Amhara Region

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Abstract

Nitrogen (N) and phosphorus (P) fertilizer recommendations for irrigated onion production is lacking for the different irrigation schemes in the Amhara region. Four different experiments were conducted at Ribb, Koga, Megech and Gurmbaba irrigation schemes to determine the N and P fertilizer levels for irrigated onion. Experiments were conducted in the years 2010 and 2011. At Ribb and Koga treatments were comprised of factorial combinations of five N levels (50, 100, 150, 200 and 250 kg N ha^{-1}) and three P levels (20, 40 and 60 kg P ha^{-1}) with one satellite control treatment (0/0 N/P) replicated three times in Randomized Complete Block Design. At Megech, factorial combinations of four N levels (0, 50, 100, and 150 kg N ha^{-1}) and four P levels (0, 20, 40, 60 kg P ha^{-1}) were replicated three times in Randomized Complete Block Design. At Gurmbaba five levels of N (0, 50, 100, 150 and 200 kg N ha^{-1}) were replicted three times in Randomized Complete Block Design. Bombay Red in Ribb and Koga, and Adam Red in Megech were onion varieties used for the study. Results showed that at Ribb application of 150 kg N ha^{-1} and 20 kg P ha^{-1} as the first recommendation and 250 kg N ha^{-1} and 20 kg P ha^{-1} as a second recommendation; at Koga application of 100 kg N ha^{-1} and 60 kg P ha^{-1} as the first option and application of 50 kg N ha^{-1} and 60 kg P ha^{-1} as a second option; at Megech application of 100 kg N ha^{-1} and 60 kg P ha^{-1}; and at Gurmbaba application of 200 kg N ha^{-1} along with the recommended phosphorus fertilizer rate (20 kg P ha^{-1}) were found high yielding and economically profitable and are recommended.

Key words: Onion, N and P fertilizers, Irrigation, Ribb, Koga, Megech, Gurmbaba

Introduction

In most irrigable lands, horticultural crops in general and vegetables in particular, play an important role in contributing to the household food security and income. Vegetables being cash crop, with high nutritional value, generate income for the poor households.

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Higher profits can be achieved by increasing the production of a particular vegetable throughout the year when efficient irrigation system is used. Onion (*Allium cepa* L.) is one of the most popular vegetables in the world. It is fourth in world production of vegetables with a volume of 57.9 million tons (FAO, 2005). In Ethiopia, it contributes substantially to the national economy apart from overcoming local demand. Onion is among the largest production and highly commercialized vegetable crops in Amhara region grown under irrigation. Currently farmers in most irrigable areas of the Amhara region produce large amount of onion bulbs every year. For instance, in 2005/06 production year the region contributed 70,652.6 tons of onion bulb from 5,338 hectares of land covered by the crop (Tadesse, 2008). In the Amhara region irrigated agriculture is expanding since recent years. Currently, more than 6,200 small scale irrigation schemes of which 95% are traditional exist in the region (Melisew, 2012). Interestingly, the irrigation schemes are owned by more than 330,000 households (or more than 1.9 million people) with an average irrigated land holding of 0.2 ha (Melisew, 2012). Further more, several new and modern irrigation schemes such as Ribb, Megech, Koga, Kobo, Robit, Gumara, etc are under development which will increase the significance of irrigation agriculture in the region. However, farmers are growing most of the irrigated crops with very limited use of improved technologies, which kept the production and productivity of the irrigated system not better than the rainfed system. For instance, in Megech and Ribb areas, only 5 and 4 percent of the households that cultivated during the dry season using irrigation used chemical fertilizers and compost, respectively. The proportion is higher for households in the Megech project area (14% vs 4%) compared with Ribb area (World Bank/DIME, 2012). For the irrigated production system appropriate agronomic technologies have rarely been developed. Therefore, this experiment was conducted with the objective of determining the optimum rates of nitrogen and phosphorus fertilizers for onion for four irrigation schemes in the region.

Materials and Methods

Description of Study Sites

Experiments were conducted at Ribb, Koga, Megech, and Gurmbaba irrigation schemes in the 2010 and 2011 production seasons. Ribb irrigation scheme is found in Fogera district situated at 11^0 41' to 12^0 02' N latitude and 37^0 29' to 37^0 59' E longitude at an altitude of 1800 m a.s.l. Koga irrigation scheme is found in Mecha district situated at 11^o25'20'' N latitude and 37^o10'20" E longitude at an altitude of 1960 m a.s.l. Megech research site is found in Dembia district situated at 12^o20'51" N latitude and 37^o20'23" E longitude at an altitude of 1786 to 1800 m a.s.l. Gurmbaba irrigation scheme is found in West Belessa district situated at 12^o29'59" N latitude and 37^o47'39" E longitude, and an altitude ranging from 1777 to 1806 m a.s.l.

The soil at the Ribb experimental site is fluvisol (an alluvial deposit). According to Bruce and Rayment (1982), the soil has high phosphorus and very low to low total nitrogen contents (Table 1). The CEC is high according to the category by Hazelton and Murph (2007). The soil at the Koga experimental site is Nitosol. The soil is strongly acidic with high exchangeable acidity and high exchangeable Al^{3+} content. It has very low organic matter content. Available phosphorus content is low according to the category by Clements and McGowen (1994). It has medium total nitrogen contents (Table 2).

At Megech experimental site the soil is dominantly Vertisol (>65% coverage) with few coverage of Luvisols. The top 60 cm soil of the experimental site is clay in texture with 11% sand, 38% silt and 51% clay content. It has 0.1% total nitrogen, 1.1% organic carbon, 24.2 ppm available phosphorous and a pH of 8. The soil is also characterized by 1.41g cm^{-3} bulk density, 44.5% field capacity, and 27.5% permanent wilting point. At Gurmbaba, the soil is sandy clay loam in texture with 42% sand, 27% silt and 31% clay contents. The soil has 9.6 cation exchange capacity, 0.74% organic carbon, 0.11% total nitrogen and pH of 7.5.

Table 1. Chemical properties of the soils of Ribb irrigation command area, 2011

Sample	**Av. P (ppm)**	**Total N (%)**	**CEC** (cmol kg^{-1})
Farmers' field	24.32-29.89	0.007-0.18	33.40-36.25
Trial site	36.71	0.003	33.00

Table 2. Chemical properties of the soils of Koga irrigation command area, 2011

pH	Exch. Al3+ (cmol kg^{-1})	Exch. H^+ (cmol kg^{-1})	Exch. acidity (cmol kg^{-1})	Total N (%)	Available P (ppm)	Organic matter (%)
5.1-5.3	0.92-2.88	0.62-2.35	1.54-5.23	0.18-0.24	3.54-8.69	2.34-4.44

Experimental Design and Procedures

At Ribb (Fogera and Libo Kemkem weredas) the trial was conducted on farmers' field whereas at Koga it was conducted inside the research station. At Ribb and Koga factorial combinations of five N fertilizer levels (50, 100, 150, 200 and 250 kg N ha^{-1}) and three P levels (20, 40 and 60 kg P ha^{-1}) with one satellite control treatment (0/0 N/P) for comparison constituted the treatments. The experimental design was randomized complete block in three replications. Onion variety, Bombay Red was used. After raising seedlings on seedbed for 50 days, healthy and uniform seedlings were transplanted to the experimental plots. Spacing between furrow, rows and plants were 40cm, 20cm and 10cm, respectively in a net plot size of 1.2 m^2. Distances between plots and blocks were 1m. Urea and TSP/DAP were used as a source of nitrogen and phosphorus fertilizers, respectively. Phosphorus was band-applied at planting in rows 2 cm below seedlings. While nitrogen was applied in split, half at transplanting and the remaining half at 45 days after transplanting on both sides of the rows of 2-3cm away from plants. Plants were cultivated four times in the cropping season. Irrigation water was supplied weakly using furrow irrigation method.

At Megech (Dembia wereda), the experiment was conducted at on-farm. Treatments were factorial combinations of four N fertilizer levels (0, 50, 100, and 150 kg N ha^{-1}) and four P levels (0, 20, 40, 60 kg P ha^{-1}). The plot size was 2m by 3m, the spacing between blocks, rows and plants were 1.5m, 20cm and 10cm respectively. The experimental design was randomized complete block in three replications. Onion variety Adam Red was used. Urea and TSP were used as a source of nitrogen and phosphorus fertilizers, respectively. Phosphorus was band-applied at planting, while nitrogen was applied in split, half at planting and the remaining half at 45 days after transplanting. Irrigation water was supplied every four days with furrow irrigation method.

At Gurmbaba (West Belesa) the experiment was conducted on farmers' fields. The plot size was 3m by 3m, the spacing between blocks, rows and plants were 1.5m, 20cm and 10cm respectively. Treatments were comprised of five levels of N fertilizer (0, 50, 100, 150 and 200 kg N ha^{-1}). Phosphorus at the rate of 20 kg P $ha^{-1}$was applied uniformly for each plot at planting. The experimental design was randomized complete block replicated three times. Nitrogen was applied by spliting, half at planting and the other half at 45 days after transplaning. Onion variety of Adama-Red was used. Irrigation water was supplied every four days with furrow irrigation method.

Composite soil samples for the determination of physicochemical properties of the experimental plots were collected prior to planting. Data on plant height, maturity date, leaf number, bulb weight, bulb length, bulb diameter, marketable and unmarketable yield and total yield were recorded.

In order to identify economically feasible recommendations partial budget analysis was done based on the manual developed by CIMMYT (1988). The analysis was based on data collected from respective district office of Trade and Transport, Cooperatives and from onion field experiment. At Fogera, the mean price of onion, urea and DAP from 2009-2011 was 3.40 ETB kg^{-1}, 7.74 ETB kg^{-1} and 8.90 ETB kg^{-1}, respectively. While at Koga, the mean price of onion, urea and DAP were 2.62 ETB kg^{-1}, 7.41 ETB kg^{-1} and 8.60 ETB kg^{-1} respectively. At Megech, during 2010-2011 production season, the mean price of Onion, urea and DAP were 3 ETB kg^{-1}, 9.87 ETB kg^{-1} and 10.7 ETB kg^{-1} respectively. Data were subjected to analysis of variance using SAS statistical package (SAS Institute, 2002) to assess treatment effects. Whenever significant treatment differences were detected, means were separated using LSD at 5% probability. For the purpose of partial budget analysis, yields were adjusted downward by 10% from the actual yield. The marginal rate of return (MRR) and net benefits are calculated by adding 10% ETB/kg increase from the current price of fertilizer. Minimum rate of return was taken at 100%.

Results and Discussion

Results of Ribb Irrigation Scheme

Results at Ribb indicated that nitrogen has significant (P<0.01) effect on the marketable and total yields of onion and bulb diameter, but phosphorus and the interaction of N and P did not show significant effect (Table 3). As compared to the control (0/0 N/P_2O_5), application of 20 kg ha^{-1} P has 3.89 ton ha^{-1} marketable yield advantage over the zero fertilizer application. This result shows that application of 20 kg/ha P fertilizer contributes 19.55% yield increment around Fogera and Libokemkem Woredas. This may have positive implication to boost the yield of onion at those Woredas. Application of N fertilizer indicated that significantly higher marketable and total bulb yields were recorded at the application of 100 kg N ha^{-1} and beyond, although high yield was recorded with the application of 250 kg N ha^{-1}. However, applying N fertilizer beyond 100 kg N ha^{-1} did not significantly increase marketable and total bulb yields (Table 4). The increase in onion bulb yield with the application of N fertilizer could be due to the fact that nitrogen increases the rate of metabolism where more carbohydrate is synthesized which increases the bulb weight and then total yield. Lack of response for phosphorus application at Ribb (Table 5) could be due to the high available phosphorous content of the soil (Table 1). Fogera plain soils are fluvisols which are deposited from upper catchments. This findig is in agreement with the general truth that fluvisols have good nutrient content. This result is also similar with findings of Baye et al. (2010), where the effect of phosphorus and its interaction with nitrogen was found statistically non-significant for all of the onion yield parameters.

The partial budget analysis for Ribb showed that applying 250 kg N ha^{-1} had the highest net benefit (41611.92 ETB ha^{-1}) and MRR of 201% followed by 150 kg N ha^{-1} with net benefit of 41491.62 ETB ha^{-1} and MRR of 325.8% (Table 6). For one kg nitrogen fertilizer investment the farmer can get 2.01 ETB and 3.25 ETB return by using 250 and 150 kg ha^{-1} respectively. Since the net benefit is more or less same (nearly 120 ETB ha^{-1} difference) for the two rates, thus 150 kg N ha^{-1} followed by 250 kg N ha^{-1} N fertilizer in combination with 20 kg P ha^{-1} are recommended for onion production at Ribb irrigation scheme as first and second option, respectively. The farmers at Fogera and Libokemkem woredas did not apply fertilizer at all for onion production; however this finding revealed that application of fertilizer has contributed much to boost yield. This has positive implication for onion production increment.

Table 3. Combined ANOVA for the effect of N and P fertilizers on the marketable and total yield of onion at Ribb irrigation scheme

Sources of variation	Df	Mean square values							
		Marketable yield	Pr > F	Total bulb yield	Pr > F	Bulb diameter	Pr > F	Bulb length	Pr > F
Rep	2	4047.30	0.0143	4162.41	0.0114	18.08	<.0001	0.42	0.002
N	4	4826.35	0.0009	4882.36	0.0007	4.20	0.022	0.089	0.200
P	2	133.42	0.8592	74.51	0.9165	1.098	0.424	0.021	0.680
Year	1	292419.60	<.0001	289736.79	<.0001				
N x P	8	846.76	0.4728	816.35	0.4796	1.52	0.3176	0.044	0.602
Error	52	874.17		850.78					

Table 4. Effect of nitrogen fertilizer on the marketable and total bulb yield of onion at Ribb combined over two years (2010 and 2011).

N rate (kg ha^{-1})	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})	Bulb diameter (cm)	Bulb length (cm)
0	19.74^{c*}	19.91^{c}	17.92^{ab}	4.37^{a}
50	21.87^{bc}	21.95^{bc}	17.06^{c}	4.41^{a}
100	22.54^{ab}	22.55^{abc}	17.5^{bc}	4.32^{a}
150	24.76^{ab}	24.86^{a}	18.68^{a}	4.54^{a}
200	24.30^{ab}	24.33^{a}	17.52^{bc}	4.33^{a}
250	25.87^{a}	25.93^{a}	18.41^{ab}	4.51^{a}
LSD (0.05)	**	**	*	NS
CV (%)	14..07	13.72	6.25	5.32

*Means followed by the same letters are not significantly different at P≤0.05.

Table 5. Effect of phosphorus fertilizer on the marketable and total bulb yield of onion at Ribb combined over two years (2010 and 2011).

P rate (kg ha^{-1})	Marketable Yield (t ha^{-1})	Total Yield (t ha^{-1})	Bulb diameter (cm)	Bulb length (cm)
0	19.74^{a}	19.91^{a}	17.92^{a}	4.37^{a}
20	23.63^{a}	23.75^{a}	17.71^{a}	4.43^{a}
40	24.04^{a}	24.06^{a}	18.45^{a}	4.39^{a}
60	23.93^{a}	23.96^{a}	17.65^{a}	4.46^{a}
LSD (0.05)	NS	NS	NS	NS
CV (%)	14..07	13.72	6.25	5.32

*Means followed by the same letters are not significantly different at P≤0.05.

Table 6. Partial budget analysis for the effect of nitrogen fertilizer on the yield of onion at Ribb irrigation scheme

N level (kg ha^{-1})	Unadjusted yield (t ha^{-1})	Adjusted yield (t ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	MRR (%)
0	19.74	17.766	35309.93		35309.93	D*
50	21.87	19.683	39119.96	932.61	38187.35	308.5
100	22.54	20.286	40318.43	1865.22	38453.21	D
150	24.76	22.284	44289.45	2797.83	41491.62	325.8
200	24.3	21.87	43466.63	3730.435	39736.19	D
250	25.87	23.283	46274.96	4663.043	41611.92	201.1

Results of Koga Irrigation Scheme

According to Hazelton and Murph (2007), suitable pH range for onion is 6-6.5. However, the soil pH at Koga (5.09 to 5.3) is far below the optimum range which indicates that the performance of onion at Koga irrigation scheme could be affected by soil acidity, especially with Al^{3+} toxicity. Onion is very sensitive to soil acidity, especially for Al^{3+} toxicity. Exchangeable Al^{3+} becomes significant at pH levels less than 5.5 in water or about 4.7 in CaCl2. The critical level of exchangeable Al^{3+} for onion is 0.4-0.8 extracted by $CaCl_2$ (Hazelton and Murph, 2007) while exchangeable Al^{3+} at Koga is 0.92-2.88 which is above the critical level. This result indicates that onion production was affected by aluminum toxicity at Koga irrigation scheme. The soil at Koga has very low organic matter content. Available phosphorus content is also low according to the category by Clements and McGowen (1994).

The interaction effect of N and P fertilizers had significant ($P<0.01$) effect on the marketable and total yield of onion at Koga (Table 7). However, there was no interaction effect of N and P fertilizer ($P<0.05$) on bulb diameter and length. Significantly higher marketable bulb yields were recorded with the application of 100 kg N ha^{-1} with 60 kg P ha^{-1} followed by application of 150 kg N ha^{-1} with 40 or 60 kg P ha^{-1}. Similarly, significantly higher total bulb yields were recorded with the application of 250 kg N ha^{-1} with 40 kg P ha^{-1} followed by application of 100 kg N ha-1 with 60 kg P ha^{-1} (Table 8). This result indicated that application of N and P fertilizer has highly significant influence on the bulb yield and vegetative growth of onion which is in harmony with the findings of Rizk (1997) who concluded that increasing the application rate of N increased growth of onion. In addition, the result indicates that higher bulb diameter was recorded by applying 150 kg N ha^{-1}.

According to Rizk (1997), in irrigated agriculture use of chemical fertilizer can increase the yield of onion more than 10 tons per hectare as compared to without fertilizer application. It is observed that maximum bulb yields were recorded at maximum phosphorus applications. This could be an indication that the applied phosphorus might have been fixed due to the strongly acidic soils. Thus, such studies need to be conducted with the application of lime to understand the readily available phosphorus applied.

Table 7. Combined ANOVA for the effect of N and P fertilizers on the marketable and total yields of onion at Koga irrigation schemes.

Sources of variation	df	Mean square values							
		Marketable yield	Pr > F	Total yield	Pr > F	Bulb diameter	Pr>F	Bulb length	Pr>F
Rep	2	2.30	0.998	318.57	0.813	1.54	0.69	6.391	<.0001
Nitrogen (N)	4	2487.82	0.160	2929.22	0.123	3.58	0.49	0.238	0.70
Phosphorus (P)	2	46812.6	<.000	48816.28	<.0001	8.09	0.16	0.066	0.86
Year	1	207526.5	<.000	325141.08	<.0001				
N x P	8	5005.93	0.002	5595.25	0.001	6.96	0.14	0.370	0.57
Error	52	1448.15		1534.19		4.11		0.436	

Table 8. Effect of N and P fertilizers on the marketable bulb yield of onion at Koga over two years (2010 and 2011)

P/N rate (kg ha^{-1})	**Marketable yield (t ha^{-1})**	**Total yield (t ha^{-1})**	**N rate (kgha^{-1})**	**Bulb dia. (cm)**	**Bulb length (cm)**	**P rate (kgha^{-1})**	**Bulb dia. (cm)**	**Bulb length (cm)**
0/0	19.74^{f*}	20.00^{g}*	0	18.21^{b}	6.53^{a}	0	18.21^{b}	6.53^{a}
20/50	24.41^{def}	25.48^{ef}	50	21.32^{a}	6.97^{a}	20	20.84^{a}	6.74^{a}
20/100	24.30^{cde}	27.68^{def}	100	22.02^{a}	6.91^{a}	40	22.21^{a}	6.84^{a}
20/150	23.34^{de}	25.90^{ef}	150	20.75^{a}	6.67^{a}	60	21.99^{a}	6.87^{a}
20/200	24.46^{cde}	34.79^{abc}	200	22.03^{a}	6.62^{a}			
20/250	25.89^{bcd}	33.93^{bc}	250	22.28^{a}	6.92^{a}			
40/50	21.86^{ef}	22.33^{f}						
40/100	24.13^{cde}	29.58^{de}						
40/150	27.74^{ab}	27.84^{ef}						
40/200	26.04^{bcd}	33.89^{bc}						
40/250	24.93^{bcd}	38.04^{a}						
60/50	25.68^{bcd}	28.91^{def}						
60/100	29.22^{a}	35.09^{ab}						
60/150	26.79^{abc}	29.04^{def}						
60/200	26.18^{abcd}	30.91^{cd}						
60/250	25.39^{bcd}	29.03^{def}						
LSD(0.05)	**3.05**	**3.42**		1.96	0.63		1.52	0.49
CV (%)	**13.64**	**12.97**		9.36	9.68		9.36	9.68

**Means followed by the same letters are not significantly different at P<0.05.*

The results of the partial budget analysis (Table 9) showed that applying 100 kg N ha^{-1} and 60 kg P ha^{-1} had the highest net benefit (65247 ETB ha^{-1}) and MRR (1996 %) followed by 150 kg N ha^{-1} and 40 kg P ha^{-1} with net benefit of 61498 ETB ha^{-1} and MRR of 1711% (Table 9). Therefore, 100/60 and 150/40 kg N/P ha^{-1} are recommended as first and second options, respectively for onion production at Koga irrigation scheme. The studies at both sites indicate that fertilizer application will increase marketable and total bulb yield for onion production under irrigation; hence farmers and other onion growers should apply N and P fertilizers to increase their income and as well the country's GDP.

Table 9. Partial budget analysis for the effect of N and P fertilizers on the yield of onion at Koga irrigation scheme.

N / P (kg ha^{-1})	Unadjusted yield (t ha^{-1})	Adjusted yield (t ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	MRR (%)
0/0	19.74	17.77	46546.92	0	46546.92	
50/20	24.41	21.97	57558.78	1513.35	56045.42	690.41
50/40	21.86	19.67	51545.88	2140.22	49405.66	D
50/60	25.68	23.11	60553.44	2838.00	57715.44	1309.973
100/20	24.3	21.87	57299.4	2399.85	54899.55	706.9403
100/40	24.13	21.72	56898.54	3026.71	53871.83	D
100/60	29.22	26.30	68900.76	3653.57	65247.19	1996.114
150/20	23.34	21.01	55035.72	3286.34	51749.38	4043.096
150/40	27.74	24.97	65410.92	3913.20	61497.72	1710.609
150/60	26.79	24.11	63170.82	4540.06	58630.75	D
200/20	24.46	22.01	57676.68	4172.83	53503.85	1535.7
200/40	26.04	23.44	61402.32	4799.69	56602.62	543.7642
200/60	26.18	23.56	61732.44	5426.55	56305.88	D
250/20	25.89	23.30	61048.62	5059.32	55989.3	R
250/40	24.93	22.44	58784.94	5686.18	53098.75	D
250/60	25.39	22.85	59869.62	6313.05	53556.57	R

D Stands for dominated treatment. R stands for rejected treatment

Results of Megech Irrigation Scheme

Results of combined ANOVA showed that bulb diameter and bulb weight did not respond to the application of N and P at Megech. But, bulb yield responded to the effects of N and P (Table 10). The interaction effect of N and P on bulb yield and the yield components was not significant. Significantly ($P \leq 0.01$) higher bulb yields were obtained with the application of 100 and 150 kg N ha^{-1} and 60 kg P ha^{-1} (Table 11).

Table 10. Combined ANOVA for the effect of N and P fertilizers on the yield and yield components of onion at Megech (2010 and 2011).

Source of variation	df	Mean square		
		Bulb diameter	**Bulb weight**	**Yield**
Replication	2	0.03ns	9.3ns	0.55ns
Nitrogen (N)	3	0.76ns	272.8ns	655.0**
Phosphorus (P)	3	0.11ns	62.6ns	109.3**
N x P	9	0.01ns	16.6ns	19.9ns
Error	78	0.47	196.4	11.9

Table 11. Effect of N and P fertilizer on the yield and yield components of onion at Megech combined over years (2010 and 2011).

Treatment	Bulb Diameter (cm)	Bulb Weight (g)	Yield (t ha^{-1})
N Level (kg ha^{-1})			
0	4.3	53.0	19.2[c*]
50	4.7	59.5	27.7[b]
100	4.7	59.7	30.4[a]
150	4.6	59.9	30.0[a]
P Level (kg ha^{-1})			
0	4.5	55.6	24.4[c]
20	4.6	58.6	26.0[bc]
40	4.6	58.8	27.4[b]
60	4.7	59.1	29.4[a]
CV (%)	14.9	24.1	12.9
LSD (0.05)	0.39	8.05	1.98

**Means followed by the same letters were not statistically significant at P ≤0.05.*

Higher total yield in onion at higher N and P (80-120 kg N $ha^{-1}$and 60 kg P ha^{-1}) rates were reported (Sheikh et al.1987; Baloch et al. 1991; Bhardwaj, 1991; and Pandey et al. 1994), which is in agreement with the present finding. The higher marketable fruit yield under higher N and P rates might have been achieved probably because the higher N and P rates might have improved fruit size thereby contributing to greater marketable fruit yield. The results of the partial budget analysis also showed that applying 100 kg N ha^{-1} and 60 kg P ha^{-1} had the highest net benefit (89594 and 84922 ETB ha^{-1} for N and P) and marginal rate of return (806 and 571 % for N and P rate) and are found economically profitable for onion production at Megech (Table 12). Therefore, 100 kg N ha^{-1} and 60 kg P ha^{-1} is recommended for onion production at Megech in Dembia wereda and other similar areas.

Table 12. Partial budget analysis for the effect of N and P fertilizers on the yield of onion at Megech irrigation scheme.

Parameters	Nitrogen level (kg ha^{-1})				Phosphorous level (kg ha^{-1})			
	0	**50**	**100**	**150**	**0**	**20**	**40**	**60**
Mean yield (t ha^{-1})	19.2	27.7	30.4	30.0	24.4	26.0	27.4	29.4
Adjusted yield (t ha^{-1})	17.3	24.9	27.4	27.0	22.0	23.4	24.7	26.5
Total Revenue (ETB ha^{-1})	69120	99720	109440	108000	87840	93600	98640	105840
Total costs (ETB ha^{-1})	17700	17700	17700	17700	17700	17700	17700	17700
Gross field benefit (ETB ha^{-1})	51420	82020	91740	90300	70140	75900	80940	88140
Fertilizer cost (ETB ha^{-1})	0	1073	2146	3218	0	1073	2146	3218
Total costs that vary (ETB ha^{-1})	0	1073	2146	3218	0	1073	2146	3218
Net benefit (ETB ha^{-1})	51420	80947	89594	87082	70140	74827	78794	84922
Dominance Analysis				D				
Marginal cost (ETB ha^{-1})	0	1073	1073		0	1073	1073	1073
Marginal net benefit (ETB ha^{-1})	0	29527	8647		0	4687	3967	6127
Marginal rate of return (%)		2752	806			437	370	571

Results of Gurmbaba Irrigation Scheme

The results of the combined ANOVA showed that bulb weight and bulb yield had responded to the application of nitrogen fertilizer, but not bulb diameter (Table 13). Results indicated that onion bulb weight and bulb yield were significantly higher at the application of 150 and 200 kg N ha^{-1} (Table 14). The increase in yield in response to application of N fertilizers is probably due to enhanced availability of nitrogen which could enhance more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation.

Table 13. Combined ANOVA for the effect of N fertilizer on the yield and yield components of onion at Gurmbaba (2010 and 2011).

Source of variation	df	Mean square		
		Bulb diameter	**Bulb weight**	**Yield**
Replication	2	0.21^{ns}	222.7*	0.40^{ns}
Nitrogen	4	0.44^{ns}	1883.3**	27.4**
Error	8	0.61	24.1	0.78

Table 14. Effect of N fertilizer on the yield and yield components of onion at Gurmbaba in 2009 and 2010.

Nitrogen (kg ha^{-1})	**Bulb diameter (cm)**	**Bulb weight (g)**	**Yield (t ha^{-1})**
0	5.07	50.4^{d*}	5.8^{d}
50	5.37	72.3^{c}	7.6^{c}
100	5.52	83.2^{b}	9.2^{b}
150	5.80	93.5^{a}	10.2^{ab}
200	5.55	92.3^{a}	11.2^{a}
CV (%)	16.3	6.3	10.1
LSD (0.05)	0.94	5.9	1.06

* Means followed by the same letters were not statistically significant at (5%)

The results of the partial budget analysis indicated that applying 200 kg N ha^{-1} had the highest net benefit of 17818 ETB ha^{-1} and marginal rate of return of 202 % and is found economically profitable for onion production at Gurmbaba (Table 15). Application of 200 kg N ha^{-1} combined with 20 kg P ha^{-1} is recommended rate of fertilizers for onion production at Gurmbaba in West Belesa and other similar areas.

Table 15. Partial budget analysis for the effect of N fertilizer on the yield of onion at Gurmbaba irrigation scheme.

Parameters	**Nitrogen fertilizer levels (kg ha^{-1})**				
	0	**50**	**100**	**150**	**200**
Mean yield (t ha^{-1})	5.75	7.64	9.18	10.18	11.15
Adjusted yield (t ha^{-1})	5.18	6.88	8.26	9.16	10.04
Total Revenue (ETB ha^{-1})	20700	27504	33048	36648	40140
Total costs (ETB ha^{-1})	17700	17700	17700	17700	17700
Gross field benefit (ETB ha^{-1})	3000	9804	15348	18948	22440
Fertilizer cost (ETB ha^{-1})	0	1156	2311	3467	4622
Total costs that vary (ETB ha^{-1})	0	1156	2311	3467	4622
Net benefit (ETB ha^{-1})	3000	8648	13037	15481	17818
Dominance Analysis					
Marginal cost (ETB ha^{-1})	0	1156	1155	1156	1155
Marginal net benefit (ETB ha^{-1})	0	5648	4389	2444	2337
Marginal rate of return (%)		489	380	211	202

Conclusion and Recommendations

At Ribb, application of 150 kg N ha^{-1} and 20 kg P ha^{-1} as the first and 250 kg N ha^{-1} and 20 kg P ha^{-1} as second options are recommended for onion production. Onion did not respond to P application at Ribb due to the high phosphorus content of the soil. Therefore, future phosphorus fertilizer recommendation for Ribb area needs to be developed based on soil test.

At Koga irrigation scheme application of 100 kg N ha^{-1} and 60 kg P ha^{-1} is recommended as the first option. As a second option application of 150 kg N ha^{-1} and 40 kg P ha^{-1} is recommended. The highest yield in response to the tested P fertilizer rates was not attained in the current study, therefore P rates above 60 kg P ha^{-1} needs to be studied for Koga irrigation scheme so as to attain the point of diminishing response. At Koga irrigation scheme fertilizer rate study needs to be done along with soil liming as the soil in the command area is acidic.

For onion production at Megech and similar agro-ecologies, based on the biological yield and partial budget analysis application of 100 kg N ha^{-1} and 60 kg P ha^{-1} which gave the maximum and profitable yield is recommended. Application of 200 kg N ha^{-1} along with the recommended 20 kg P ha^{-1} which gave the maximum and profitable marketable yield is recommended for onion production at Gurmbaba irrigation scheme and similar agro-ecologies in West Belesa.

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Response of Irrigated Potato (Solanum tuberosum L.) to Nitrogen Fertilizer at Koga Irrigation Scheme, West Gojam

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Abstract

Poor soil fertility is one of the factors that limit crop productivity both in rainfed and irrigated production systems. Nitrogen fertilizer recommendation for irrigated potato production is lacking for the different irrigation schemes in the Amhara region. A field experiment was conducted to determine the response of potato (Solanum tuberosum L.) to different rates of nitrogen fertilizer at Koga irrigation scheme in 2010 and 2011 irrigation seasons. Treatments were seven nitrogen fertilizer levels (0, 54, 81,108, 135, 162 and 189 kg N ha^{-1}). The experimental design was randomized complete block in three replications. Results showed that application of 189 kg N ha^{-1} followed by 162 kg N ha^{-1} were agronomically high yielding and economically profitable and were, thus, recommended as first and second options for potato production in Koga irrigation scheme.

Key words: Nitrogen fertilizer, Potato, Koga

Introduction

The three major essential plant nutrients namely nitrogen, phosphorus and potassium are found increasingly in short supply in the soils of Eastern, Western and Southern Africa (Rao *et al*., 1998). Nutrient mining in East Africa is among the highest in Sub-Saharan Africa, with an estimated annual nutrient depletion rate of 41 kg nitrogen (N), 4 kg phosphorus (P) and 31 kg potassium (K) per hectare (Bekunda *et al*., 2005). Continuous removal of biomass from crop land without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardize the sustainability of agricultural production (Esilaba *et al*., 2000).

Potato is a heavy nutrient feeder crop which often needs addition of plant nutrients for higher productivity. Potatoes respond well to the application of both farmyard manure and inorganic fertilizers. According to Bereke (1988), an application of 150-66 kg N-P_2O_5 ha^{-1} under rainfed conditions resulted in a tuber yield advantage of 32% over the unfertilized. The amount of nitrogen a potato crop requires varies from 100-200 kg ha^{-1} (occasionally 300 kg) depending on the purpose of production and the soil fertility status. N supply in potato may substantially delay leaf senescence leading to enhanced leaf area duration and increased tuber yield (MacKerron and Heilbronn, 1985).

In Koga irrigation command area from a total of land covered by irrigation 41% is covered by potato production in 2012. However, farmers are growing potato without any fertilizer input and yields are far below the potential of the crop. The objective of this study was, therefore, to determine the optimum rate of nitrogen fertilizer for potato production in Koga irrigation scheme.

Materials and Methods

Description of Study Area

Koga irrigation scheme is found in Mecha district situated at 11^{o} 25’ N latitude, 37^{o} 09’ E longitude and at an altitude of 2020 m asl. The soil at the Koga experimental site is Nitosol. The soil is strongly acidic according to USDA classification with high exchangeable acidity and high exchangeable Al^{3+} content. It has very low organic matter content. Available phosphorus content is very low according to the category by James (2004). This might be due to the acidic nature of the soil. It has medium total nitrogen contents (Table 1). The very low available phosphorus content could be due to the high acidity of the soil.

Table 1. Physicochemical properties of the soils in the Koga irrigation command area.

Parameter	Values
pH	5.18
Total N (%)	0.21
Available p (ppm)	6.28
Organic matter (%)	3.71
Exchangeable acidity (cmol/kg)	2.93
Exchangeable Al^{+3} (cmol/kg)	1.65

Experimental Design and Procedures

Experimental treatments were seven nitrogen fertilizer levels (0, 54, 81, 108, 135, 162, 189 kg N ha^{-1}) arranged in a randomized complete block design with three replications.

Belete, a recently released improved potato variety, was used for the experiment. The gross plot size was 9 m^2 with spacing between rows of 75 cm and plants of 30 cm.

Urea and TSP were used as a nitrogen and phosphorus fertilizer sources, respectively. Nitrogen was applied in split where $^1/_3$ of the N was applied at planting, $^1/_3$ at emergence and the remaining $^1/_3$ at flowering stage. The recommended phosphorus fertilizer rate (69 kg P_2O_5 ha^{-1}) was applied for all the plots uniformly and applied in band at planting at a depth of 5 cm below the tubers. Cultivation was done four times in the cropping season including split application of urea. Irrigation water was applied by furrow application method at weekly intervals. Data on plant height, number of main stem, unmarketable yield, and marketable yield were collected. Composite soil samples to determine the physicochemical properties of the soil were collected prior to implementing the experiment.

Analysis of variance was carried out for yield and yield components using SAS statistical package (SAS Institute, 2008) following statistical procedure appropriate for the experimental design. Whenever treatment effects were found statistically significant, means were separated using Duncan's Multiple Range Test. Partial budget analysis was done using CYMMYT (1988) manual to recommend economically feasible fertilizer rates. The price of fertilizer in the farmers' cooperative (union) shop and farm price of potato in the command area was used for the analysis. Nitrogen fertilizer price used for the analysis was ETB 6.23 kg^{-1} and price of potato was ETB 2.09 kg^{-1}. Marketable yield was adjusted down by 10% to bring down yield to farmers' productivity level and cost of fertilizer was also adjusted up by 10% to accommodate the rise in hard currency every year.

Results and Discussion

Results indicated that there were significant ($P \leq 0.05$) treatment differences in plant height, marketable tuber yield and total tuber yield of potato (Table 2). Plant height was significantly higher with the application of 189 kg N ha^{-1} (Table 3). The highest marketable tuber yield was found at the rate of 189 N ha^{-1} followed by 162 kg N ha^{-1}

while the lowest marketable tuber yield was recorded for the unfertilized or control plot (Table 3). Total tuber yield was significantly higher with the application of 108 kg N ha^{-1} and beyond, however applying nitrogen fertilizer beyond 108 kg N ha^{-1} did not bring significant increase in total tuber yield (Table 3). This result agrees with the results of Tesfaye *et al*. (2008) who recommended 108 and 81 kg N ha^{-1} as first and second economically profitable recommendation for South Gondar zone and 81 kg N ha^{-1} for Adet and Injibara areas.

Table 2. Combined ANOVA for the effect of nitrogen fertilizer on the yield and yield components of potato at Koga irrigation scheme (2010/11 and 2011/12)

		Means square			
Sources of variation	df	Plant height	Marketable yield	Unmarketable yield	Total yield
Rep	2	79.270**	2638..487*	1692.538**	1801.751*
N rate	6	143.680**	26811.377**	103.304ns	27510.260**
Year	1	24.259**ns**	1960.302ns	7590.097**	1835.768*
N_rate*Year	6	24.576*	2888.851**	57.755ns	2542.088**
Error	12	5.577	509.630	117.198	326.202

Table 3. Response of irrigated potato to nitrogen fertilizer combined over years (2010/11 and 2011/12) at Koga irrigation scheme

N_rate (kg ha^{-1})	Stand count	PH (cm)	MTY (t ha^{-1})	Total TY (t ha^{-1})
0	15.33	46.35d	13.877e	15.636d
54	14.83	50.27c	17.548d	19.3364c
81	15.83	51.48c	23.978c	25.746b
108	14.83	56.23b	27.964b	30.727a
135	15.33	56.27b	29.130ab	30.9460a
162	15.67	56.36b	29.950ab	32.040a
189	15.50	61.02a	31.142a	32.598a
CV (%)	8.69	4.37	8.51	6.89

**Means within a column followed by the same letter are not significantly different at P≤ 0.05. PH =Plant height, MTY = Marketable tuber yield, TY = Tuber yield.*

The partial budget analysis result showed that applying 189 kg N ha^{-1} had the highest net benefit and marginal rate of return followed by 162 kg N ha^{-1} (Table 4). These rates are agronomically high yielding and economically profitable, thus, are recommended as the first and second options for potato production in Koga irrigation scheme.

Table 4. Partial budget analysis for the effect of nitrogen fertilizer on the yield of potato at Koga irrigation scheme.

N rate (kg ha^{-1})	Adjusted marketable yield (t ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal rate of return (MRR) (%)
0	12.49	23479.3	0	23479.3	
54	15.79	29692.7	807.2	28885.5	669.70
81	21.58	40570.4	1210.9	39359.5	2595.01
108	25.17	47315.8	1614.5	45701.4	1571.22
135	26.22	49295.5	2018.1	47277.4	390.47
162	26.96	50675.4	2421.7	48253.7	241.88
189	28.02	52692.6	2825.4	49867.3	399.78

Conclusion and Recommendations

Results indicated that irrigated potato responded well to application of nitrogen fertilizer. Adding nitrogen fertilizer for irrigated potato at Koga increased the marketable yield of potato. For each application of additional 1 kg of N there was a yield advantage between 130 kg ha^{-1} to 67 kg ha^{-1} marketable tuber yield at the rate of 108 to 54 kg ha^{-1} nitrogen rate. The result indicated that application of each kg N can give at least 67 kg ha^{-1} additional tuber yield as compared to the control. The result of economic analysis also revealed that applying 189 kg N ha^{-1} and 162 kg N ha^{-1} gave the highest net benefit. Therefore, applying 189 kg N ha^{-1} which is 385 kg urea ha^{-1} along with the recommended phosphorus fertilizer rate (69 kg P_2O_5 ha^{-1} or 150 kg DAP ha^{-1}) is recommended for potato production in Koga irrigation command area and as a second option applying 162 kg N ha^{-1} which is 325 kg urea ha^{-1} along with the recommended phosphorus fertilizer rate (69 kg P_2O_5 ha^{-1} or 150 kg ha^{-1} DAP) is recommended. Further studies on Phosphorus-Nitrogen interaction and organic fertilizer should be conducted for Koga area to develop holistic and integrated soil fertility management technologies.

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Response of Irrigated Tomato (Lycopersicon esculentum L.) to Nitrogen and Phosphorus Fertilizers at Megech Irrigation Scheme, North Gondar

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Abstract

Nitrogen (N) and phosphorus (P) fertilizer recommendations for irrigated tomato production is lacking for the different irrigation schemes in the Amhara region. An experiment was conducted in 2010 and 2011 at Megech to determine economically feasible nitrogen and phosphorus fertilizer levels for irrigated tomato. Factorial combinations of four levels of nitrogen fertilizer (0, 50, 100, and 150 kg N ha^{-1}) and four levels of phosphorus fertilizer (0, 20, 40, 60 kg P ha^{-1}) constituted the treatments. The experimental design was randomized complete block in three replications. Tomato variety Roma VF was used. Results showed that based on the biological yield and partial budget analysis, application of 150 kg N ha^{-1} and 60 kg P ha^{-1} were found high yielding and economically feasible and are recommended for tomato production in Megech irrigation scheme and other similar areas.

Key words: N and P fertilizers, Tomato, Megech,

Introduction

Tomato (*Lycopersicon esculentum* L.) is the most widely grown vegetable in the world being recognized as a reach source of vitamins and minerals. It is also among the most important vegetable crops in Ethiopia. The total production of this crop in the country has shown a marked increase (Lemma et al., 1992). However, tomato production is highly constrained by several factors, especially in developing nations like Ethiopia. The national average tomato fruit yield in Ethiopia is often low (12.5 t ha^{-1}) compared to the neighboring African countries like Kenya (16.4 t ha^{-1}) (FAO, 2004). Current productivity under farmers' condition is 9.0 t ha^{-1}, while yields up to 40.0 t ha^{-1} were recorded on research plots (Tesfaye, 2008).

In Ethiopia, farmers get lower yield mainly due to diseases and pests, as well as due to sub-optimal fertilization. Nitrogen and phosphorus are the two essential macronutrients for plants. Their deficiency as well as excess levels may change plant functions (Glass *et al*., 2002; Mahmud *et al*., 2003). Normally fertilizer is applied at planting time of tomato in irrigated areas but most of the farmers in irrigated areas usually apply less or no fertilizer in order to avoid losses in case of crop failure. Moreover, the fertility status of the soil is depleted due to continues cropping of cereals without any fertility restoration effort. The current government policy on agricultural development emphasizes on producing high value and marketable crops with efficient soil and water management. Hence, farmers are being encouraged to grow high value crops like vegetables, fruits, spices and high yielding cereals using irrigation. Furthermore, with the increasing irrigation scheme development in the area tomato is becoming an important crop. However, fertilizer rates required for irrigated tomato were not yet determined for the area. The objective of this research was, therefore, to determine economically feasible rate of nitrogen and phosphorous fertilizers for irrigated tomato production in Megech irrigation scheme.

Materials and Methods

Description of Study Area

Field experiments were carried out in 2010 and 2011 on farmers' field at Megech irrigation command area, Dembia district. The experimental site is located at $12^0$20'51" N latitude and $37^0$20'23" E longitude and at elevation of 1786 to 1800 m above sea level. The study area is characterized by homogeneous flat topography, with slope of 1% to 2%. The soil is dominantly Vertisols (>65% coverage) with few coverage of Luvisols. The top 60 cm soil of the experimental site is clay in texture with 11% sand, 38% silt and 51% clay content. It has 0.1% total nitrogen, 1.1% organic carbon, 24.2 ppm available phosphorous and a pH of 8. The soil has 1.41 g cm^{-3} bulk density, 44.5% field capacity, and 27.5% permanent wilting point (MoWR, 2008). Agro-ecologically, the study area is in a tepid thermal zone and moist to sub-humid moisture zone (180–220 day growing period), termed as tepid moist and sub humid lowland (MoA, 1998). The mean annual potential evapotranspiration is about 1560 mm. Mean maximum and minimum annual temperatures are 27 ^{O}C and 13 ^{O}C, respectively and the mean annual temperature is 19 ^{O}C.

Experimental Design and Procedures

The experiment was conducted at on-farm. Treatments were factorial combinations of four nitrogen fertilizer levels (0, 50, 100, and 150 kg N ha^{-1}) and four phosphorus levels (0, 20, 40, 60 kg P ha^{-1}). The experimental design was randomized complete block in three replications. The plot size was 3 m*3 m, and the spacing between blocks and plots was 1.5 m and 1 m, respectively. Tomato variety Roma VF was used as test crop, where the spacing between rows and between plots was 75 cm and 30 cm respectively. Urea and TSP were used as sources of nitrogen and phosphorus fertilizers, respectively. Phosphorus was band-applied at planting, while nitrogen was applied in split, half at planting and the remaining half at 45 days after transplanting. Irrigation water was supplied weekly with furrow system.

The yield and yield component data were subjected to statistical analysis using SAS statistical package. Whenever the variance analysis revealed significant treatment differences, means were separated using LSD test at 5% probability level. Partial budget analysis was also done using the market price data collected at Kola Diba town, Denbia. The mean price of tomato was 3.0 ETB kg^{-1}, mean price of Urea was 9.87 ETB kg^{-1}, and mean price of phosphorus was 10.5 ETB kg^{-1}. Yields were adjusted down by 10% to bring down yield to farmers' productivity level.

Results and Discussion

Results of the combined ANOVA showed that number of fruits per plant responded only to the main effects of nitrogen. Fruit weight responded neither to the nitrogen and phosphorus effects nor to the interaction. Tomato fruit yield responded to the main effects of nitrogen and phosphorus fertilizers (Table 1).

Fruit number per plant was significantly ($P \leq 0.05$) higher for all nitrogen fertilizer levels over the control (Table 2). Tomato fruit yields were significantly ($P \leq 0.01$) higher with the application of 150 kg N ha^{-1} and 40 and 60 kg P ha^{-1} (Table 2). Fruit yield increased following the increase in the N level. Similarly, fruit yield tended to follow the increase in P level; although fruit yield at 40 kg P ha^{-1} did not significantly differ from fruit yield at 60 kg P ha^{-1}. Higher total fruit yield in tomato at higher N and P rate was reported by several researchers (Pandey *et al*., 1996; Tesfaye, 2008; Mehla *et al*., 2000), which is in agreement with the present finding. The higher marketable fruit yield under higher N and P rate might have been achieved probably because the higher N and P rate might have improved fruit size thereby contributing to greater marketable fruit yield per plot.

Table 1. Combined ANOVA for the effect of N and P fertilizers on the yield and yield components of tomato at Megech (2010 and 2011).

Source of variation	df	Mean square		
		Number of fruit per plant	**Fruit weight**	**Yield**
Nitrogen (N)	3	924.6*	12.8ns	433.9**
Phosphorus (P)	3	62.8ns	6.2ns	138.6**
N x P	9	8.6ns	7.1ns	10.2ns
Error	78	228.7	89.6	12.3

Table 2. Effect of nitrogen and phosphorous fertilizer on the yield and fruit number of tomato at Megech combined over years (2010 and 2011).

Treatment	Fruit number $plant^{-1}$	Marketable Yield (t ha^{-1})
N level (kg ha^{-1})		
0	22.6[b*]	21.2[d]
50	30.8[ab]	25.6[c]
100	34.7[a]	28.6[b]
150	36.6[a]	31.1[a]
P level (kg ha^{-1})		
0	29.1	23.4[c]
20	30.8	26.1[b]
40	32.4	28.2[a]
60	32.5	28.7[a]
LSD (0.05)	8.69	2.02
CV (%)	48.5	13.2

**Means followed by the same letters were not statistically significant at P≤ 0.05.*

Results of the partial budget analysis indicated that the marginal rate of return was higher with the application of 150 kg N ha^{-1} and 60 kg P ha^{-1} (Table 3). Thus, based on the biological yield response and partial budget analysis maximum and profitable marketable yields of tomato at Megech could be obtained with the application of 150 kg N ha^{-1} and 60 kg P ha^{-1}.

Table 3. Partial budget analysis for the effect of nitrogen and phosphorus fertilizers on the yield of tomato at Megech irrigation scheme.

	Nitrogen level (kg ha^{-1})				**Phosphorous level (kg ha^{-1})**			
	0	**50**	**100**	**150**	**0**	**20**	**40**	**60**
Mean yield (t ha^{-1})	21.2	25.6	28.6	31.1	23.4	26.1	28.2	28.7
Adjusted yield (t ha^{-1})	19.1	23.0	25.7	28.0	21.1	23.5	25.4	25.8
Total Revenue (ETB ha^{-1})	95400	115200	128700	139950	105300	117450	126900	129150
Total costs (ETB ha^{-1})	17700	17700	17700	17700	17700	17700	17700	17700
Gross benefit (ETB ha^{-1})	77700	97500	111000	122250	87600	99750	109200	111450
Cost that vary (ETB ha^{-1})	0	1073	2146	3218	0	1073	2146	3219
Net benefit (ETB ha^{-1})	77700	96427	108854	119032	87600	98677	107054	108232
Dominance Analysis								
Marginal cost (ETB ha^{-1})	0	1073	1073	1073	0	1073	1073	1073
Marginal net benefit (ETB ha^{-1})	0	18727	12427	10177	0	11077	8377	1177
Marginal rate of return (%)		1746	1158	949		1033	781	110

Conclusion and Recommendations

Tomato yield has responded to nitrogen and phosphorus application in Megech. The increase in yield in response to nitrogen fertilizers could probably be due to enhanced increase in leaf area which could result in higher photo assimilates. Based on the biological yield and partial budget analysis, maximum and profitable marketable yields were obtained when 150 kg N ha^{-1} and 60 kg P ha^{-1} were applied. Thus, it is recommended that farmers in the Megech irrigation command area and similar agroecology should apply 150 kg N ha^{-1} and 60 kg P ha^{-1} for maximum and profitable tomato production under irrigation.

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Determination of Irrigation Requirement and Irrigation Schedule of Onion at Ribb and Kobo Irrigation Schemes, Amhara Region

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Abstract
Irrigation scheduling is an essential daily water management practice for small holder farmers who are growing irrigated crops. It is a plan to determine when and how much water to apply for a given crop in order to maintain optimum plant growth. Field experiments were conducted to determine the irrigation water requirement and irrigation scheduling of onion at Ribb in Fogera district and Kobo irrigation schemes of the Amhara region during 2010 and 2011 irrigation seasons. Irrigation requirement and optimal irrigation scheduling for onion was determined using CROPWAT version 8. In the field verification trial, combination of different levels of irrigation depths and irrigation frequencies were selected on the bases of CROPWAT model and local water application experiences of the farmers. Factorial combination of two irrigation intervals (4 and 7 days) and four fixed and one variable irrigation depths were the treatments at Ribb. At Kobo research station, factorial combination of 5, 7, and 9 days irrigation intervals and 23, 30, and 38 mm irrigation depths were used. The treatments were arranged in randomized complete block design with three replications. Bombay red and Adama red onion varieties were planted at Ribb and Kobo.

The results have shown significant difference in marketable and total yield as well as the water use efficiency. At Ribb, independent results show that application of 33 mm irrigation water at 7 days interval gave marketable yield, total yield and water use efficiency of 20.0-34.0 t ha^{-1}, 20.0-35.0 t ha^{-1} and 4.0-7.0 kg m^{-3} respectively. At Kobo, application of 38 mm irrigation water at 7 days interval gave marketable yield, total yield and water use efficiency of 17.0-27.5 t ha^{-1}, 17.0-28.0 t ha^{-1} and 3.2-5.3 kg m^{-3} respectively. Irrigation water requirements of onion were found to be 462 mm and 570 mm corresponding to 14 and 15 irrigations at Ribb and Kobo respectively. Therefore, in order to attain an optimum yield and water use efficiency, at Ribb and Kobo areas onion can be irrigated with 33mm water at 7 days interval and 38 mm water at 7 days interval respectively.

Key words*:* Irrigation scheduling, Onion, Kobo, Ribb

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increased food demand. To maintain self-sufficiency in food supply, one viable option is to raise the production and productivity per unit of land through irrigation. Proper amount and timing of irrigation water applications is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources (Richard et.al 1998).
Onion need frequent irrigation to maintain the soil water demand through out the growing period. Irrigation scheduling highly matters in onion production. This is because onion is extremely sensitive to water stress. Regardless of the type of irrigation system used, both yield and quality can suffer if irrigation is delayed and available soil moisture is allowed to drop too low (Shock et al., 2010). Studies made in Turkey gave clear proof that the bulb and dry matter production of onion were highly dependent on appropriate water supply (Serhat and Cigdem, 2009).

Among the common irrigated vegetables, onion (Allium cepa L.) shares the largest in both area coverage and local consumption in Ethiopia. Particularly, it is the popular vegetable grown under irrigation in most of the traditional and the recent modern irrigation schemes in Amhara region. However, the largest production of onion is not supported with improved water management practices to improve its productivity and bulb quality. There is lack of location specific research results of how much water and when to irrigate onion. Therefore, the objective of the current study was to determine the crop water requirement and irrigation schedule of onion grown under irrigation for specific localities of Kobo and Fogera districts.

Materials and Methods

Description of the Study Areas

The experiments were conducted at Ribb and Kobo irrigation schemes for two years (2010 and 2011). Ribb is located at about 60 kilometres from Bahir Dar to the Northeast direction in Fogera wereda. It is situated at $11^0 58'45''$ N latitude and $37^0 44'55''$ E longitude and at an altitude of 1800m a.s.l. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperatures are 27.3 ^{0}C and 11.3^{0}C respectively. The highest temperature (29.5^{0}C) of the area occurs from February to May. The lowest temperature (9.8^{0}C) occurs in January. The soil type is generally Fluvial in its nature.

Kobo research station is located at about 50 km from Woldia town to the Northeast direction in Kobo district and situated at 12.08^0 N latitude and 39.28^0 E longitude and at an altitude of 1470 m a.s.l. The 15 year mean annual rainfall is about 630 mm and average and maximum daily reference evapotranspiration rate of 5.94 mm and 7.69 mm respectively. The soil type in the experimental site is silty clay loam with FC and PWP of 11.5% and 3.2% on volume basis respectively. The site is characterized by average infiltration rate of 8 mm/hr and pH value of 7.8. Some of the physical and chemical properties of the soils of the experimental field were presented in Table 1.

Table 1. Selected soil properties for the study sites (Ribb and Kobo)

Location	Depth (cm)	pH	EC mmohs/g	% OM	Av.K mg/kg
Kobo	0-30	8.05	0.125	4.25	0.49
	30-60	7.60	0.09	3.65	0.36
Ribb	20	6.02	0.042	3.29	0.52
	40	5.96	0.047	3.12	0.52

Where: EC- electrical conductivity, OM-organic matter, Av.K-available Potassium

Experimental set up

The experiments are conducted in *two phases*.

Phase One: ***Estimation of net irrigation requirements and optimal scheduling***

CROPWAT version 8.0 for Windows was used to generate the crop water requirement and the irrigation schedule for onion in the study areas. Calculations of the crop water requirements and irrigation schedule were carried out taking inputs of climate, soil and crop data. In order to estimate the climatic data (wind speed, sunshine hours, relative humidity, minimum and maximum temperature) LOCCLIM, local climate estimator software (FAO, 1992) was used at Ribb where there is no class A meteorological stations and to estimate missing data at Kobo. The estimator uses real mean values from the nearest neighbouring stations and it interpolates and generates climatic data values for the study site. Assuming 90% and 80 % application efficiency at Ribb and Kobo respectively, the gross water requirement was calculated.

Phase Two: ***Verifying the CROPWAT generated scheduling***

Principally, CropWat outputs generated by default were used to identify irrigation timing of when 100% of readily available moisture occurs and application depth where 100% of readily available moisture status is attained. To verify the CroWat output, field experiments were carried out for two consecutive years at Kobo and Ribb. Rainfall data was recorded and used for daily adjustment of the application depth when there was an occurrence of unpredictable and too much amount of rainfall than the predetermined irrigation depth.

At Ribb, a total of 10 treatments which are a combination of irrigation depth and irrigation interval were selected (Table 2). Based on the model estimate and farmers traditional practice in the area, at Ribb two irrigation intervals, i.e. 4 and 7 days were selected. The amounts of irrigation depths were selected systematically depending on these two intervals and length of onion growing period (LGP). The treatments are composed of four levels of fixed depths at all stages, and one variable depth applied at four growth stages (initial stage, crop development stage, mid-season stage and late season stage). These five water levels were estimated independently for 4 and 7 days irrigation intervals. Fixed application depths were included in the treatment purposely. This is because; they are easily taken by farmers as compared to the variable depths which need frequent adjustment throughout the crop growing season.

At Kobo, initially the optimum CROPWAT generated depth and interval was determined (30 mm and 7 days). A factorial combination of three irrigation intervals (5, 7, and 9 days) and three irrigation depths (23, 30, 38 mm) were used which are based on initial estimated CROPWAT generated depth (CWGD) and plus or minus 25% of the optimum depth (Table 2). The experimental design was RCB with three replications at both Ribb and Kobo.

Table 2. Treatment setup in 2010 and 2011

Ribb			Kobo		
Irrigation Interval (days)	Irrigation Depth (mm)	Seasonal irrigation (mm)	Irrigation Interval (days)	Irrigation Depth (mm)	Seasonal irrigation (mm)
4	17	425	5	30	630
4	20	500	7	30	450
4	24	600	9	30	390
4	27	675	5	23	483
4	20 (initial stage: 20 days) 27 (dev. stage: 30 days) 24 (mid season stage: 30 days) 17 (late season stage: 15 days)	559	7	23	345
7	31	434	9	23	299
7	33	462	5	38	798
7	37.5	525	7	38	570
7	40	560	9	38	494
7	33 (initial stage: 20 days) 37.5 (dev. stage: 30 days) 40 (mid season stage: 30 days) 31 (late season stage: 15 days)	502			

The field experiments were carried out from December to April at Ribb and from February to June at Kobo. The test crop onion, variety Adama red at Kobo and Bombey red at Ribb, was planted on 1.8 m by 2 m plot size at Kobo and 2.4m by 3m at Ribb with 40 cm spacing between furrows, 20cm between plant rows and 10 cm between plants. DAP fertilizer was applied at a rate of 200 kg ha^{-1} at planting and 100 kg Urea ha^{-1} was applied half at planting and the remaining half at 45 days after planting. All the agronomic practices were equally done for each treatment. Agronomic data such as stand count, total bulb yield, marketable yield, bulb diameter, bulb weight, and unmarketable yield were collected. Irrigation water productivity was calculated as the ratio of crop yield (marketable yield) and applied irrigation water.

Results and Discussion

Results at Kobo

As it is presented in Table 3, the ANOVA result shows that treatment and treatment by year interaction effects were significant for most agronomic parameters of onion at Kobo. The ANOVA shows that year variation and its interaction with treatment were significantly different, thus need to discuss separately. Even though the optimum seasonal irrigation water requirement which was estimated by CROPWAT was 450 mm applied in 15 irrigations, the field experiment verified that the irrigation requirement should be increased up to 570 mm in 15 irrigations at Kobo. Though irrigation requirement is location specific, similar study on onion done in Turkey showed that seasonal water requirement ranges from 350 to 450 mm for optimum bulb yield depending on the environmental conditions of each year (Halim and Mehmet, 2001).

Table 3. ANOVA for marketable, unmarketable, total yield and water productivity at Kobo (2010 and 2011)

		Mean Square				
Sources of variation	df	Marketable yield	Total yield	Bulb Weight	Bulb diameter	Water productivity
Yr	1	1.944**	0.934**	2.12**	0.0975**	0.204**
Trt	8	4.125**	1.982**	4.49*	0.2069**	0.433*
Rep(Yr)	4	0.698	0.923	1.07	0.0548	0.210
Yr*Trt	8	5.834*	2.803*	6.35*	0.2926*	0.612**
Error	34	3.516	3.433	7.78	0.3583	0.749

Where: Yr-year, Trt-treatment, Rep.-Replication, df- Degree of freedom and ** highly significant

In 2011, the overall productivity was high as compared to the first year. All agronomic parameters respond significantly to water application depth at different application intervals (Table 4 and 5). Maximum (33.7 t ha^{-1}) and minimum (19.3t ha^{-1}) marketable yields were obtained by applying 38 mm every 5 days and 23 mm every 9 days interval respectively. With respect to the water use efficiency (WUE), except the application of 38 mm every 5 days, all have comparable WUE ranging between 4.3 and 6.5 kg m^{-3}. The highest WUE (6.5 kg m^{-3}) was obtained by applying 23 mm every 9 days and the lowest WUE (4.22 kg m^{-3}) was recorded by applying 38 mm every 5 days interval. The highest bulb weight (72.7 g) was obtained by the application of 38mm every 5 days followed by the application of 38 mm every 7 days (70.0 g). In general, although there is highest yield of onion by applying 38 mm every 5 days, the water productivity was the lowest. Similar study conducted at Melkasa found that 50 mm of water application at 3-6 days interval gave the highest yield with the optimum water use efficiency (Lemma and Hearth, 1992). Therefore, considering the two year results independently an optimum marketable yield of16.8 t ha^{-1} and 27.6 t ha^{-1} as well as water productivity of 3.21 kg m^{-3} and 5.33 kg m^{-3} were obtained by applying 38 mm every 7 days in 2010 and 2011 respectively.

Table 4. Mean values of total bulb yield, marketable yield, bulb diameter, bulb weight and water productivity in 2010 at Kobo

Treatments	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})	Bulb diameter (cm)	Bulb weight (g)	Water productivity (kg/m^3)
30mm,7days	13.3 ^{b}	12.95 ^{bcd}	3.80 ^{bc}	29.60 ^{ab}	3.09 ^{a}
30mm,5days	13.4 ^{ab}	13.05 ^{abc}	3.63 ^{bc}	28.60 ^{ab}	2.13 ^{abc}
30mm,9days	9.14 ^{cd}	8.94 ^{de}	3.50 ^{bc}	21.70 ^{bc}	2.34 ^{ab}
23mm, 7days	6.28 ^{e}	5.97 ^{f}	3.47 ^{cd}	22.13 ^{bc}	1.79 ^{d}
23mm,5days	9.91 ^{cd}	9.74 ^{de}	3.33 ^{cd}	22.87 ^{abc}	2.05 ^{bcd}
23mm,9days	8.55 ^{de}	6.53 ^{ef}	2.87 ^{d}	19.80 ^{c}	2.86 ^{a}
38mm, 7days	16.83 ^{a}	16.79 ^{a}	3.83 ^{b}	25.97 ^{ab}	3.21 ^{a}
38mm,5days	16.02 ^{ab}	15.94 ^{ab}	4.10 ^{a}	33.40 ^{a}	2.01 ^{cd}
38mm,9days	11.33 ^{bc}	11.24 ^{cd}	3.53	22.1 ^{bc}	2.29 ^{ab}
Mean	11.63	11.24	3.56	3.563	2.50
CV (%)	15.1	16.6	16.6	5.8	15.9
LSD (0.05)	3.04	3.23	0.30	0.3595	7.023

Table 5. Mean values of total bulb yield, marketable yield, bulb diameter, bulb weight and water productivity in 2011 at Kobo

Treatments	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})	Bulb diameter (cm)	Bulb weight (g)	Water productivity (kg/m3)
30mm,7days	20.15 ^{bc}	19.9 ^{bc}	5.00 ^{bc}	56.61	4.69
30mm,5days	27.09 ^{ab}	26.78 ^{a}	5.27 ^{ab}	62.18	4.30
30mm,9days	20.26 ^{abc}	20.17 ^{abc}	4.47 ^{c}	46.75	5.20
23mm, 7days	20.69 ^{abc}	20.42 ^{abc}	4.90 ^{bc}	52.05	6.00
23mm,5days	23.92 ^{ab}	23.43 ^{ab}	5.00 ^{bc}	57.35	4.95
23mm,9days	19.44 ^{c}	19.23 ^{c}	5.07 ^{ab}	56.04	6.50
38mm, 7days	27.99 ^{a}	27.52 ^{a}	5.50 ^{ab}	70.07	5.33
38mm,5days	33.66 ^{a}	33.66 ^{a}	5.83 ^{a}	72.73	4.22
38mm,9days	29.12 ^{a}	29.12 ^{a}	5.27 ^{ab}	62.99	5.90
Mean	24.70	24.47	5.14	59.6	5.23
CV (%)	18.3	18.7	6.4	16.4	18.5
LSD (0.05)	7.82	7.90	0.573	ns	ns

Results at Ribb

As can be seen in Table 6, year and year by treatment effect showed significant difference at Ribb. Hence, we can't combine two years data. Generally reduction in the amount of most biological traits (yield and yield related traits) was seen during the second year. This is primarily due to the occurrence of pest (onion thrips) during the irrigation season. Even if the results of the biological parameters are low as compared to the previous year, the trend is more or less similar with the first year.

Table 6. ANOVA for marketable, unmarketable, total yield and water productivity at Ribb (2009/10 and 2010/11)

		Mean Square				
Source	df	Marketable yield (t ha^{-1})	Unmarketable Yield (t ha^{-1})	Total yield (t ha^{-1})	Bulb Weight (g)	Water productivity (kg/m^3)
Yr	1	556.7**	34.7**	869.4**	5360	18.5**
Tret	9	45.4**	2.7**	41.4**	183.3	3.6**
Rep(Yr)	4	2.9	2.1**	2.97	278.2	0.09
Yr*Tret	9	35.01**	3.1**	29.1	284.3	1.53**
Error	36	1.59	0.4	2.07	85.4	0.057

Where: Yr-year, Trt-treatment, Rep – Replication, Df – Degree of freedom, and ** highly significant

The irrigation water requirement of onion at Ribb was found to be 462 mm. As can be clearly seen in Tables 7 and 8, almost all biological parameters respond considerably for irrigation depth at a given irrigation frequency. There was statistically significant difference in mean values of marketable yield. Application of 33 mm of water at 7 days interval brought the highest marketable yield of 33.8 and 19.0 t ha^{-1} in 2009/10 and 2010/11 respectively. The least yield of 19.5 t ha^{-1} in 2009/10 and 14.9 t ha^{-1} in 2010/11 was obtained with the application of 20 mm irrigation depth at 4 days irrigation interval. The unmarketable yield is also statistically significant. The lowest value (0.89 t/ha) was obtained with application of 37.5mm of irrigation water at 7 days interval. Total yield also showed statistically significant difference. The highest total yield (34.9 t/ha) and acceptable unmarketable yield (1.2 t/ha) was recorded with application of 33mm of water at 7 days interval.

Application of 33mm water at 7 days interval gave a better water productivity (7.1 kg/m^3) and 40 mm with 7 days interval brought the least (3.5 kg/m^3). The yield response for water at different water level over years is indicated in Fig. 1.

Table 7. Mean of marketable, total yield and water productivity in 2009/10 at Ribb

Treatments	Marketable yield(t ha^{-1})	Total yield (t ha^{-1})	Water prod. (kg/m^3)	Bulb dia. (mm)	Bulb weight (g)
4D-17mm	24.5[c]	26.6[dc]	5.3[b]	19.1[e]	80.1[d]
4D-20mm	19.5[d]	21.6[e]	3.6[de]	19.4[e]	78.0[d]
4D-24mm	22.2[c]	26.4[dc]	3.6[de]	25.8[dc]	85.1[d]
4D-27mm	27.6 [b]	30.7[b]	3.93[de]	31.1[ba]	101.9[ba]
4D-(20mm, 27mm, 24mm, 17mm)	22.47[c]	24.5[d]	4.0[dc]	27.5[bc]	86.1[bdc]
7D-31mm	17.71[d]	20.8[e]	4.37[c]	31.3[ba]	77.8[d]
7D-33mm	33.8[a]	34.9[a]	7.07[a]	23.0[de]	111.7[a]
7D-37.5mm	24.5[c]	25.5[dc]	4.4[c]	25.0[dc]	85.7[dc]
7D-40mm	22.4[c]	27.6[c]	3.57[e]	34.5[a]	101.6[bac]
7D-(33mm, 37.5mm, 40mm, 31mm)	17.7[d]	19.8[e]	3.7[de]	32.8[a]	92.7[bdc]
Mean	23.2	25.8	4.35	26.9	90.1
CV(%)	5.7	5.8	5.64	9.3	10.4
Lsd (0.05)	2.28	2.56	0.42	0.43	16.1

Table 8. Mean of marketable, total yield and water productivity in 2010/11 at Ribb

Treatments	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})	Water Productivity (kg/m^3)	Bulb diameter (mm)	Bulb weight (g)
4D-17mm	14.6[c]	16.0[e]	3.1[dc]	20.4[c]	77.3
4D-20mm	14.9[c]	16.3[de]	2.73[fe]	20.3[c]	76.9
4D-24mm	19.1[a]	19.8[ba]	3.07[dce]	20.3[c]	68.6
4D-27mm	17.9[ba]	18.6[bdac]	2.6[f]	21.3[bc]	66.8
4D-(20mm, 27mm, 24mm, 17mm)	15.4[c]	16.9[dec]	2.8[dfe]	21.2[bc]	68.6
7D-31mm	19.3[a]	19.6[ba]	4.8[a]	21.1[bc]	68.1
7D-33mm	19.0[a]	20.3[a]	4.0[b]	21.8[bac]	67.8
7D-37.5mm	17.9[ba]	18.6[bdac]	3.2[c]	20.6[c]	67.1
7D-40mm	16.0[bc]	17.5[bdec]	2.5[f]	22.8[ba]	71.5
7D-(33mm, 37.5mm, 40mm, 31mm)	17.5[ba]	18.7[bac]	3.7[b]	23.7[a]	79.0
Mean	17.2	18.2	3.24	21.3	71.2
CV(%)	6.95	7.6	7.2	5.7	12.8
Lsd (0.05)	2.05	2.38	0.399	0.21	ns

Where: 4D-17mm:17mm water applied every 4 days, and so on.

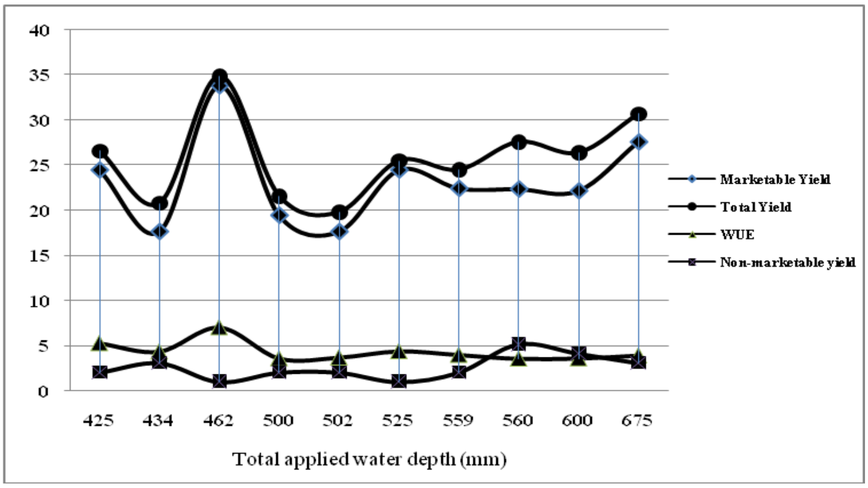

Fig 1. Yield function: marketable yield (MY) - t ha^{-1}, unmarketable yield (UMY) - t ha^{-1}, total yield (TY) - t ha^{-1} and Water productivity (WUE) - kg/m3)

Conclusion and Recommendations

In Ribb area, two irrigations for establishment and a total of 14 (fourteen) irrigations afterwards were applied during the growing season. The irrigation water requirement was found to be 462 mm. Application of 33 mm irrigation depth at 7 days interval gave significantly better marketable yield, total yield, water productivity and bulb weight as compared to the optimum level. At Kobo, the irrigation requirement is a bit higher than the amount determined by CropWat model. It is 25% more than the normal CropWat estimated value for the area. a need to validate CropWat for Kobo condition.

In general, in Fogera area onion can be irrigated with 33mm water at 7 days interval with an optimum yield range between 20 and 34 t ha^{-1} and water productivity between 4 and 7 kg m^{-3}. In case of Kobo, application of 125% of CROPWAT generated depth which is about 38 mm at 7 days interval gave the highest marketable yield between 17.0 and 28.0 t ha^{-1} and water productivity between 3.2 and 5.3 kg m^{-3}. This implies that there is a need to validate the CROPWAT model under local conditions.

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Determination of Crop Water Requirement and Irrigation Schedule of Tomato at Jare, South Wollo

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Abstract
The study area, Jare is endowed with different irrigation schemes and water harvesting ponds as an irrigation water source for the surrounding farmers. However, irrigation amount, frequency, net and gross seasonal irrigation requirements were not known for most vegetable crops which are currently growing in the area. Tomato is the second major vegetable produced in the study area. This study was conducted to determine crop water requirement and irrigation scheduling of tomato at Jare. Estimations of crop water requirements and irrigation scheduling were carried out using CROPWAT version 4 software. The field experiments were conducted during 2010 and 2011, at Jare research station. Combination of different levels of irrigation depths and irrigation frequencies were selected on the bases of CROPWAT and local water application experiences of the farmers. Factorial combination of three irrigation intervals (7, 9 and 11 days) and three irrigation depths (75%, 100% and 125% of cropwat geberated depth) were tested in randomized complete block design with three replications. The irrigation was applied using watering cans. Statistically significant difference ($p<0.05$) was observed among treatments in total yield, marketable yield and water productivity. However, fruit diameter and fruit weight showed non-significant difference. Application of 14mm depth of irrigation (i.e. 75% of cropwat generated depth) at 11 days interval gave the highest total yield, marketable yield and water productivity of 63.28 t ha^{-1}, 55.73 t ha^{-1} and 6.18 kg m^{-3} respectively. About 70 mm irrigation water can be saved. Hence, 14mm irrigation depth at 11 days irrigation interval with a total seasonal irrigation requirement of 168 mm is recommended for Jare and areas having similar agro ecology.

Key words: Water productivity, Yield, Irrigation interval, Irrigation depth, Jare

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increased food demand. To maintain self-sufficiency in food supply, one viable option is to raise the unit yield. A favorable method for raising yield per unit is through proper utilization of irrigation water resources and by increasing water productivity per unit of land and water.

Efficient irrigation water utilization techniques can be realized by using irrigation scheduling. Irrigation scheduling is planning when and how much water to apply in order to maintain healthy plant growth during the crop growing season. It is an essential daily management practice for farm managers who are growing irrigated crops. The ultimate economic and environmental consequence of poorly managed irrigation is the destruction of an area's productive base because application of too little water is an obvious waste as it fails to produce the desired benefit and excessive flooding of the land is still more harmful as it tends to saturate the soil for too long, inhibit aeration, leach nutrients, induce greater evaporation and salinity, and ultimately raise the water table to a level that suppress normal root and microbial activity and that can only be drained and leached at great expense (Daniel, H. , 1997). The issue of efficient use of water and bringing more area under irrigation through available water resources can be achieved by introducing advanced methods of irrigation and improved water management practices (Zaman et al., 2001).

Based on preliminary assessments and survey results tomato is a second major irrigable crop in the study area, Tehuledere woreda. Yet, frequency of irrigation and amount of application per irrigation, seasonal net irrigation requirement and gross irrigation requirements were not determined for tomato and most vegetable crops in the study area. Therefore, information on irrigation water management is an urgent need to improve the existing irrigation production condition. Using climatic data is one of the quickest and fairly reliable means for the determination of when and how much to irrigate. Therefore, this experiment was conducted with the objective of estimating water requirement, net irrigation requirements and irrigation schedule of tomato grown under irrigated conditions in Tehuledere Woreda, Jare.

Materials and Methods

Description of the Study Area

The experiment was conducted during 2010 and 2011 at Jare sub center in South Wollo zone, Tehuledere woreda. Geographically the area lies at 11^{o}21'N latitude, 39^{o}38'E longitude and at an altitude of 1680m above sea level. The mean effective rainfall is around 231.5mm in the irrigation period and average annual temperature ranges from 12.20^{0}c to 26.70^{o}c. The soil is texturally clay loam and has pH of 6.8. Average daily evaporation amount is around 3.98 mm/day. The district is endowed with different irrigation schemes and water harvesting ponds, which can be potentially used to bring large amounts of crop land under irrigation. In most of the irrigation schemes, both in traditional and modern schemes, there is poor irrigation water management practices.

Methods

The test crop tomato (Roma VF variety) was selected based on farming system survey reports done on major irrigation schemes found in South Wollo zone. Local climate estimator called New- LocClim software was used for the estimation of meteorological data based on neighbouring metreological stations since there is no class A meteorological station in the study area.

Calculations of the crop water requirements and irrigation schedule were carried out by using CropWat version 4 software using climatic, crop and soil data. First, crop water requirement was determined by inserting crop data and climatic data. Irrigation amount and schedules were determined by using soil data **(**total available moisture (TMA), maximum infiltration rate (8mm/hr), maximum rooting depth (70cm) and initial soil moisture depletion. Irrigation scheduling criteria were set based on the allowable depletion which enables the calculation of the readily available soil moisture content in the root zone (RAM). Prior to planting all plots were irrigated with equal amount of water up to the field capacity to ensure the survival of transplanted tomato seedlings.

The experiment was conducted in randomized complete block design with three replications. Experimental plot size was 3m*3m and the spacing between plants, rows, plots and blocks were 35cm, 75cm, 1m and 1.5m, respectively. Urea was split applied at a rate of 100 kg/ha of which half at planting and remaining half after 45 days of planting and 50 kg/ha DAP was applied at planting. During the two experimental years, planting was carried on similar dates. Harvesting of tomato fruit made four times in the growing season. Factorial combination of three irrigation depths and three irrigation intervals were tested.

Table1. Experimental treatments used at Jare in 2010 and 2011

Treatments	Net irrigation depth (mm)	Seasonal irrigation requirement (mm)
75% of CWGD at 11 days interval	14	168
75% of CWGD at 9 days interval	14	196
75% of CWGD at 7 days interval	14	266
CWGD at 11 days interval	19	228
CWGD at 9 days interval	19	266
CWGD at 7 days interval	19	361
125 % of CWGD at 11 days interval	24	286
125 % of CWGD at 9 days interval	24	336
125 %of CWGD at 7 days interval	24	456

CWGD-cropwat generated depth

Irrigation water is applied using watering cans and its irrigation application efficiency was estimated to be 80%. Irrigation water use efficiency is generally defined as crop yield per water used to produce the yield (Viets, 1962; Howell, 1996). Thus, IWUE was calculated as fresh weight (kg) obtained per volume of irrigation water applied (m^3).

$$\frac{Yield}{Water\ applied} = IWUE$$

IWUE is an important factor when considering irrigation systems and water management, and probably will become more important as access to water becomes more limited (Shdeed, 2001). For statistical analysis GenStat 9.1 software was used. In addition, Duncan's multiple mean tests were used to compare treatment means.

Results and Discussion

Even though there was variability in measured parameters over years, the general trend is more or less similar in both years. Amount of effective rainfall estimated by the model was 231.2mm but the actual effective rain fall occurred in the 1st and 2nd year varied from 110mm to 180mm. This implies that the net irrigation depth actually applied during the experimental period was likely underestimated. Moreover, the occurrence of varied rainfall during the first and second year significantly affected the yield and yield components of tomato.

As can be seen in tab1e 2, treatments and treatments by year interaction effects were significant. In 2010, treatment effects were significant ($p<0.05$) in all parameters except for average fruit weight. Maximum and minimum marketable yield of 31.3 t/ha and 24.41t/ha were obtained by applying 24mm irrigation water at 11 days interval and 19mm at 9 days interval, respectively. The highest water productivity value of 4.7 kg/m^3 was obtained by applying 14mm at 7 days interval (Table 3).

Table 2. Mean squares of fruit diameter, fruit weight, marketable yield, total yield and water productivity at Jare in 2010 and 2011

Sources of variation	**df**	**Fruit diameter (cm)**	**Fruit weight (g)**	**Marketable yield (t ha^{-1})**	**Total yield (t ha^{-1})**	**WUE (kg m^{-3})**
Trt	8	0.11ns	51.96ns	116.47**	126.02**	5.42*
Yr	1	109.14**	9348.34**	1909.14**	2357.63**	17.01**
Yr*Tret	8	0.08ns	69.78ns	99.23**	167.94**	4.55*
Error	34	0.10	87.47	4.49	6.03	1.8

* Significant ** Highly significant NS-non significant

In 2011, total and marketable yields were statistically different among the treatments ($p<0.01$). The highest marketable yield of 55.7 t/ha was obtained by applying 14mm irrigation depth at 11 days interval (Table 4). There was no statistically significant difference in fruit diameter and fruit weight. The highest water productivity (6.18 kg/m^3) was recorded by the application of 14mm irrigation depth at 11 days interval. About 60mm irrigation water was saved per one irrigation season. Hence, application of 14mm irrigation depth at 11 days interval (i.e. 75% of CWGD at 11 days interval) can be considered optimal for Jare and similar areas having the same agro-ecology.

Table 3. Effect of irrigation amount and frequency on total yield, marketable yield, water productivity, fruit weight and fruit diameter in 2010

Treatments	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})	Water productivity (kg m^{-3})	Fruit diameter (cm)	Fruit weight (g)
14mm, 7 days	34.92^{bc}	28.59^{abc}	4.695^{a}	3.567^{ab}	35.67
14mm, 9 days	32.75^{bc}	29.37^{abc}	4.217^{ab}	3.5^{ab}	33.67
14mm, 11 days	**36.44^{ab}**	**30.84^{ab}**	**3.66^{b}**	**3.067^{b}**	**32.67**
19mm, 7 days	31.37^{bc}	28.16^{abc}	2.112^{d}	3.5^{ab}	37.33
19mm, 9 days	28.46^{d}	24.41^{c}	2.759^{c}	3.9^{a}	36.67
19mm, 11days	30.48^{bc}	25.85^{bc}	1.856^{de}	3.533^{ab}	36.33
24mm, 7 days	32.84^{bc}	28.36^{abc}	0.987^{f}	3.367^{ab}	37.67
24mm, 9 days	35.69^{ab}	29.68^{abc}	2.775^{c}	3.467^{ab}	38.33
24mm, 11 days	42.43^{a}	31.30^{a}	1.454^{ef}	3.6^{ab}	36.67
Mean	33.93	28.51	2.724	3.500	36.11
CV (%)	6.6	6.1	7.2	4.9	7.2
LSD (0.05)	3.86**	2.99*	0.3410**	0.2956*	NS

The same letters are not significantly different (P <0.05), ** significant (p<0.001) & * significant (p<0.05)

Table 4. Effect of irrigation amount and frequency on total yield, marketable yield, water productivity, fruit weight and fruit diameter in 2011

Treatments	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})	Water productivity (kg m^{-3})	Fruit diameter (cm)	Fruit weight (g)
14mm, 7 days	50.23^{b}	43.15^{b}	3.78	6.39	65.17
14mm, 9 days	49.18^{bc}	42.58^{b}	3.42	6.57	67.90
14mm, 11 days	**63.28^{a}**	**55.73^{a}**	**6.18**	**6.20**	**59.57**
19mm, 7 days	36.35^{e}	30.54^{e}	4.40	6.36	62.90
19mm, 9 days	50.7^{b}	41.58^{bc}	3.84	6.33	64.73
19mm, 11 days	41.87^{d}	33.84^{d}	1.98	6.23	59.97
24mm, 7 days	53.05^{b}	47.07^{a}	5.37	6.49	68.63
24mm, 9 days	46.01^{c}	38.65^{c}	2.73	6.23	48.40
24mm, 11 days	33.62^{e}	30.44^{e}	2.92	6.29	64.57
Mean	47.15	40.4	3.85	6.34	62.4
CV (%)	4.8	4.2	3.85	6.1	21
LSD (0.05)	3.93**	2.94**	NS	NS	NS

Conclusion and Recommendations

Even though tomato is a medium moisture stress tolerant vegetable crop, the result of the study showed that application of 14mm irrigation depth in 11 days irrigation interval brought good result relative to other irrigation regimes. The rainfall distribution in the study area is a bimodal and there was around 231.5 mm effective rainfall during the irrigation season. The seasonal irrigation water was 168mm irrigation water. About 400mm total crop water requirement of tomato for the growing length of 125 days is estimated. Hence, application of 75% of Cropwat generated depth (14mm) at 11 days irrigation interval with a total (seasonal irrigation requirement of 168mm) can be recommended for Jare and areas with similar agro ecology. Moreover, due to effects of climate change the rainfall distribution in the area is becoming unpredictable from time to time.

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Yield Response of Mung Bean to Deficit Irrigation in North Wollo

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Abstract
Deficit irrigation is becoming an important strategy to optimize agricultural water use in arid and semiarid regions. The regulated deficit irrigation experiment was conducted on mung bean, one of the newly introduced and promising crops to the mandate area at Lalibella, North Wello in 2010/2011 irrigation season. Furrow irrigation method was used to apply water. There were eight treatments: independent application of 25% ET_c at first, second, third and forth crop growth stages (that is one period stresses); application of 25% ET_c, 50% ET_c, 75% ET_c and 100% ET_c throughout the growth stages. The treatments were arranged in Randomized Complete Block Design. It was found that application of 25% ET_c, irrigation water independently a first, second and forth crop growth stages and 75% ET_c throughout the growth stages were statistically non significant in terms of yield compared to full irrigation application (100% ET_c). While application of 25% ET_c at third growth stage provided significant yield difference compared to 100% ET_c application. The lowest (492 kg ha^{-1}) and the highest (1366 kg ha^{-1}) grain yield were obtained by applying 25% ET_c and 100% ET_c irrigation application throughout the growth stages, respectively. Water use efficiency was improved by 6-23% using deficit irrigation application. The lowest and the highest water use efficiency was found at deficit irrigation application of 25% ET_c in the third growth stage and 50% ET_c throughout the growth stages, respectively. The result indicated that crop productivity can be optimized through application of deficit irrigation considering the different growth stages of the crop. Therefore, farmers who are cultivating mung bean under irrigation condition are advised to practice irrigation application of 25% ET_c (75% deficit) either at initial, development and late growth stages in one period stress or 75% ETc (25% deficit) throughout the growth stages.

Key words: Growth stage, Deficit irrigation, Water use efficiency, Mung bean, Ethiopia

Introduction

Increasing global demand for food and other agricultural products call for urgent measure to increase agricultural production. As the pressure on land increases, more and more marginal areas are being used for agriculture. And much of this land is located in arid and semi-arid belts where rainfall is erratic. Irrigated agriculture makes a major contribution to this pressure on land and drought risk. Increasing water productivity through effective development (adaptation) of genotypes and development of new water management technologies in arid and semi-arid regions for better utilization of the limited water resource have paramount importance (Montazar, 2009). One of the option regulated deficit irrigation is relatively inexpensive and easy to implement (Webber *et al*., 2006). Under conditions of water scarcity, deficit irrigation can lead greater water use efficiency by maximizing yield per unit of water used. The improvement of on farm irrigation systems and the introduction of low cost, water saving irrigation technologies are identified as key and attainable components for reducing agriculture's water demand (Horst *et al*., 2005).

According to Geerts and Raes (2009), review of selected research works around the world confirms that deficit irrigation successfully increased water productivity for various crops. For instance, Zwart and Bastiaanssen (2004) reviewed measured crop water productivity for several crops around the world and concluded that the crop water productivity could be significantly increased if irrigation was reduced and crop water deficit was intentionally induced. Oweis and Hachum (2001) demonstrated that, the higher level of crop cycle control and the lower sensitivity to climate resulting from deficit irrigation, sowing dates can be staggered, thus reducing peak supply by 20%. In this way, irrigation level water productivity is increased through managing planting date.

Mung bean is one of the most important short season grain legumes in the conventional farming system of tropical and temperate regions. The crop is known to perform well under condition of low soil moisture and have short life cycle to be used for crop intensification, and it is widely practiced for maximizing water use efficiency (Sadeghipour, 2008). According to Webber *et al*. (2008), regulated deficit irrigation reduced the crop consumptive water use for mung bean. Mung bean had shown greater potential to reduce its water use and maintain yield levels and increase water use efficiency. In mung bean cultivation post flowering and pod filling stages are most sensitive to water stress (Uperty and Bhatia, 1989). Thus, irrigation is critical during pod filling and flowering stages for mung.

Understanding the yield response factor of mung bean with deficit irrigation at different growth stages and throughout the growing season is important for optimal scheduling of the limited water supply and for better crop management practice related to soil moisture. The objective of the study was thus to identify optimum irrigation water management strategies using deficit irrigation and identify the yield reductions of mung bean under different water stress regimes at different stages and throughout the growth stages.

Materials and Methods

Descriptions of the Study Areas

The field experiment was conducted at Lalibela in North Wello, one of the experimental sites of Sekota Dry land Agricultural Research Center during 2010/11 dry season, where an irrigation scheme was available. The site is located at 12°02'N and 39°03'E and, 2050 m.a.s.l. The mean annual rainfall of the area is 635 mm but very erratic and mean annual reference evapotranspiration of approximately 1481 mm. The mean annual minimum and maximum temperature vary between 11.4 °C to 13.7 °C and 23.8 °C to 25 °C, respectively. The soil is well drained, dark brown in color, and very shallow in depth and clay loam in texture. The soil field capacity and permanent wilting point is 24.32% and 13.86% by volume which gives a soil water holding capacity of 104.2 mm with 1.39 gcm^{-1} bulk density.

Experimental setup

The field experiment was set on a field plot where regulated flow of water is possible. Every experimental unit had a metal sheet at the head for dividing water equally to every (eight) furrows of experimental plot. The irrigation water was pumped from a canal supplied from Medagie River and stored in barrel of known volume and then measured amount of water was applied to the experimental plots (through furrows) using watering cans.

The experiment was made in a randomly complete block design with four replications. A spacing of 1.5 m and 1 m was used between blocks and between plots respectively. Within each block, eight deficit irrigation applications (Table 1) were randomly distributed. Then each experimental unit was prepared in such a way that each of them consisted of eight furrows and seven ridges with furrow length of 5 m. Mung bean (N_{26}

variety) was planted at 10 cm spacing between plants and 30 cm spacing between rows on a 2.4 m x 5 m plots. DAP fertilizer was applied at the rate of 100 kg/ at planting. Frequent weeding was done manually when there was an invasion of weeds.

Table 1. Description of irrigation treatments setup used for deficit irrigation of Mung bean at Lalibela during 2010/2011

No.	Treatments.	Growth Stage				
		P1	P2	P3	P4	
1.	T1 (1111)	1	1	1	1	Normal irrigation
2.	T2 (0000)	0	0	0	0	All stress
	One period stress					
3.	T3 (0111)	0	1	1	1	Stress at P1
4.	T4 (1011)	1	0	1	1	Stress at P2
5.	T5 (1101)	1	1	0	1	Stress at P3
6.	T6 (1110)	1	1	1	0	Stress at P4
	Partial stress throughout the growing season					
7.	T7 (50%)	50 %	50 %	50 %	50 %	
8.	T8 (25%)	25 %	25 %	25 %	25 %	

Note: 1= Normal watering- watering 100 % of ETc, 0= Stress (75% deficit) indicates stressed - watering only 25% of ETc , 50 % = 50% Deficit - watering 50% of ETc, 25% = 25% Deficit - watering 75% of ETc, and P1, P2, P3 and P4 are initial, developmental, mid and late season growth stages.

The depth of water applied for eight treatments and its irrigation period is presented in Table 3. The depth of total irrigation water applied was the sum of pre irrigation (25 mm) and all subsequent scheduled amount of irrigation calculated from the CROPWAT model. The purpose of pre irrigation was to encourage a full and even plant stands.

Table 2. Reference evapotranspiration, crop and irrigation water requirement of mung bean at seven days irrigation interval for Lalibela during 2010/2011

Date	ET_o (mm/peroid)	Crop Kc	CWR (ET_c) (mm/peroid)	Net Irr. Req. (mm/peroid)
15 Novmber	3.83	0.50	13.6	13.6
21 Novmber	22.98	0.50	16.7	16.7
28 Novmber	26.81	0.50	19.3	19.3
5 December	26.32	0.63	21.6	21.6
12 December	26.11	0.79	24.2	24.2
19 December	26.11	1.00	28.0	28.0
26 December	26.11	1.05	29.7	29.7
2 January	26.53	1.05	27.4	27.4
9 January	27.58	1.05	27.9	27.9
16 January	27.58	1.05	28.3	28.3
23 January	27.58	1.05	28.0	28.0
30 January	27.58	0.81	27.3	27.3
6 Febrauary	31.92	0.56	21.2	21.2
17 Febrauary	31.92	0.35	17.5	17.5
Total	358.96		330.7	330.7

ET_o = Reference evapotranspiration, K_c = Crop coffiecient , CWR = Crop water requirment

Determination of Crop and Irrigation Water Requirement

The FAO Penman–Monteith equation (Allen *et al*., 1998) was used to calculate the reference evapotranspiration ET_o using the CROPWAT Program (Table 2). Crop water requirement (ET_c) over the growing season was determined from ET_o using crop coefficient Kc according to the following equation:

$$ETc = K_c \times ET_o \quad (1)$$

Where ET_c is the crop water requirement, K_c is the crop coefficient and ET_o is the reference evapotranspiration. Since there was no rainfall during the experimental period, net irrigation requirement was taken to be equal to ET_c. Irrigation water use efficiency (IWUE) was calculated as:

$$IWUE = \frac{Y}{IW} \quad \text{(Ibragimov } et\ al\text{., 2007)} \quad (2)$$

Where Y is the crop yield (kg/ha) and IW is total irrigation water applied (m^3ha^{-1}).

The yield response factor for deficit irrigation application was determined following Doorenbos and Kassam (1979) equation.

$$1-\frac{Y_a}{Y_m} = K_y(1-\frac{ET_a}{ET_m}) \quad (3)$$

Where: Y_a and Y_m are actual and maximum crop yields, corresponding to and actual (ET_a) and maximum (ET_m) evapotranspiration, respectively; Ky is yield response factor.

Table 3. Total water depth applied for the eight treatments (mm) at Lalibela 2010/2011

Date	Interval (days)	Treatments							
		T1	T2	T3	T4	T5	T6	T7	T8
13 Novmber	**	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
15 Novmber	0	11.6	2.9	2.9	11.6	11.6	11.6	5.8	8.7
21 Novmber	6	15.6	3.9	3.9	15.6	15.6	15.6	7.8	11.7
28 Novmber	7	18.2	4.6	4.6	18.2	18.2	18.2	9.1	13.7
5 December	7	20.7	5.2	20.7	5.2	20.7	20.7	10.4	15.5
12 December	7	23.2	5.8	23.2	6.8	23.2	23.2	11.6	17.4
19 December	7	27.1	6.8	27.1	7.3	27.1	27.1	13.6	20.3
26 December	7	29.2	7.3	29.2	14.0	7.3	29.2	14.6	21.9
2 January	7	27.4	6.9	27.4	27.4	6.9	27.4	13.7	20.6
9 January	7	27.9	7.0	27.9	27.9	7.0	27.9	14.0	20.9
16 January	7	28.3	7.1	28.3	28.3	7.1	28.3	14.2	21.2
23 January	7	28.0	7.0	28.0	28.0	28.0	7.0	14.0	21.0
30 January	7	27.3	6.8	27.3	27.3	27.3	6.8	13.7	20.5
6 Febrauary	7	21.2	5.3	21.2	21.2	21.2	5.3	10.6	15.9
Total	95	330.7	101.6	296.7	263.8	246.2	273.3	178.1	254.3

*Note: ** = pre-irrigation two days before planting*

The agronomic data were collected from the middle 5 rows of each plot. Plant phenological stages such as days to flowering and maturity, thousand seed weight (g) and grain yield (kg/ha) were recorded on plot bases. Parameters such as number of seeds per pod and number of pods per plant were recorded on plant bases.

Statistical Analysis

Analysis of variance and treatment mean comparisons for the different measured parameters were carried out using SAS(R) software window 9.0. Mean separation for the recorded plant parameters were made using Least Significance Difference Test (at 0.05siginificance level). Model efficiency developed by Nash and Sutcliffe (1970) was used to evaluate the performance of models. It was calculated as:

$$ME = \frac{\sum_{i=1}^{n}(Ym - Ya)^2 - \sum_{i=1}^{n}(Yp - Ym)^2}{\sum_{i=1}^{n}(Ym - Ya)^2}$$

(4)

Where: ME is model efficiency (%), Y_m measured value of yield reduction (%), Yp is CROPWAT predicted value of yield reduction (%) and Ya is the average value of measured yield reduction (%) and n is 8^{th} number of treatments tested.

Results and Discussion

Crop and Irrigation Water Requirement

Reference evapotranspiration (ET_o) and crop evapotranspiration of mung bean, as estimated by the FAO Penman–Monteith equation, is presented in Table 2. Crop water requirements were calculated by multiplying the reference evapotranspiration values with the mung bean crop coefficients given by Allen *et al*. (1998), 0.5 for the initial stage, $0.5 < K_c < 1.05$ for the development stage, 1.05 for the mid-season stage and $0.35 < K_c < 1.05$ for the late season stage. Based on the calculation the reference evaporation, crop water requirement and irrigation requirement is for mung bean in Lalibela area 359 mm, 330.7 mm and 330.7 mm respectively.

Yield Components of Mung bean

The phonological stages and yield component results such as number of days from planting to 50% flowering and days to maturity are presented in Table 4. Mung bean supplied with only 25% ET_c, (75% deficit water from the full) application throughout the growth stages gave shorter number of days to reach flowering while full irrigation application gave longest days to flowering from planting. Flowering was shortened by about a week with an application of 75% deficit water as compared to full irrigation water application. This finding is in line with those obtained by Ahmed *et al*. (2008), flowering and maturity for faba bean; plants try to escape from unfavorable stress conditions by ending their life few days earlier than those under normal soil moisture conditions.

Table 4. Phenological stages and yield components of mung bean as influenced by different deficit irrigation applications at Lalibela during 2010/2011

Treatments	Days to flowering **	Days to maturity **	Number of pods per plant**	Number of seeds per pod**	1000 Seed Weight (g) *
T1(1111)	51.75^{a}	89.75^{a}	12.01^{a}	12.26^{a}	53.88^{a}
T2 (0000)	44.50^{e}	81.75^{d}	5.88^{e}	7.70^{d}	46.38^{c}
T3 (0111)	49.50^{bcd}	88.75^{ab}	11.76^{ab}	11.99^{a}	51.88^{ab}
T4 (1011)	49.25^{dc}	86.75^{b}	11.04^{bc}	11.23^{b}	51.50^{ab}
T5 (1101)	50.00^{bc}	88.75^{ab}	10.65^{c}	10.18^{c}	51.38^{ab}
T6 (1110)	51.00^{ab}	89.50^{a}	11.29^{abc}	10.32^{c}	50.63^{ab}
T7 (50%)	48.00^{d}	84.50^{c}	9.20^{d}	9.93^{c}	48.50^{bc}
T8 (25%)	50.50^{ab}	88.25^{ab}	11.56^{abc}	12.05^{a}	52.75^{a}
Grand Mean	49.31	87.25	10.42	10.71	50.86
LSD (0.05)	1.52	2.11	0.966	0.459	3.816
CV (%)	2.09	1.64	6.30	2.92	5.10

*LSD- Least Significant Difference and CV- Coefficient of Variation **Means followed by different superscripts are statistically different*

The result for average number of pods per plant, seeds per pod and thousand seed weight for each irrigation application revealed that these parameters were influenced by variations in levels of irrigation water application. The number of pods per plant and seeds per pod have shown highly significant difference among the deficit irrigation applications ($p<0.01$). There was no significance difference in number of pods per plant among deficit irrigations 75% ET_c at first and last growth stages 25% deficit at all stages and the full application. Whereas the number of pods per plant obtained at 75%

at all stages, 75% deficit application at second and third stages and 50% deficit application deficit at all stages were significantly different with the full application. This indicate that the development and mid season growth stages are more sensitive to water stress than other growth stages. This is in line with research findings of Sadeghipour (2008) which reported that moisture stress at flowering and pod formation stage resulted in minimum number of pods per plant, number of seeds per pod and 1000 seed weight of mung bean. Simsek *et al*. (2011) also reported that water stress during reproductive stage in common bean increased the number of aborted flowers and reduced the number of pods per plant.

Yield and Water Use Efficiency of Mung bean

The mean grain yield and irrigation water use efficiency results are presented in Table 5. A significant difference in grain yield among the deficit irrigation application was observed. Water stress at third growth stage (mid season) that is at flowering and reproductive stage had produced lower yield (24.94% yield reduction) as compared to full irrigation. Deficit application of 75% during initial, development and late season stages resulted in respective yield reduction of 4.54%, 7.80% and 5.93% as compared to the full irrigation application. Through imposing deficit at early growth stages the crop gets enough time to recover from the stress during the rest of the growing seasons to produce reasonable yield. Comparable grain yield reduction (non significance difference) was obtained by applying 75% deficit water at first, second and last growth stages.

This finding provides an indication of the growth stage when it is worth to save water with little or optimal yield reduction. Stress during mid season stage has more severe impact on yield. This is in line with other findings which indicate that water stress that occurs at reproductive stage specially flowering and pod formation stages, affected grain yield more severely (De Costaa et *al*., 1999; Simsek *et al.*, 2011).

Table 5. Effects of deficit irrigation levels on grain yield, irrigation water use efficiency and the amount of saved water at Lalibela during 2010/2011

Treatment	Average yield (kg/ha)**	IWUE (kg/m^3)*	Water saved(m^3/ha)
T1(1111)	1366.25^a	0.248^c	-
T2 (0000)	492.00^c	0.290^{ab}	2291
T3 (0111)	1304.25^a	0.264^{bc}	340
T4 (1011)	1259.75^a	0.287^{abc}	669
T5 (1101)	1025.50^b	0.250^c	845
T6 (1110)	1285.25^a	0.282^{abc}	574
T7 (50%)	902.50^b	0.304^a	1526
T8 (25%)	1271.75^a	0.300^{ab}	764
Grand Mean	1113.41	0.278	-
LSD (0.05)	149.72	0.040	-
CV (%)	9.14	9.65	-

*Where: IWUE- irrigation water use efficiency LSD- Least Significant Difference and CV- Coefficient of Variation *, **=significant at 5 and 1% level. Means followed by different superscripts are statistically different*

The irrigation water use efficiency of mung bean varied from 0.248 kg m^{-3} to 0.304 kg m^{-3}. The probable reason why water use efficiency decreased under optimal irrigation water application may attribute to water loss through evaporation reduced in deficit irrigation treatments than full irrigation application. Maximum mean IWUE was obtained when 50% of the crop water requirement was applied throughout the growth stages. Plots which received three-fourth of the full irrigation water throughout the growth stages resulted in the second largest IWUE. This result is suported with the findings of Onder *et al.* (2009). Webber *et al*. (2008) which reported that mung bean had greater potential to increase water use efficiency under deficit irrigation. According to Geerts and Raes (2009), in their selected research review works around the world confirm that deficit irrigation increase water productivity for various crops.

The second lowest mean value of IWUE (0.250 kg m^{-3}) was found when 75% deficit was imposed at mid season stage. Thomas *et al*. (2004) reported that the grain yield of mung bean is severely affected by soil moisture stress at flowering and pod filling stages and then ultimately the water use efficiency. Therefore, application of adequate water during flowering and pod development was the most significant factor in bean irrigation (Simsek *et al*., 2011). This has important economical implications because it means that under water limited conditions, mung bean fully irrigated around flowering and pod filling stages can produce more yields per unit of irrigation water applied.

Figure 1 shows that there is a linear relationship between the amount of water applied and the grain yield. The coefficient of determination (R^2) indicates that more than 92.6% of the yield variation is coming from the variability in irrigation water application.

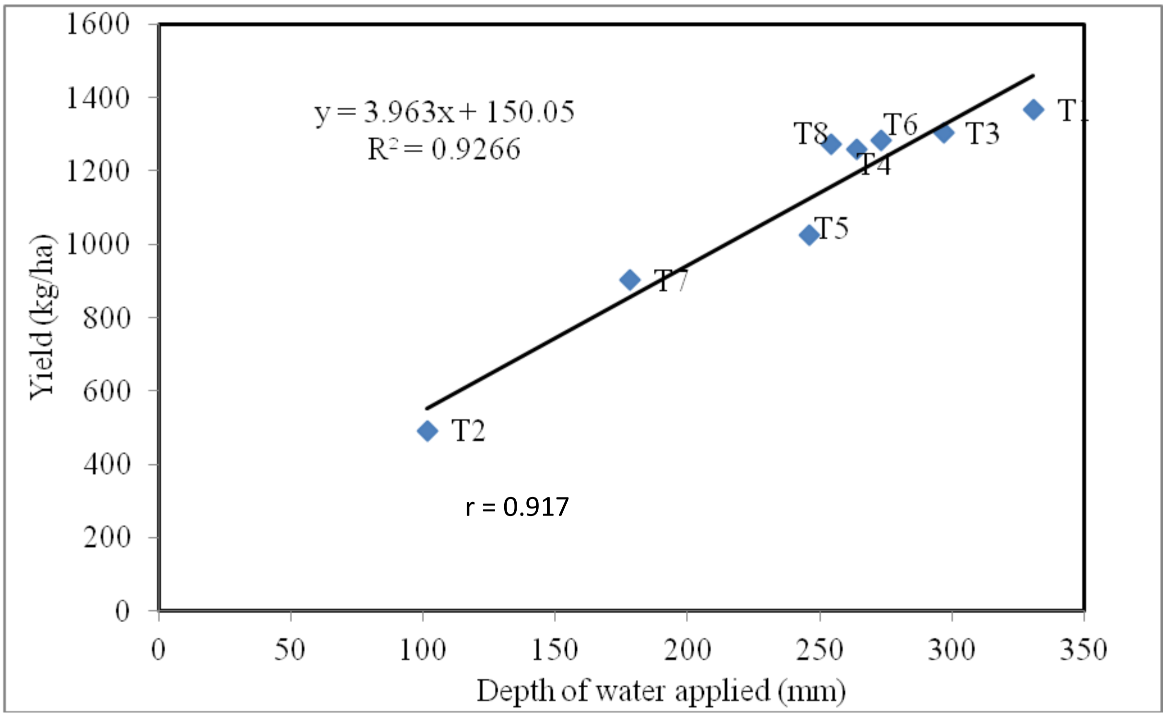

Figure 1. Yield - water relationships of mung bean at Lalibela during 2010/2011 G.C. The relationship can be expressed by linear equation as: Grain yield (kg/ha) = 3.96(depth of irrigation (mm)) + 150

Sadeghipour (2008) also reported that water stress reduced mung bean yield and yield component regardless of whether the stress had imposed when the plant was in vegetative or reproductive stage. The slope of the regression line which indicates the increment of grain yield for a unit increment of irrigation water was near to four fold. Similarly the calculated Modeling efficiency is 93.2% which implies the model was satisfactorily predicting the yield reduction as a result of stress imposition. The yield reductions calculated by CROPWAT model were comparable with the measured yield reduction at field conditions.

From Figure 2, the yield response factor for each of the growth stages was less than unity which implies the relative yield reduction was less than the relative evapotranspiration deficit. The highest K_y value (0.98) was obtained in the mid season stage. Thus, irrigation was critical during mid season stage for mung bean. This shows that trying to improve crop water production by adopting deficit irrigation without due consideration of its timing might not be beneficial. The overall production of mung bean will be increased by extending the area under irrigation without meeting full water requirement. Mung bean had shown greater potential to reduce its water use and maintained yield levels and increased water use efficiency under soil moisture deficit (Sadeghipour, 2008).

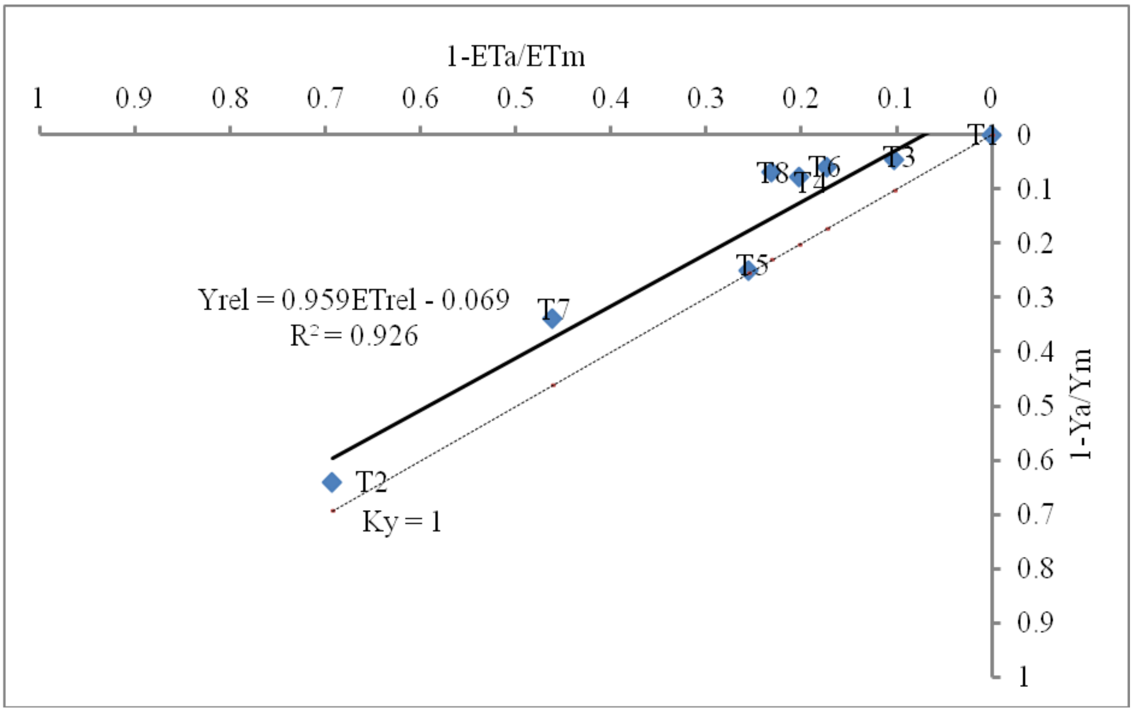

Figure 2. The relationship between relative yield reduction and relative seasonal water deficit for mung bean at Lalibela during 2010/2011 G.C where: Yrel is relative yield reduction and ETrel is relative evapotranspiration deficit.

Conclusion and Recommendations

The field experiment has revealed that when water stress is imposed at initial, development or late season growth stages high yield of mung bean could be easily sustained provided that adequate watering conditions take place during the rest of the growing season. Then more positive results could be obtained from deficit irrigation by imposing 75% deficit either at the initial, development or late season growth stages or the 25% deficit could be distributed at all growth stages. The most critical period for mung bean irrigation is the mid season growth stage. Imposing water stress during the mid season growth stage is found to produce lower yield indicating the severe effect of water stress during flowering and pod filling stage on grain yield. This shows that trying to improve crop water productivity by adopting deficit irrigation without due consideration of its timing might not be beneficial. Water use efficiency increased with decreasing the amount of water applied. However, water stress inversely affect water use efficiency when the deficit was imposed at mid season growth stage via severely affecting the grain yield. As finding of this research suggest, farmers are advised to practice full irrigation water application when water is not a limiting factor. However, when irrigation water is a limiting factor farmers are advised to practice 75% deficit irrigation either at the initial, development, late season stages or 25% deficit application throughout the growth stages.

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PART 3

EFFICIENCY AND PRODUCTIVITY OF WATER HARVESTING PONDS

Comparative Analysis of Lining Materials for Reduction of Seepage in Water Harvesting Structures at Adet, West Gojam

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Abstract
Rain Water harvesting is the artificial collection, storage and use of runoff or rain water. The water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level. This experiment was designed to explore different lining materials that can improve storage efficiency of small household rainwater harvesting ponds. The experiment was conducted at Adet agricultural research center on two sets with luvisols and Vertisols, the two dominant soil types in the research farm between 2009 and 2011. On Luvisols four types of pond lining techniques were tested (clay lining (15cm thick), soil + cement lining (1:5 ratio), Table Salt (at a rate of 2kg/m^2) lining, and Geo-membrane). But on the Vertisols only two lining materials were taken (i.e. Clay lining (15cm thick), salt lining (at a rate of 2kg/m^2)). In both cases unlined pond was included as a control. Required data on daily variation of storage depth and water temperature was continuously monitored throughout the experimental period.

Based on the result of analysis, the variation in storage efficiency was seen only in Luvisols. Application of salt considerably improved storage in these types of soils. But in Vertisols storage efficiency didn't show improvement with application of salt. Regarding the change in temperature, no significant variation was seen between treatments on both types of soils. Geo-membrane was also proved to have not as such significant change in temperature as compared to the other treatments. Furthermore, the cost of labour and salt is by far smaller for salt treated ponds than the other treatments. Application of salt improved storage efficiency of pond from 0.24 to 0.87 on Luvisols. Moreover, the cost of the pond is smaller as compared to other treatments.

Key words: Rain Water harvesting, Lining materials, Seepage

Introduction

Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. A study also indicated that one of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro dams, water harvesting structures, etc. (Awulachew et al. 2005).

Excluding the purely pastoralist areas, more than 90 Woredas' with a total of more than two million households in Ethiopia are drought prone and regularly hit by severe water shortage according to the ministry of agriculture. This seriously threatens the lives of more than 12 million people. But Ethiopia is not the country poor in water. The challenge is keeping and preserving the precious resource when it falls abundantly from the sky and then store and distRibbute it wisely for efficient use when the rains stop (Rami, 2003).

Ethiopia's mean annual rainfall reaches approximately 1090mm. However, 70% of the total arable land receives annual rainfall of less than 750mm, while an estimated 110 billion cubic meters of rainwater annually are lost through surface runoff (Rami, 2003). This is the equivalent to a one meter deep square pond with sides of 330km or a full river ten meters deep , 100 meters wide and hundred and ten thousand kilometers long! The ground water resource is impressive as well, estimated at 4.6 billion cubic meters. Ethiopia's water potential is huge and harnessing it is the challenge facing the government and the people of Ethiopia.

Nevertheless, large-scale dam and irrigation projects have not been widely implemented in Ethiopia as they have often proved to be too expensive and demanding construction and maintenance. Therefore, water harvesting tanks and ponds at the village or household level are proposed as a practical and effective alternative to improve the lives of rural people at little cost and with minimal outside inputs. In theory, household water harvesting can be done mainly through the effort of individual farmer. Use of stored rainwater could supplement natural rainfall and make farming families less vulnerable to drought and therefore less dependent on outside help in hard times (Rami, 2003).

One of the main pillars of the Ethiopian government's food security strategy is the development and implementation of water harvesting schemes mainly in the drought prone and chronically drought affected areas of the country. In Amhara and Tigray a total of approximately 70,000 ponds and tanks were constructed in 2002. Implementers on all levels struggle with a range of problems, many of which originate from the speed and scale on which the water harvesting program is being implemented. Flaws in the design of the structures, insufficient building experience, luck of skilled personnel and shortage of materials were some of the problems. Currently, a very large number of completed thanks simply didn't hold water and are leaking. This of course, doesn't necessarily mean that the concept is wrong. The water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level (Rami, 2003). This work was designed with two objectives: 1) to quantify storage efficiency of each structure 2) to select lining material with reasonable cost and seepage loss.

Materials and Methods

In the year 2009/10 the first set of ponds with four types of pond lining techniques were tested (clay lining (15cm thick), soil + cement lining (1:5 ratio), Table Salt (at a rate of 2kg/m^2), Geo-membrane and Control) were constructed on Luvisols and in 2010/11 the other set of ponds was constructed on black (Vertisols) at Adet research station. Three treatments (i.e. control, clay lined and table salt treated ponds) were tested in the second set. These treatment combinations are selected because, most of them are currently in use for water harvesting in Ethiopia.

Before starting the actual excavation work, the lay out work was done first. Seven square plots of area 3mx3m were marked on the ground using pegs.

Fig. 1. Lay out of pond

Fig. 2. Land leveling

Fig.3. Edge of the pond

From the edge of these squares 0.5m area is marked around each square and leveling work is done only on this part rather than leveling the whole plot area. This area later served as the edge of the pond and as a zero level for the pond. Pond excavation work was then started step by step and layer by layer down to one meter depth. To attain the actual pond side slope of 1:1 (H: V) we followed two types of excavation procedures, refill and cut type.

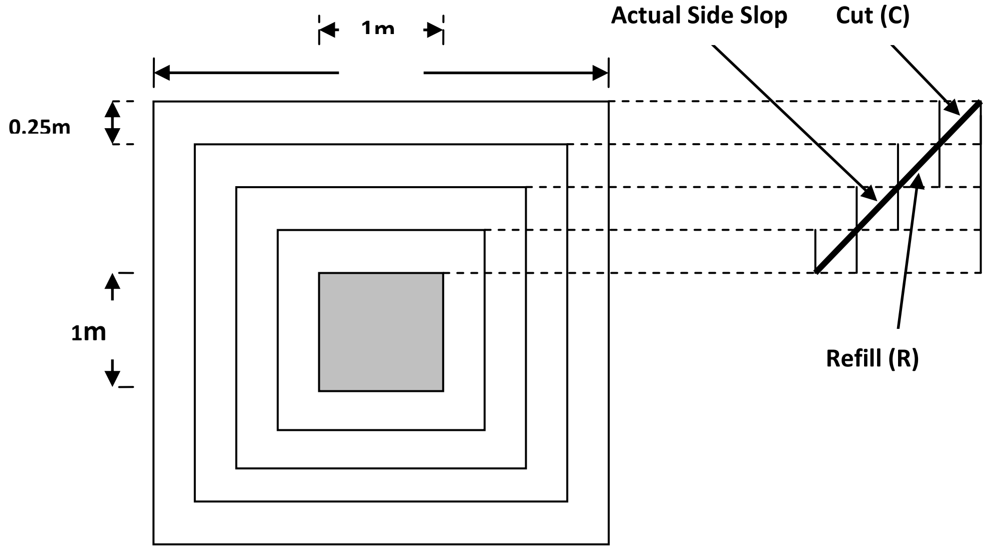

Fig.4. Pond construction technique used at Adet during 2009/10

For the cut type procedure 25cm was measured outside the square area from the edges and marked by pegs at the four corners. The area was enclosed with Nylon rope and the remaining 2.5mx2.5m square area was excavated to a depth of 25cm. Again after maintaining 2.5mx2.5m square and level area, another 25cm is measured inside this square from each edge and 2mx2m square area is delineated. This square plot is again excavated to a depth of 25cm. This procedure is repeated up until a total of 1m depth and 1m X 1m square bottom area is obtained.

Fig.5. Step by step digging procedure

Fig. 6. Clay re-filling technique used

For the fill type ponds also the procedure was the same. The only difference was that at the inception the first square to start working on had a size of 3.5mx3.5m rather than

3mx3m as opposed to the previous condition. In the fill type ponds (i.e. Clay lined pond, Cement+soil filled ponds), the actual side slope 1:1 (H:V) was obtained by systematically filling the aforementioned materials.

For the clay fill pond, clay material (Vertisol) was transported to the area and step by step filling was done starting from the base by compaction. Small amount of water was applied during compaction to moisten and facilitate binding of the soil material. Then the set of stairways were re-filled carefully up until the desired side slope (1:1) and smooth surface was finally maintained.

Fig.7. Actual shape of clay lined pond

Fig. 8. Shape of cement+soil lined pond

For cement +soil filled pond, cement and excavated soil material were mixed in 1:5 ratio. The bottom area of the pond excavated to 15cm depth and re-filling of the subsequent stairs started from the base of the pond.

For the remaining ponds (i.e. Geo-membrane lined pond, Table salt treated pond and Control), side slope was maintained by carefully re-shaping the subsequent stairs step by step. In the geo-membrane lined pond, the pond surface was covered with plastic sheet after smooth 1:1 (H: V) side wall was maintained. The edges of the plastic sheet were buried under soil by digging ditch around the edge of the pond.

Fig.9. Geo-membrane lined pond

Fig.10. Table salt treated pond

For the table salt treated pond, around 11.5kg of table salt was dissolved in water and applied on the pond surface at a rate of 2kg/m^2 during the first application. Again after a week the remaining 11.5 kg was applied.

The control pond is also excavated in the similar fashion by reshaping the subsequent stairs and was left untreated.

Fig. 11. Bare pond (Control)

Fig.12. Final Experimental Setup

Finally, the edge of all the ponds was constructed with stone masonry so as to avoid uncontrolled entry of external runoff into the pond. To monitor the daily water level (depth) in the pond, stationary graduated measuring bar was prepared from iron bar by painting, leveling and putting it into a concrete footing. Totally, five ponds on Luvisols and three ponds on vertisols were constructed and filled with water and the respective data collection process continued accordingly. Finally, daily storage efficiency and Present Effective cost per unit volume, labour and material requirement were calculated for each pond.

1. Daily storage efficiency

The daily storage efficiency (SE) was calculated by making use of the relation indicated below.

$$SE = \frac{Water\ Input - Loss}{Water\ Input} \text{ ------------------------------------- (1)}$$

The storage efficiency of the two sets of soil types (Luvisols and Vertisols) was treated independently.

2. Present Effective cost per unit volume (PEC)

It is defined as:

$$\text{PEC} = \frac{\textit{Cost of Constraction}}{\textit{Storage Volume} * \textit{Storage Efficiency}} \text{ ----------- (2)}$$

Results and Discussions

Required data on daily variation of storage depth and water temperature was continuously collected for two seasons. Data analysis work was done at the end of the season using simple t-test with SAS software. Result of analysis was summarized and presented in tables for each parameter.

1. Daily storage efficiency

a. Luvisol

The results of storage efficiency were subject pair wise comparison using t-test with SAS software. Results of analysis on Luvisols showed (Table 1), existence of significant difference in daily storage efficiency between the control and other treatments.

Table 1. Storage efficiency and temperature of ponds with different lining materials compared at Adet during 2009/10 to 2010/11 on luvisols

No.	Treatment	Storage efficiency	t-test (Prob.)	Temperature Change (^{o} C)	t-test (prob.)
1	Clay	0.29	*	9.2	ns
2	Cement+Soil	0.74	*	8.5	ns
3	Table salt	0.87	**	8.7	ns
4	Geomembrane	0.99	**	9.7	ns
5	Control	0.24		9.1	

*- Significant **- Highly significant ns- Non significant difference

Salt treated treatment showed better storage efficiency next to the geo-membrane lined pond. In this experiment table salt was applied in the soil to create sodium-induced clay dispersion on the soil. The principle works in such a way that dispersed clay particles within the soil solution can clog soil pores when the particles settle out of solution. Additionally, when dispersed particles settle, they form a nearly structure-less cement-like soil depending on the sodium concentration and clay type. This pore plugging and cement-like structure in-turn impedes water flow and water infiltration into the soil (Silva and Uchida, 2000).

On the contrary, analysis of the temperature change showed absence of significant difference between treatments. The change in temperature showed an increasing trend from the month of July to January. Water surface heating in geo-membrane covered ponds is not different from others.

b. Vertisol

As described earlier, only three of the treatments (bare/control, Table salt treated and Clay lined ponds) were taken and tested on Vertisols. Results of analysis proved (Table 2) absence of significant difference both in storage efficiency and change in water temperature between the control and other treatments.

Table 2. Storage efficiency and temperature of ponds with different lining materials compared at Adet during 2009/10 to 2010/11 on Vertisols

No.	Treatment	Storage efficiency	t-test (Prob.)	Temperature Change	t-test (Prob.)
1	Control	0.974		8.4	
2	Table salt	0.976	ns	8.6	ns
3	Clay	0.984	ns	8.2	ns

Present Effective cost per unit volume

The value for the present effective cost varied between 522 birr/m^3 (for Soil + Cement) and 125 birr/m^3 (for salt treated pond). As can be seen from Table 3 salt treated pond resulted into least (125 birr/m^3) present effective cost per unit volume.

Table 3. Present effective cost per unit volume of water for ponds with different lining materials compared at Adet during 2009/10 to 2010/11

Treatment	**Cost (Bir)**	**Storage efficiency**	**Storage Volume(m^3)**	**Present effective cost/volume (bir/ m^3)**
I. Luvisol				
1. Clay lining	540	0.29	3.6	517
2. Soil +cement lining	1390	0.74	3.6	522
5. Table salt treated pond	391	0.87	3.6	**125**
6. Geo-membrane lining	790	0.99	3.6	222
7. Control	315	0.24	3.6	365
II. Vertisol				
1.Control	585	0.974	3.6	167
2. Table salt	750	0.976	3.6	213
3. Clay	915	0.984	3.6	258

Labour and Material Requirement

The total labour and material requirement for each pond (Table 4) was summarized below. The overall cost of construction is also indicated. The labour and material requirement is maximal for Soil + Cement lined pond.

Table 4. Labour and materials used for ponds with different lining materials compared at Adet during 2009/10 to 2010/11

Treatment	**Labour**	**Cement (qt)**	**Geo-membrane (m^2)**	**Sand, m^3**	**Mesh (m^2)**	**Table salt (kg)**	**Cost birr**
I. Luvisol							
1. Clay lining	36		-		-		540
2. Soil +cement lining	26	2.5	-		-		1390
3. Table salt treated pond	23	-	-			23kg	391
4. Geo-membrane lining	26	-	16		-		790
5. Control	21	-	-		-		315
II. Vertisol							
1.Control	39						585
2. Table salt	48					23	750
3. Clay	61						915

Laboratory Experimentation

Equal volumes of disturbed soil samples (Fig. 13) were taken in four buckets from both soil types (Luvisols and Vertisols) and treated with table salt at a rate of 2 kg/m^2 under controlled / laboratory condition.

Fig. 13. Storage characteristics of table salt treated and un-treated soils compared at Adet during 2009/10 to 2010/11

Electrical conductivity of water sample, Texture, exchangeable sodium, calcium and magnesium of the soil were analyzed for each treatment after fifteen days and the results were summarized in the following table. Sodium Adsorption Ratio (SAR) is a widely accepted index for characterizing soil sodicity. When SAR is greater than 13, the soil is called sodic soil. Excess sodium causes poor water movement and poor aeration. ESP is also another index that characterizes soil sodicity. By definition, sodic soil has an ESP greater than 15 (Leticia et al., 2012).

A measure of water salinity that is important for crop yield is Electrical Conductivity (EC). The higher the EC the higher the level of salts in the water and the more difficult it is to grow plants with that water. Increasing salinity affects growth mainly by reducing the plants ability to absorb water (Robert and Richard, 1999).

Table 5: Results of laboratory analysis of stored water and soil samples at Adet during 2009/10 to 2010/11

Parameters	Unit	Luvisol control	Luvisol salt-treated	Vertisol control	Vertisol salt-treated
Clay + Silt	%	98	98	94	98
Silt	%	80	82	78	86
Clay	%	18	16	16	12
Sand	%	2	2	6	2
Texture	Class	heavy clay	heavy clay	heavy clay	heavy clay
Electrical conductivity (EC) of water	micro mhos/cm	36	**231**	44.8	**612**
Ca + Mg	mleq/100g	21.78	25.02	38.97	25.78
Exchangeable Ca	mleq/100g	16.47	7.02	28.08	8.19
Exchangeable Mg	mleq/100g	5.31	18	10.89	17.55
Exchangeable Na	mleq/100g	0.086	2.056	0.19	22.063
Sodium adsorption ratio(SAR) of soil		0.026	**0.581**	0.043	**6.15**
Exchangeable Sodium percentage(ESP) of soil	%	0.4	**7.6**	0.5	**46.2**
NB In clay soils exchangeable sodium percentage of 5 is considered high.					
Low salinity water 0< EC <=250, Medium salinity water 250< EC <=750, High salinity water 750< EC <=2250, Very high saline water 2250< EC <=5000 micro mhos/cm					

Electrical conductivity (EC) of water for table salt treated Luvisols (231 micro Siemens) is low implying low salinity level (Table 5). But samples taken from Vertisols (612 micro Siemens) show medium salinity. This implies that the stored water can safely be used for irrigation. Moreover, the exchangeable sodium percentage (ESP) is greater than 5 indicating presence of high exchangeable sodium in both types of soils. Moreover, ESP in salt treated vertisols is more than the critical sodicity level.

Conclusion and Recommendations

Significant Variation in storage efficiency was seen only in Luvisols as compared to the Vertisols. Clay filled ponds were seen to be less effective. This may be due to existence of internal crack in the structure and presence of loose interface between the two clay layers. On the contrary, application of Sodium Chloride /NaCl/ considerably improved storage in Luvisols. But in Vertisols storage efficiency didn't show improvement with application of table salt. This could be due to absence of sodium-induced clay dispersion in the soil to create clogging of pores. Applications of salts disperse soil aggregates, which in turn reduce the number of large pores in the soil. These large pores are responsible for aeration and drainage. A negative effect from the breakdown of soil aggregates is soil sealing and crust formation (Stephen, 2002). Regarding the change in temperature, no significant variation was seen between treatments on both types of soils. Geo-membrane was also proved to have not as such significant change in temperature as compared to the other treatments. Hence, it will have no different evaporation as compared to the other treatments. Furthermore, the cost of construction is by far smaller for table salt treated ponds than the other treatments.

Laboratory assessment also vividly proved dramatic improvement of storage with salt application. Moreover, analysis result of the stored water after treatment showed low to medium salinity, implying the stored water can safely be used for irrigation. But its impact on crop should be assessed further in future research. Impact of salt on soils other than Luvisols and Vertisols should be seen further. The amount of salt to be applied and the effective duration/life span of the applied salt also needs further research. Moreover, the result should be seen at large scale by increasing the size and volume of pond and with introduction of different test crop having varied salt tolerances.

Generally it can be concluded that, on Luvisols application of table salt improves storage dramatically and can be used to improve storage efficiency of ponds. On the contrary, application of table salt brought no significant variation in storage efficiency on Vertisols. Hence, unlined pond is by far preferable.

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Adaptability and Growth Performance of Nile Tilapia (*Oreochromis niloticus*) Fish in Small Scale Water Harvesting Ponds, East Gojam and South Wollo

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Abstract

Irresponsible activities on the capture fisheries sector coupled with improper management has led over fishing of most terrestrial waters. Therefore, more attention has been given to fish farming (aquaculture) in the developing countries. Currently aquaculture contributes over 30% of the fish consumed throughout the world. The production target from this sector by the year 2030 is over 50%. A research was conducted in two zones of Amhara Region for two years (from 2009 to 2010) to integrate fish farming with backyard vegetable production to supplement family food source. Nile tilapia (O. niloticus) fish fingerlings have been stocked in concrete water harvesting ponds constructed by the Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) project in East Gojjam and South Wollo zones of the region. The concrete ponds had two different kinds of shapes; circular and rectangular. A total of 9 farmers (3 circular and 6 rectangular) from the two zones had been selected. Each pond had a capacity to store 90 to 200 m^3 *water. About 800 Nile tilapia fish (cichlid) fingerlings, 10 to 70 g in size, were stocked. The total number of fish stocked in each pond varied from 30 to 210. The experimental fish were supplemented (at a rate of 5% ofthe biomass of the fish) with mixed meal of bran, oilcake and fish milling. Fish samples were taken every two months to evaluate their growth performance through time. The ponds were supervised and managed regularly to keep the water at its optimum quality required for fish growth in a grow-out pond. The growth of fishes differed depending on place (altitude), structure, fish size and the pond water temperature fluctuations. The fish in circular shaped concrete ponds failed to grow very well, but 95% of the fish stocked in the rectangular ponds had faster growth performance. Bigger fingerlings (70 g) stocked at rectangular shaped ponds reached the recommended table size (180 g and more) within 7 months of time. But those with smaller and medium size (below 40 g) could not attain the expected size during one experimental time (7 months). The result of this research trial assured the possibility of integrating fish farming with backyard agricultural production in water harvesting practices to sustain the livelihood and availability of additional food for the family.*

***Key words**:* Aquaculture, Altitude, Fish farming, Water harvesting ponds,

Introduction

Water is a universal need and is considered as a limiting factor for human and other organisms' life. Despite the water source available in nature (whether stagnant or running), it is possible to trap water infiltrated from rain. Water harvesting is practice of collecting and storing water in ponds from different sources for beneficial use. It is the way to help assure adequate water supplies for household, agriculture, fish culture and other uses available to farms and communities. Those designed for livestock watering and irrigation must be built near the use they serve and also contain adequate water (Helfrich and Pardue, 1997). Ponds constructed for fish and wildlife production or recreation are designed and constructed for (1) easy access, (2) adequate volume and, (3) water level manipulation. Farm ponds can be designed and built to serve multiple purposes with advanced planning. Pond fish culture is the most popular method of growing tilapia. One advantage is that the fish are able to utilize natural foods (Rakocy and Mc Ginty, 2005) and farmers can receive higher net returns from fish farming integrated with crop cultivation using the harvested water. Even small ponds can contribute to farm income or reduce family spending as fish are sold, bartered or eaten.

The various types of aquaculture form a critical component within agricultural and farming systems development that can contribute to the alleviation of food insecurity, malnutrition and poverty reduction through the provision of food of high nutritional value, income and employment generation, decreased risk of production, improved access to water, sustainable resource management and increased farm sustainability (Little and Edwards, 2003). Aquaculture, especially integrated one, is sustainable because it makes use of locally available materials. Integration with other forms of agriculture diversifies farm productivity; provide opportunities for intensified production with more efficient allocation of land, water, labor, equipment and other limited capital than enterprises which run independently. Fish culture integrated with garden irrigation, livestock watering and various domestic uses are all possible.

Production cost of fish, if the ponds are constructed once, is lower when compared with poultry, beef and pork. According to Rakocy and Mc Ginty (2005) approximately 22 kg of fish can be produced from an acre of pond per year. Fish convert food in to flesh efficiently as they are essentially weightless in water, and thus expend little energy for locomotion or maintain a normal upright position. They are cold blooded animals and do not expend energy to maintain a relatively high body temperature as other warm blooded ones. Thus, the amount of energy required to produce one kg of fish is much less than the amount required producing an equal weight of terrestrial animal.

Tilapia are growth rates at temperatures between 25 and 30°C (Bocek, 2003), making them more likely to become established extremely tough fish that can thrive in poor quality water on low-cost feeds (Bronson, 2005). They exhibit maximum and invasive in tropical climates. Nile tilapia (O. niloticus) is the least cold tolerant of the farmed tilapia and prefers tropical to subtropical climates. Nile tilapia (O. niloticus) is the most predominant species of tilapia in aquaculture (Gupta and Acosta, 2004) and well adapted to artificial culture environments, gain weight quickly at optimum conditions and reproduce on the farm without special management or infrastructure. Nile tilapias (O. niloticus) reach sexual maturity at about 5 to 6 months (Gupta and Acosta, 2004). The usual fingerling size supplied for grow-out ponds is mostly 1- 3 g. Growth rate is very rapid during fingerling stages. During these stages they have different biological characteristics from adults, especially in terms of feeding habits, growth and habitat preferences. The growth rate declines as the fish gets older.

If the natural productivity of a pond is increased through fertilization or manuring significant production of tilapia can be obtained without supplemental feeds. To maximize fish production, manure should be added daily to the pond in amounts that do not reduce dissolved oxygen (DO) to harmful levels as it decays. The ponds were fertilized by using organic fertilizers mostly from livestock sources at a rate of 10 kg for cattle, equine and sheep/goat manure and 6-8 kg for chicken in a 100 m^2 ponds every week. The maximum rate was determined on the quality of manure, oxygen supply in the pond and water temperature.

The rate of manuring should be increased gradually as the fish grow (Rakocy and McGinty, 2005). Lime was applied at a rate of 1500 kg/ha to neutralize the pond water and promote the growth and multiplication of important planktons for fish.

The communities in many tropical food insecure areas basically lack water for drinking and irrigation. Apart from lower crop production, livestock productivity is getting low to the extent that couldn’t meet the protein requirement of the household. This leads malnutrition to be the single greatest cause of child mortality in Ethiopia, caused 470 Ethiopian children to die every day because of protein-energy malnutrition (Linkages project, 2001).

To minimize this health hazard, alternative protein sources should be sought and fish could potentially be integrated with the water harvesting structures. Fish culture using these structures could be one of the best options among the possible integrations. Thus, this experiment was conducted to evaluate the adaptability of Nile Tilapia on water harvesting ponds and demonstrate the possibility of integration of fish farming in these structures under small holder farmers’ condition.

Materials and Methods

Study areas

The project was done in two zones of the Amhara region; namely East Gojjam and South Wollo. Six ponds among the other ones constructed by SWHISA were selected and stocked with target species of fish; three ponds from Goncha Siso Enesie and the other three from Were-Illu weredas. NileTilapia male fingerlings reared from on-station ponds were stocked to the ponds. The pond water in both study areas were fertilized using animal manure prepared by farmers.

Methods

Lime was applied at a rate of 1500 kg/ha before stocking. Fish fingerlings were packed in a 50 l polythene bag filled with half water and half oxygen. Each polythene bag that held fish were placed in big plastic bucket and transported. Water parameter readings and fish weight had taken before and after stocking. The fish were kept for 7 months from September till March.

The fish were supplemented with mixed feed of oil cake, bran and fish millings at a rate of 3:3:1 for the first three months where the fingerlings are expected to grow faster. Feeding rate was adjusted on a monthly basis by estimating the fish biomass in the pond. To determine the fish biomass, fish fingerling samples were caught and weighed. The average weight of fish in the sample was multiplied by the number of fish stocked and alive.

Nile Tilapia fingerlings of different sizes, 10 - 20, 21 - 40 and 41 - 70g were used to test the growth performance and demonstrate the integration of tilapia fish in water harvesting ponds. The ratio of small, medium and big sized fingerling was 1:1:1 and the stocking density was 2 fish per square meter. The total number of fish fingerlings stocked in all experimental ponds was 600. Measurement has been made, every two months, on the biological and physical parameters of pond water using probes and kits as well as growth of fish using measuring board and balance. During sampling, as it is very difficult to count the whole fish stocked in the pond and compare with the original population, 20% of the fish was taken randomly for sampling (weight and length measurements). The experiment was conducted for 7 months in 2009 and 2010 (September to March) and all the fish in a pond were harvested at the end of the experimental period.

Result and Discussion

Effectiveness of the pond water for fish

Rectangular shaped concrete ponds were very good; rich in plankton, easy to add supplemental feed, easy to manage the fish, reliable to fertilize the pond water and take samples of water and fish compared to circular ones. The rectangular pond has got fertilized within 5 to 7 days after the addition of manure. The plankton species number, abundance and distribution was better than circular ones. This could be due to the larger surface area of the pond water exposed to sunlight which in turn helps an active photosynthetic activity to take place.

There was no any record of over fertilization of pond water in all areas. But, in a circular pond from East Gojjam, the level of water dropped to 40 cm during the 4th month after stocking and this event resulted temperature fluctuation. The pond water temperature had fluctuated frequently from the optimum level for Nile Tilapia. It had even dropped to lethal level (below 2 ^{0}C) and all fish died within a day.

Once manure (cow dung) was applied, the pond has got fertilized and become rich in plankton. Circular ponds with limited entrance of sunlight had very low plankton biomass. The population of phytoplankton and zooplankton in rectangular ponds was much greater than circular ponds (Fig.1) indicating the suitability of rectangular ponds for fish production. Among the zooplankton, moina were the dominant species and their number varied in between 37 and 80 per milliliter, with an average of 55/ml of water. The average population of phytoplankton in circular ponds was 26/ml of water. The zooplankton diversity and population was higher also in rectangular wider ponds than circular ones.

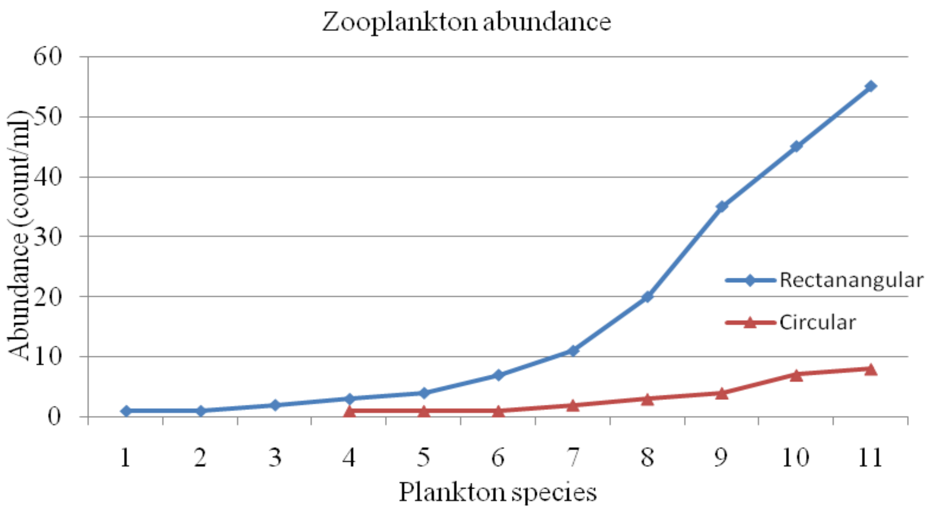

Figure 2 Zooplankton diversity in different structures. *Note:- 1 = Mytilia, 2 = Keratella, 3 = Cyclopoid, 4 = Filinia, 5 = Diaphanosoma, 6 = Nuplia, 7 = Branchionus, 8 = Diffuligia, 9 = Lepadela, 10 = Asplanchna and 11 = Moina.*

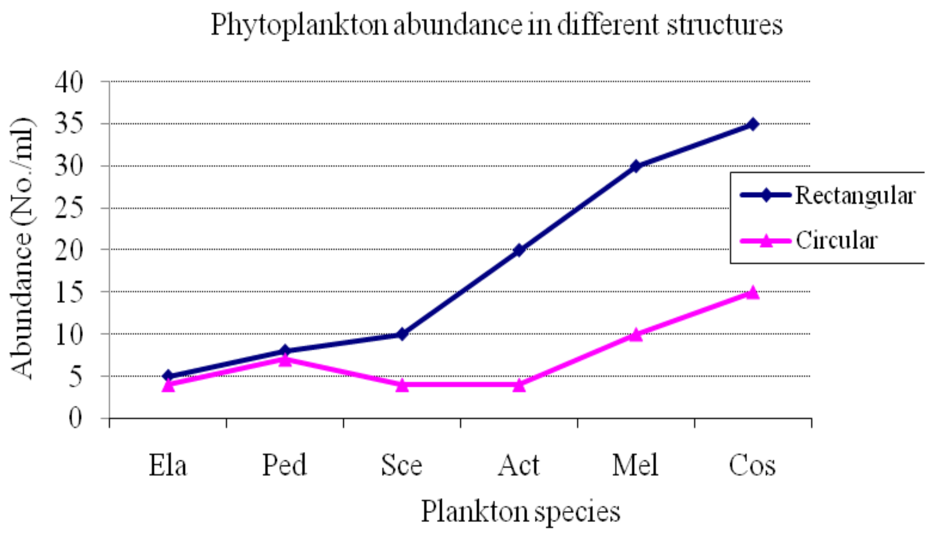

Figure 3. Diversity of phytoplankton genera. **Note:-** *Mel = Melosira, Cos = Cosmarium, Ped = Pediastrum, Act = Actinastrum, Ela = Elakatathrix, and Sce = Scenedesmus.*

Fish growth

More than 97% of the total fish stocked in a pond adapted and reached for harvesting. Adaptation of fish in the rectangular ponds was relatively good. There was no pronounced dissolved oxygen (DO) depletion. The total number of fish stocked (fish biomass) in the different ponds varied depending on the size of the pond. Those water harvesting ponds which had an area of 100 m^2 received 100 fishes of different size. Nile Tilapia fishes stocked in one circular pond at East Gojjam zone could not adapt because of the lower water temperature happened in the area. In the remaining eight ponds fish were growing continuously (Fig 3). The biggest size of fish recorded at the end of the experimental time was 220 g and the smaller one was 72 g. The overall average weight of a fish attained at the end of the 7^{th} month was 138 g, including those fish stocked at their smaller size (10 g).

Fish produced in ponds

An integration of fish farming with water harvesting ponds brought a new product to the farm family, edible fish. The total fish produced in a pond varied in between 5 and 16 kg depending on the size and shape of the pond. Rectangular shaped ones were suitable for management and best for fish growth so that enabled individual farmers to harvest an average of 16 kg of Nile Tilapia fish in a 100 m^2 pond. Farmers with the same size circular pond were able to produce 10 kg of fish. Bigger ponds (100 m^2) gave higher production (160 g m^{-2}) compared to smaller ones (50 g m^{-2}). The total maximum production in one 100 m^2 rectangular pond in East Gojjam Zone was 21 kg. This was possible as the average pond water temperature was 21.6 ^{0}C and the pond got fertilized within 5 days after manuring.

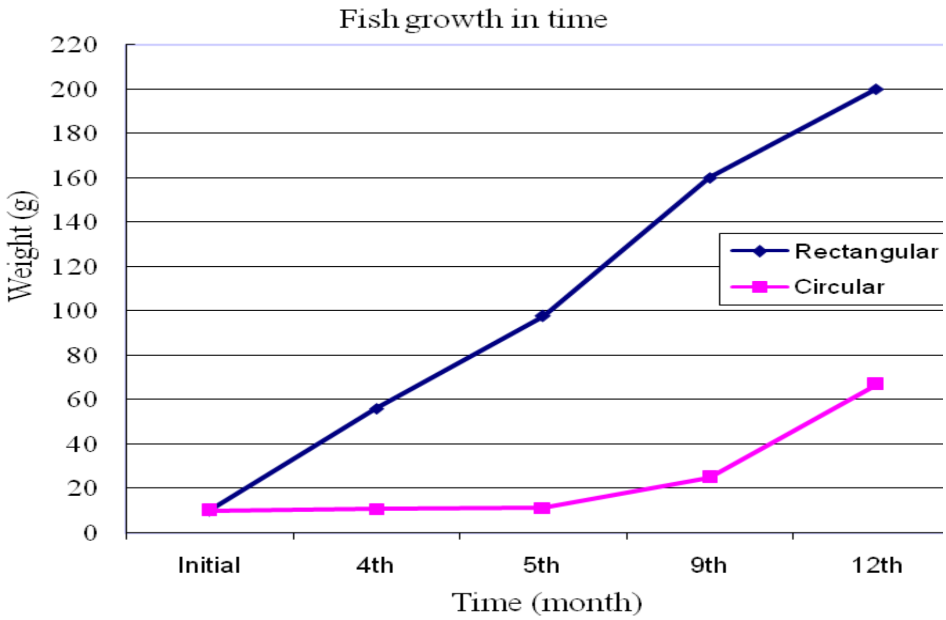

Figure 4. Average growth performance of the fishes

Conclusion and Recommendations

In most ponds fish were successfully grown and possible to have a harvest at the 7th month. Both types of ponds can produce fish, but rectangular ponds were very suitable due to their larger surface area exposed to sunlight. According to this study, it is important for the farm family to stock different sized fingerlings, starting from 70 g, so that continuous and earlier harvest is possible.

According to the results of this study fish introduction (but not less than 70 g in weight) in water harvesting ponds is recommendable in food insecure areas of the region especially because people in these areas are suffering from scarcity of protein as well as malnutrition. The pond water temperature should not drop below 20 ^{0}C, it should not be turbid, no barrier for sunlight and should be rich in plankton (green in color). Training should be given to the farm family towards pond water and fish management as well as fish handling, processing and feeding since the technology and the fish itself will be new product for the family.

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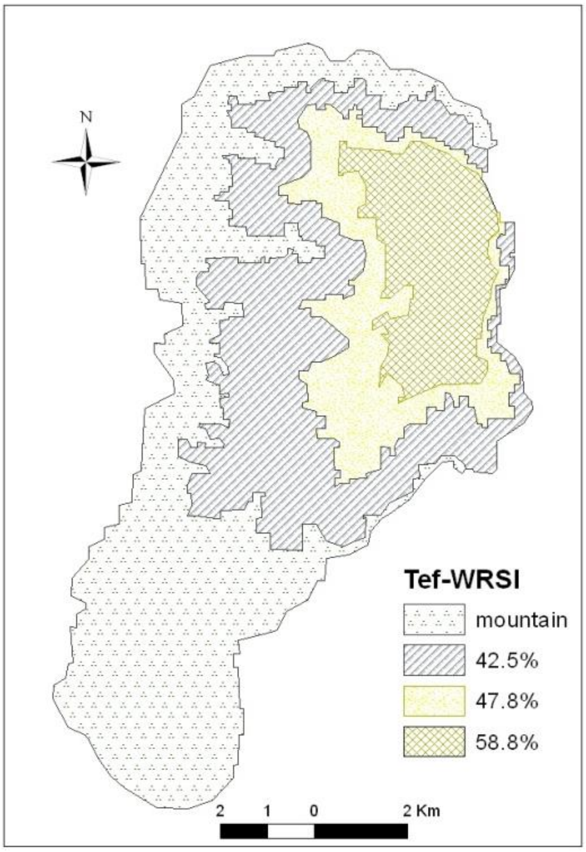
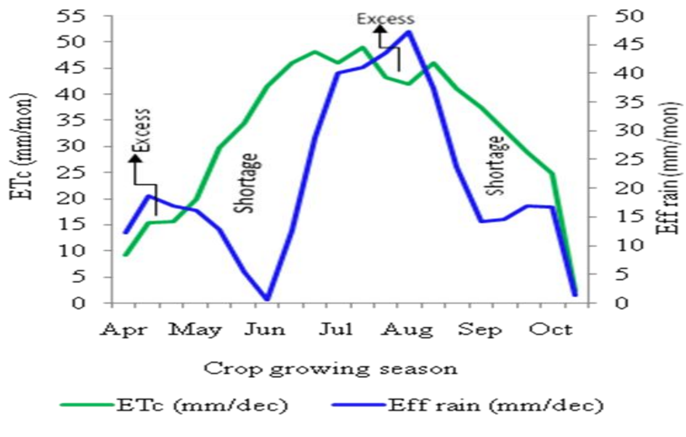
PART 4

RAINFED WATER SUPPLY AND DEMAND IN MIXED FARMING SYSTEM: IN MOISTURE STRESS AREAS OF AMHARA REGION





Water Balance in Crop-Livestock Farming System in Lenche Dima Watershed, Gubalafto Woreda, Amhara Region

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Abstract
This study was undertaken to investigate the water balance of crop-livestock farming system in Lenche Dima watershed, Gubalafeto Woreda, North Wello zone, Amhara Regional State. The water balance has two components: the water supply component (rainfall, ponds and ground water) and water demand component (crops, livestock and domestic use). Based on meteorological, crop, and soil data, the crop water requirements were calculated using CROPWAT software. Additionally, a total of 120 households were randomly selected and surveyed for evaluating the water demand and supply of livestock and domestic use including socio-economic characteristics of the watershed. The standard deviation and coefficient of variation of the rainfall ranges from 18 to 75mm and 41 to 94%, respectively, indicating the uncertainty in rainfall over the study area. Results show that the seasonal crop evapotranspiration (ET_c) and effective rainfall in the watershed area are 652 and 419 mm for sorghum, 371 and 300 mm for tef, 307 and 177 mm for chickpea, and 731.1 and 403 mm for maize. Hence, seasonal water shortage was observed for all of the crops. On the other hand, the total depleted water in the watershed for feed production is 6.46 mill. m^3 $year^{-1}$ and water consumption for livestock is 36677 m^3 $year^{-1}$ summing up to 6.49 mill. m^3 $year^{-1}$. The total domestic water use is about 11065 m^3. The water supply for domestic use was from ground water estimated to be 11408 m^3. The results also show a discrepancy between water supply and demand in the crops-livestock farming system. Crops and vegetation have by far the largest user of the water that is 14.34 mill. m^3 (95%), whereas domestic use is the lowest (11,065 m^3, 0.36%).

The estimated water supply from rainfall, ponds and water pumps for domestic and livestock use are 10.79 million, 10,632 and 11,408 m^3 respectively. Comparison of supply and demand shows that water availability is significantly lower than the demand. The supply is covering only 75% of the water demand in the watershed. This indicates that the water needs for the production of crops, livestock and domestic water use are not adequate. Therefore, to mitigate the shortage of water in the watershed, development of rain water harvesting technologies, growing low moisture demanding crops, improving the vegetation cover, enhancing soil and water conservation are suggested to promote productivity and sustainable intensification of the rain fed agriculture.

Key words: Water balance, Crop-livestock water requirement, Lenche Dima

Introduction

In Ethiopia, agriculture is mainly rain-fed, subsistence and small scale with low input use, which often leads to low productivity. This is further aggravated by water shortage due to shortage of rainfall and land degradation caused by excessive soil erosion. Rainfall is the major source of agricultural water and most important environmental factor limiting agricultural activities in the arid and semi-arid regions of the tropics. Rainfed agriculture is still the dominant practice in most developing countries. Soil moisture management in semi-arid and arid areas of the tropics is faced with limited and unreliable rainfall and high variability in rainfall pattern (Kipkorir, 2002). Even though the country has huge water resources, water is a very scarce commodity for many of the smallholder farmers and their livestock, and the situation is aggravated by seasonal variations in availability of water (Zinash Silesh *et al.*, 2003).

As noted above, rainfall in Ethiopia is characterized by high degree of spatial and temporal variability. The rainfall is highly variable both in amount and distribution across regions and seasons (Mersha Engida, 1999). The seasonal and annual rainfall variations are results of the macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (NMSA, 1996).

To alleviate the above stated problems and to increase production, water balance study (supply-demand gap analysis) is needed to determine the deficiency of water in crop-livestock farming system at watershed scale. Water scarcity due to the unpredictable, spatial and temporal variability of rainfall and its relationship to food security rationalize the need for conserving all the available water resources. In this respect, there is special need for determination of the different water balance components in relation to the temporal and spatial distribution of water supply and demand for enhanced livelihoods of farmers. Therefore, the overall objective of the study was to determine the water balance in crop livestock farming systems for the Lenche Dima watershed. And the specific objective was to estimate the water demand and supply components for crop and livestock production and the water balance for the whole watershed area.

Materials and Methods

Description of the Study Area

The study was conducted in Lenche Dima watershed in Gubalafeto Woreda, in North Wello zone of Amhara Regional State. Geographically, the watershed extends from 11°49’13” to 11°51’57” N latitude and from 39°40’07” to 39°44’22” E longitude. The watershed drains to Alewuha River and eventually into Awash River Basin (Figure 1). The climate of the watershed is characterized by dry sub humid with 687 mm mean annual rainfall (NMSA, 2008) and mean monthly maximum temperature of 32^{o}C in June and the mean monthly minimum temperature of 12^{o}C in November (Figure 2). The rainfall distribution is bimodal with a small rainy season during March - May (*Belg*, with a mean of 140 mm*)* and main rainy season during July – October (Kremt, mean 421 mm) (NMSA, 2008). The rainfall is characterized by intense erosive storms with high temporal and spatial variability. Even during normal non-drought years, the area suffers from recurrent dry spells (Solomon Gizaw *et al*., 1999).

The major soils of the Lenche Dima sub-watershed are Regosol, Leptosol, Luvisols, Vertisols and Fluvisol. Regosol and Leptosols are formed on high gradient dissected hills and mountains (> 30% slopes), covering 508 ha. The soils of the lower foot slopes (8-15% slope) and the upper foot slopes (15-30% slope) are classified as Vertic Luvisols and Regosols, respectively with a total of 371 ha. Most of the cultivated lands (2-5% slope) are covered by Vertisols of area 544 ha. The plain area (0-2% slope) which receives fresh alluvial sediments at regular intervals is dominated by Fluvisols with an extent of 123 ha (FAO, 1998).

Methods of Data Collection

Pre-tested questionnaires, group discussion, interview of key informants, field soil sampling and laboratory analysis and secondary data were used for data collection. Bulk density from 0-30cm and 30-60cm depths with two replications was determined using core-sampling method (BSI, 1975). The samples were oven dried at 105 ^{0}C to constant weight for 24 hours in laboratory. Then the dry weight was measured, and bulk density was calculated as:

$$\text{Bulk density } (P_b) = \frac{mass\ of\ dry\ soil}{bulk\ volume\ soil} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

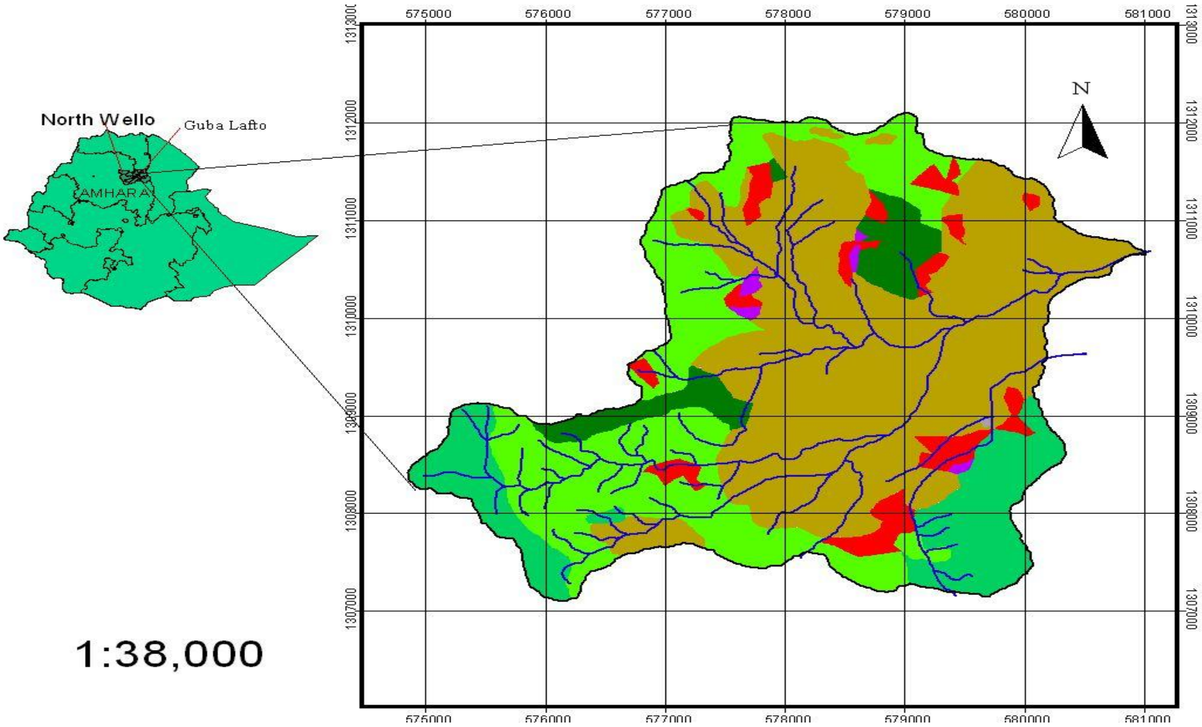

Figure 1. Location map of Lenche Dima Watershed

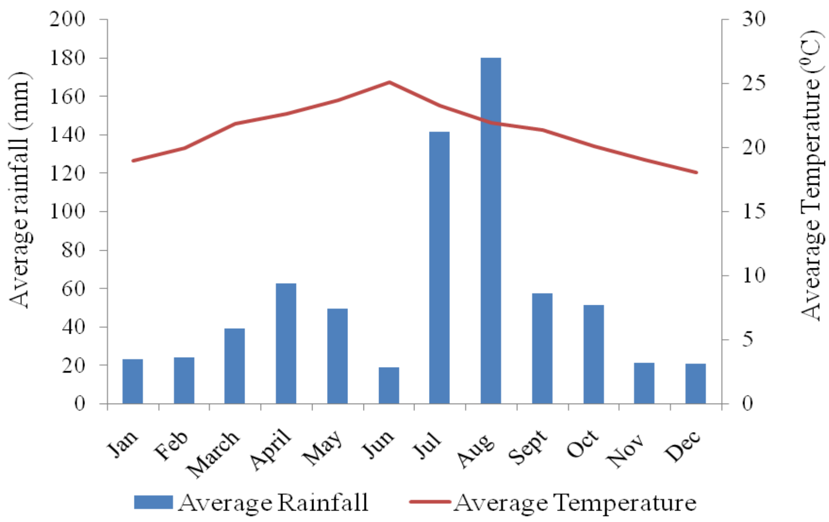

Figure 2. Mean monthly rainfall and temperature (1976-2007) for Lenche Dima watershed

The moisture content on weight basis of each soil samples was calculated using the following equations (FAO, 1987; Kamara and Haque, 1991)

$$W\% = \left(\frac{Ww - Wd}{Wd}\right)*100 \qquad (2)$$

Where:

W % = soil water content on a dry weight basis, %

$\mathbf{W_w}$ = wet weight of the soil, g

$\mathbf{W_d}$ = dry weight of the soil, g

The moisture contents in volume bases (θ %) of the soils collected from the farmers' fields at different depths were determined.

$$\text{Soil moisture content } (\theta\%) = (W\% \times P_b) \qquad (3)$$

The normal ratio method was used to estimate the missing rainfall data (Dingan, 2002). This approach enables to estimate missing data by weighing the observation at five stations by their respective annual average rainfall values and expressed by the equation;

$$P^0 = \frac{1}{G} \times \sum \frac{Po}{Pg} \times PG \qquad (4)$$

Where

P^o = the missing data

P_o = the annual average precipitation at the station gauge with missing data

Pg = monthly rainfall data in station for the same month of the missing station,

P_G = annual average of neighboring station

Rainfall over arid and semiarid areas present difficulties not only due to its insufficient amount but also due to the inherent degree of variability associated with it. In order to indicate month to month and year-to-year variability of the rainfall for the selected station, percent deviation and coefficient of variation from the mean were used. These were calculated as follows:

$$\%Deviation(annual) = \left(\frac{\text{Annual rainfall} - \text{Mean annual rainfall}}{\text{Mean annual rainfall}}\right)*100 \text{ --------- } (5.1a)$$

$$\%Deviation(monthly) = \left(\frac{\text{Monthly rainfall} - \text{Mean monthly rainfall}}{\text{Mean monthly rainfall}}\right)*100 \text{ ---- } (5.1b)$$

$$CV = \left(\frac{\text{Standard deviation of monthly or annual rainfall}}{\text{Mean monthly or Annual rainfall}}\right)*100 \quad \ldots\ldots\ldots.. (5.2)$$

Determination of Water Supply Components

Runoff measurements have been carried out on different land use types for the study area and the result of this study was used for estimation of runoff depth (Mc Hugh, 2006). Twenty dome shaped private ponds were constructed by 19 individual farmers with the help of the AMAREW project in 2002. Each pond has a storage capacity of 60m^3 of water. Community and private ponds are characterized as a small reservoir managed at a community and household level and located around their homestead that allows farmers to capture runoff water from nearby micro-catchments, gully or streams with a diversion structure. During the survey period, the common means of water lifting used by pond owners was using the bucket and rope method to irrigate their backyard plots.The water is used to grow vegetables and fruit trees at backyard and farm plots, provide water for their livestock and used for domestic use. The total water volume of community ponds and private ponds for use by the watershed community is the sum of water volume stored of both community and private ponds minus the evaporation losses.

Volume of ponds was determined based on its area and average pond depth. The shape of the pond is assumed to be trapezoidal. Area of trapezoidal pond was determined by the following formula.

$$A = \left(\frac{b1 + b2}{2}\right) \times W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.1)$$

$$V = \left(\frac{A + 4B + C}{6}\right) \times D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.2)$$

V= volume of trapezoidal pond

A = area of the pond at ground surface

W= Width of the pond

B= Area of at mid depth (D/2)

C= Area at the bottom of the pond

D= average depth of the pond

b1 = base of lower floor

b2 = base of upper part

Serving Period of Communal Ponds is the period of time during which the water stayed in ponds to serve for livestock watering and domestic uses. It is a function of the stored volume of water, the evaporation loss, seepage and siltation. In this study only the volume of stored water and the evaporation loss were considered as there was lack of data on seepage losses and yearly siltation. The following formulas were used to estimate the serving time.

$$\text{Serving time of pond} = \left(\frac{\textit{Total monthly volume of water}}{\textit{Monthly average pond evaporation}} \right) \text{............(7)}$$

Daily data of water pumped from ground water were used to estimate the supply of domestic water use in the watershed area. In the watershed, households access various water sources for themselves and their livestock. The accessed domestic and livestock water sources were rivers, wetland, community ponds and private ponds. Accessibility of water sources were analyzed using Arcview GIS.

Determination of Water Demand

The crop water requirement (*CWR*, mm/dec) over the period from planting to harvest under the present climatic condition was estimated with the CROPWAT software developed by the Food and Agriculture Organization (Allen *et al*., 1998; FAO, 2003). The total crop water demand for the 2008 cropping season of Lenche Dima watershed was estimated by multiplying the area coverage and the crop water requirements of each crop. The result for each crop was changed from depth to volume i.e. m^3 / season.

$$\mathbf{E}Tc = (Kc \times ET_0) \quad \text{..} \quad (8)$$

Where:

ETc = Crop water requirement (mm)

Kc = Crop coefficient (dimensionless)

ET_0= Reference crop evapotranspiration (mm)

The total livestock water demand was estimated based on the feed intake and average livestock water required per tropical livestock unit (TLU). Total livestock population per household was converted to TLU using a conversion factor of 0.7 for cattle, 0.1 for sheep and goats, 0.5 for donkeys and 1.0 for camels (Jahnke, 1982). Depleted water for Livestock Feed Production, which is the amount of water consumed or removed by evapotranspiration. The crop residues were then calculated based on the harvest index for each crop type (FAO, 1987). The water depleted on the grazing land was adjusted based on the amount of grass assumed to be available for livestock grazing. Utilization and recoverable factor of 50% and 75% were applied for crop residue of crops and grazing land respectively (WBISPP, 2000).

In order to estimate depleted water for crop residue, the total water requirement of the particular crop was partitioned into grain and crop residues water requirement according to the conversion factor (i.e. grain-residue ratios) (FAO, 1987). To obtain crop water use per kg of residue, conversion factors from grain to residues were derived from Kossila (1988) and Herrero *et al*., (2008). The total depleted water for crop residue at household level was then estimated based on the crop evapotranspiration and area covered for each crop grownin the watershed.

$$WRCR_{il} = \frac{R_i * ET_{cil}}{1 + R_i} \quad \text{..} \quad (9)$$

Where

$WRCR_{il}$ = water requirement of i^{th} crop residue in l^{th} location (mm)

R_i = conversion factor for grain yield to crop residue yield of the i^{th} crop type

ETc_{il} = crop water requirement in mm per unit of time of the i^{th} crop type at l^{th} location.

Then the water requirement for the total crop residue production was estimated in m^3.

$$WRCR_j = \sum_{il} WRCR_{il} \times AC_{il} \text{ .... } (10)$$

Where:

$WRCR_j$ = the water requirement of total crop residue type in j^{th} household during the reference year (m^3)

$WRCR_{il}$ = water requirement of i^{th} crop residue in l^{th} location (m)

AC_{il} = total area of i^{th} crop type cultivated by the j^{th} household in the reference year (m^2).

The water requirement for Grazing (grass and shrub) lands was calculated as follows:

$$GLWR_{ij} = Kc * ETo * GLA_j * GLU * LGP \text{ .... } (11)$$

Where:

$GLWR_j$= grazing land water requirement in mm per square meter of jth household (= Depleted water of grazing land that is utilized by livestock),

GLA_j = Grazing land area in square meter of the jth household

GLU = Utilization factor of grazing land by livestock (proportion of the grass biomass production that is available for livestock feeding,

Kc = crop coefficient for grazing land (Kc value of extensive grazing)

ETo = Reference evapotranspiration in mm per unit time

LGP = Length of growing period in days.

The water requirement livestock feed was calculated as

$$DWLF = \sum_{j=1}^{n} WRCR_j + \sum_{j=1}^{n} GLWR_{ij} \text{ .... } \quad \text{Eq. (12)}$$

Where:

$DWLF_l$ = Depleted water in mm per square meter for livestock feed in the watershed

$WRCR_j$ = the water requirement of total crop residue type in j^{th} household during the reference year (m^3)

$GLWR_{ij}$= grazing land water requirement in mm per square meter of in j^{th} household (Depleted water of grazing land that is utilized by livestock)

Determination of Water for Livestock

Data on total livestock numbers and species of the watershed were collected from the development agent of the watershed. Water consumption by livestock based on TLU per day were generated from survey results. Finally, the total consumption per day was calculated by multiplying the total TLU values with daily water requirement.

Determination of Domestic Water Consumption

The following steps were carried out to determine domestic water consumption: 1) Data on total number of households within the watershed area was collected, 2) The average water consumption for domestic uses per household per day in liters from different water points were collected from the survey data and literature, and 3) The total water consumption was calculated based on step 1 and 2.

Water Balance Model

A water balance considers parts of the hydrologic cycle. A water balance is calculated for a specified period of time with the resulting net surplus or deficits. It is expressed as seasonal or annual values. The water balance is expressed as an equation relating these components:

Change in storage = Water Supply - Water Demand or

$$\Delta S = (\text{Effrain} + P + GW) - (\text{crop and vegetations} + \text{livestock} + \text{domestic use}) \quad \ldots\ldots \quad (13)$$

Where:

ΔS = the change in storage

Effrain = Effective rainfall

P= ponds (communal and private)

GW= ground water.

Results and Discussion

The major crops grown in the study area are sorghum, teff, maize, and chickpea under rainfed conditions, whereas onion (Allium cepa), tomato (Solanum lycopersicum) and pepper (Capsicum annuum) are grown under irrigated conditions outside of watershed area. Within the watershed, irrigation is not used for crop production due to the absence of perennial rivers or other water sources.

Of the total 318 ha of cultivated land by the respondents, sorghum covered 48% (153 ha) of the cropped land area with an average of 1.3 ha per household and followed by tef covering 45.06% (143.2 ha) with1.2 ha per household. Chickpea covered the lowest share at 2.73% (8.7ha) of the total cropped land with an average 0.07ha per household. Maize covered 4% (12.54ha) of the cropped land area with an average 0.1ha per household (Table 1). Sorghum and tef were the two most widely grown crops in the watershed. According to the survey result, the average cultivated cropland area was 2.7 ha per household per year (Table 2).

Table 1. Cultivated lands (ha) by sampled households for each crop grown at Lenchdima watershed in 2008

Sub-watersheds	Total cultivated land (ha) covered by different crop types				
	Sorghum	**Teff**	**Chickpea**	**Maize**	**Total cropped area (ha)**
Oromo	68.2	64.0	4.4	6.6	143.3
Kolokobo	58.9	51.8	2.8	3.5	116.9
Lench dima	26.3	27.4	1.5	2.4	57.5
Over all (ha)	**153.4**	**143.2**	**8.7**	**12.5**	**317.8**
Over all (%)	**48.3**	**45.1**	**2.7**	**4.0**	**100**

Table 2. Area (mean and standard error) of cultivated land per household at Lenchdima watershed

Land use	Oromo	Kolokobo	Lench dima	Overall
	Mean±SE	**Mean±SE**	**Mean±SE**	**Mean±SE**
Total crop land	2.3±0.2	2.9±0.2	3±0.3	2.7±0.2
Total Sorghum	1.3±0.2	1.09±0.1	1.46±0.2	1.3±0.1
Total Tef	1.1±0.1	1.2±0.1	1.37±0.2	1.2±0.08
Total Chick pea	0.06±0.2	0.10±0.04	0.07±0.05	0.07±0.02
Total Maize	0.05±0.01	0.1±0.02	0.14±0.03	0.1±0.01

Based on the above total area coverage by each crop type, total grain and crop residues production was calculated for each type of crop cultivated under the three sub-watersheds. The contribution of sorghum (1.5t per household) was higher in grain than the other two crops, and tef (4t per household) had higher crop residue (Table 3).

Livestock numbers and holdings in the three sub watersheds and the entire watershed area are presented in Table 12. The overall livestock holding was 2.9, 2.0, 2.3 and 2.6 TLU per household for Oromo, Kolokobo, Lenche Dima and the entire watershed, respectively. The highest proportion of TLU holding was for cattle followed by donkey. This might be due to the importance of cattle for farm draught power.

Table 3. Average grain and crop residues production (ton) per households at Lench Dima watershed

Watershed	Production	type of production	Crop type			
			Sorghum	Tef	Chick pea	Total
Over all	Total production	Grain	179.1	118	4.3	301.3
		Residue	447.7	475	5.2	927.9
	Average production	Grain	1.5	1	0.04	2.5
		Residue	3.7	4	0.04	7.7

Water Supply Components

The mean annual rainfall, based on the periods 1976-89 and 1992-2007, over Lenche Dima watershed is 687 mm and varies from 193mm in 1984 to 998 mm in 1978 (Figure 3). The standard deviation and coefficient of variation for the monthly rainfall from 1976 to 2007 range from 18 to 75 mm and 41 to 94 % , respectively, confirming the uncertainty in rainfall over the study area.

The total effective rainfall during 2007/8 for the different land use/cover types was 10.79 million m^3. Cultivated area received 5.29 million m^3 (49%) and areas under rock out crop received the lowest effective rain 0.005 million m^3 (0.04%) (Table 4).

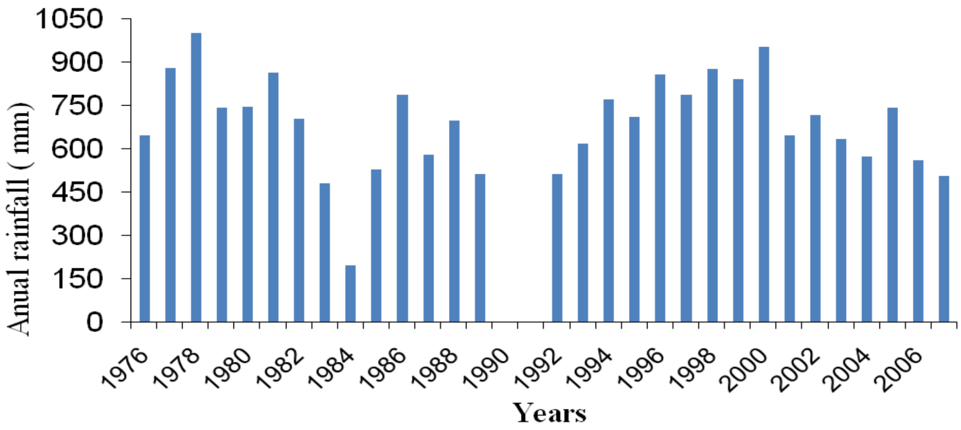

Figure 3. Mean annual rainfall in Lench Dima watershed area (1976-2007)

Table 4. Total and effective annual rainfall in the watershed based on land use/land cover types in Lench Dima watershed

Land use/cover classes	**Area (ha)**	**Total rainfall (mm/year)**	**Total rainfall ($10^6 m^3$/year)**	**Effective rainfall ($10^6 m^3$/year)**
Cultivated Land	962.9	687	6.62	5.29
Forest Land	108.5		0.75	0.6
Grazing Land	11.3		0.08	0.06
Open Shrub Land	517.6		3.56	2.84
Open wooded shrub Land	248.4		1.71	1.37
Rock Out Crop	0.8		0.01	0.005
Village	114		0.78	0.63
Total	**1963.5**		**13.49**	**10.79**

Estimation of runoff was based on the findings of McHugh (2006). The total runoff volume from cultivated land was high (1.79 million m^3) contributing 72% from the total runoff and the lowest total runoff was from grazing lands (0.01 million m^3) contributing only to 0.041%. The reason for high runoff amount from cultivated land was due to high runoff coefficient values and greater area coverage as compared to the other land use/cover types. Actual events of runoff measurements indicate that CROPWAT over estimates effective rainfall so the events should be interpreted in the above way. The total runoff volume for the different land uses in the watershed was 2.47million m^3 (Table 5).

Table 5. Runoff coefficient and volume for different land uses in the Lench Dima watershed

Land use/cover classes	Total annual rainfall ($10^6 m^3$/ha)	Runoff coefficient	Total runoff ($10^6 m^3$/ha)	Runoff (%)
Cultivated land	6.62	0.27	1.79	72.37
Forest land	0.75	0.03	0.02	0.91
Grazing land	0.08	0.13	0.01	0.41
Open shrub land	3.56	0.13	0.46	18.73
Open wooded shrub land	1.71	0.05	0.09	3.46
Village	0.78	0.13	0.10	4.12
Total			**2.47**	**100**

Among the community ponds, Tuluba Dime pond was the biggest pond having a volume of 8478 m^3, representing 74% of the total water stored in pond in the watershed. The smallest pond was Sefede Ameba having a volume of 56.5 m^3, equaling only 0.5% of the harvested water in the watershed using ponds. The estimated volume of water (m^3) stored in all ponds was 10291 m^3 (Table 6).

Table 6. Volume of stored water in community ponds in the Lench dima watershed

ID	Location	Average depth (m)	Average area (m^2)	Volume of water stored (m^3)	% from total
1	Gerado	1.2	98	133	2.1
2	Lench $dima_1$	2	189	314	4.3
3	$Kolokobo_1$	1.2	98	133	2.1
4	$Kolokobo_2$	2.2	189	393	5.4
5	Tuluba demi	3	2159	8478	74.8
6	Sefede $ameba_1$	2.2	189	393	5.4
7	Sefede $ameba_2$	0.5	69	57	0.5
8	Bole chaka	2	189	393	5.4
	Total volume			**10,291.0**	**100**

From Table 7, the estimated water consumption for livestock from the 20 ponds was 509 m^3 $year^{-1}$. The total water volume of community ponds and private ponds for use by the watershed community is the sum of water stored in both community and private ponds minus the evaporation losses. The total stored water volume of ponds is 10,291 m^3 and the total evaporated water from ponds is estimated to be 858.6 m^3. Hence, the volume of water in ponds for use is estimated to be 10,632 m^3. Seepage was not accounted because it was assumed to be negligible.

Table 7. Total consumption and storage capacity of private ponds in the Lench Dima

Farmers name	Ponds	Consumption (l/year)			Total water Consumption /year (m^3)	Estimated capacity (m^3)
		Domestic	Irrigation	Livestock		
Desale Belete	1	2040	8232	0	10.272	60
Fantaw Abigaz	1	6000	16820	12000	34.82	60
Abate Neguz	1	4800	6240	6000	17.04	60
Yasin Ahmed	2	6000	46900	15480	68.38	120
Bekaris Molla	1	6900	4640	11700	23.24	60
Mohamed Said	1	2700	11900	9750	24.35	60
Total	**7**	**28440**	**94732**	**54930**	**178.102**	**420**

Determination of Crop Water Requirement

The CROPWAT software results show that the annual crop water requirements are 652.6, 371.8, 307.8 and 731.1 mm per season for sorghum, tef, chick pea and maize, respectively (Table 8). The lowest and peak monthly water requirements for these crops occur, respectively, during the following periods: for sorghum in October (2.2mm) and in July (48mm), for teff in July (9.8mm) and Sep. (45.7mm), for chickpea in November (12.2mm) and October (43.8) and for maize in March (8.8mm) and June (64.7mm). Crop water requirements were found to be higher than total rainfall and total effective rainfall for all the crops in the reference cropping season under consideration. This implies moisture deficit (water shortage) for all crops which is associated with low rainfall resulting in mid and late season drought.

Table 8. Crop water requirement (CWR) of crops (mm/season m^{-2}) at Lench Dima watershed, (2008 cropping season)

Crop	TRF	CWR	TERF	IR
Sorghum	516.6	652.6	419.6	247.6
Tef	373.4	371.8	300.8	170
Chick pea	209.2	307.8	177.8	157.7
Maize	503.8	731.1	403	354.6

TRF=Total rainfall (mm/season m^{-2}) (from planting to harvesting); TERF= Total effective rainfall (mm/season m^{-2}); CWR= crop water requirement (mm/season m^{-2}); IR= Irrigation requirement (mm/season m^{-2})

Figure 4 shows the effective rainfall and crop evapotranspiration (ET_C) and growing stages from April to October for the sorghum crop. The figure shows excess moisture supply during the planting (initial) stage (April – mid-May), whereas moisture is in short supply during the development stage and mid-stage (mid may-July). Also excess moisture availability is seen during August, while the period after August is characterized by shortage of moisture. During the critical stages of development and mid-season lack of moisture can reduce the yield.

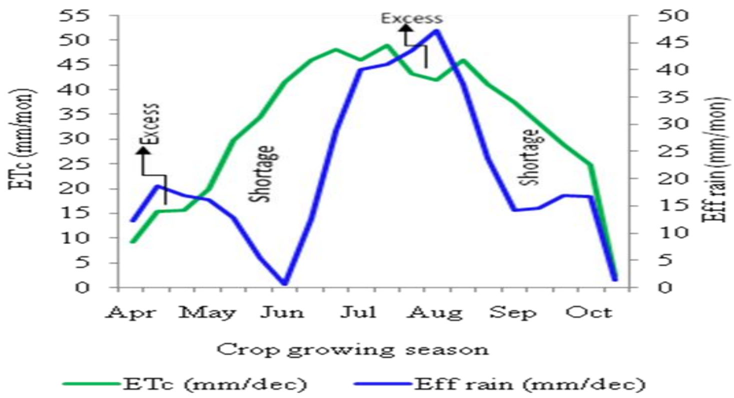

Figure 4. Excess and shortage of water for Sorghum

Figure 5 compares the effective rainfall and crop evapotranspiration (ET_C) in different growing stages for tef. In contrast to sorghum, excess moisture is available during the initial and development stages (July-August). However, shortage of moisture is observed during the mid and late season stages (September- November). This shortage can critically affect yield of tef between September and November.

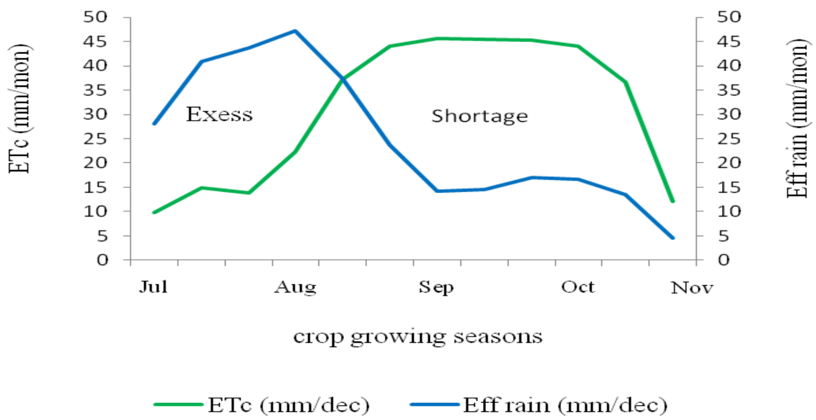

Figure 5. Excess and shortage of water for tef

As seen in Figure 6, excess moisture is available during the initial growth stage of chickpea (August-early September), whereas moisture is critically short during the rest of the growing stages (September-November). Similarly, Fig. 7 shows ample moisture availability during the initial (March-April) and late season (July-August) stages of maize, while the crops may suffer from moisture shortage during the development and mid-season stages (May-July). The peak monthly water requirements happened in the July with 48.1 mm for sorghum, September with 45.7mm for tef, October with 43.3mm for chickpea and June with 64.7 mm for maize.

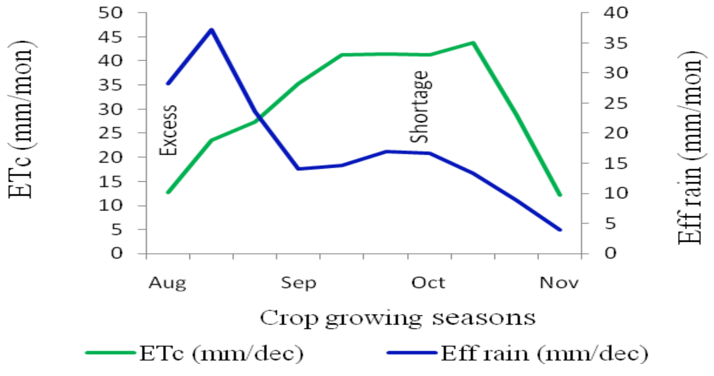

Figure 6. Excess and shortage of water for chickpea

Therefore, as shown in Figs. 4-7, the rainfall amount and distribution does not satisfy the crop water requirement at different stages of crop growth and yield can be adversely affected. Hence, additional water is required to supplement crop growth in the watershed.

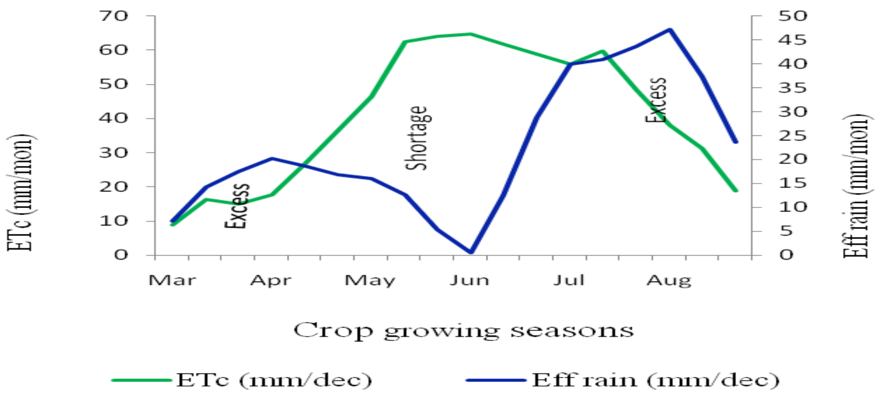

Figure 7. Excess and shortage of water for maize

Table 9 summarizes the total water requirement of the different land use and land cover types for the 2007/2008 cropping season of Lenche Dima watershed. The water requirements of forest (1105 mm per season) are higher than bushes and grazing lands. Grazing land has the lowest water requirement (480 mm per season). In general, due to the largest area coverage of bush land over the watershed, it has the highest total water requirement (demand) (5.1 million m^3 $year^{-1}$) and the lowest water demand is for forest land (1.2 million m^3 per $year^{-}$).

Table 9. Results of forest and range lands water requirement of Lenche Dima watershed for the year 2007/2008

Cover type	Area (ha)	Total rain (mm)	CWR (mm)	P_{eff}(mm)	CWR (10^6 m^3)	Effrain (10^6 m^3)	Deficit (10^6 m3)
Forest land	105.97	689.3	1105.4	579.4	1.2	0.6	0.6
Bush land	766	538.8	664.8	429.6	5.1	3.3	0.3
Grazing land	11.27	417.7	480	339.8	2.5	1.8	1.3
Total			**2250.2**	**1348.8**	**8.8**	**5.7**	**2.2**

For instance, total water depleted for livestock feed production and agricultural production (crop and livestock) were (12,869m^3 $year^{-1}$ hh^{-1}) and (17,718m^3 $year^{-1}$ hh^{-1}) respectively (Table 10). The total depleted water for livestock feed production in the watershed was estimated to be 6.46 million m^3 per year (Table 11).

Table 10. Total depleted water for feed production per year in the Lench dima watershed

Land use types	Area (ha)	Depleted water (m^3ha^{-1})	Total depleted water for livestock feed production (m m^3)
Sorghum	485.08	4662	2.26
Tef	452.83	2231	1.01
Chick pea	27.49	1679	0.05
Grazing lands	528.85	3600	1.9
Enclosure lands	248.43	4986	1.24
Total			**6.46**

NB. For the cultivated land, the depleted water for the crop residues of the three crops were considered
M=million

The results of the survey show that water consumption of livestock varies from water source to water source. Average rates of water consumed in the watershed from different sources were 23±2, 12±1.6, 22±1.75 and 24±2 liters per TLU per day in community ponds, pumps, river and wetland, respectively. On average, the amount of water consumed in the sub-watershed from different sources were 22±2, 21±2.1 and 17±1.8 for Oromo, Kolokobo and Lenche Dima sub- watershed, respectively. At watershed level, the average consumption was 20±2 liters per TLU per day (Table 11).

Table 11. Water consumed (liters day^{-1} TLU^{-1}) by livestock in Lench Dima

Sub watersheds	**Community Pond**	**Pump**	**River**	**Wetland**	**Over all**
	Mean±SE	**Mean±SE**	**Mean±SE**	**Mean±SE**	**Mean±SE**
Oromo	23±3	11±2.1	25±3.3	28±3.4	22±2
Kolokobo	23±2.5	16±2.75	20±2.2	24±2.5	21±2.1
Lenche dima	23±3	12±4	11±2	21±3	17±1.8
Overall	**23±2**	**12±1.6**	**22±1.75**	**24±2**	**20±2**

Location and distribution of community and private ponds are presented in figure 5. Private pond is being used to grow fruit trees and vegetables at Lenche Dima watershed

Total water consumption (m^3/year) of livestock is the sum of total water depleted for feed production and livestock water consumption (voluntary water intake) per year. The total depleted water for feed production was estimated to be 6.46 (million m^3/year) and water consumption was 36,677 (m^3/year). Then the total water consumption of livestock for the watershed was 6.49 (million m^3/year). The percentages of water depleted for feed production was 99.5% and depleted water for voluntary intake (drinking) was 0.5% respectively.

The total human water consumption in Lenche Dima watershed was estimated to be 11065m^3 (including drinking, cooking and bathing). Oromo sub-watershed has the highest water consumption (6717 m^3) because of high population living in this sub-watershed and the lowest was for Lenche Dima (1836 m^3) (Table 9). The water supply for domestic use was from water pumps in the watershed and estimated to be 11408m^3 (Table 12).

Water Balance

The water demand estimates were made for three categories of use: crops and vegetation, livestock and domestic. Crops and vegetation has by far the largest demand 14.34 million m^3 and domestic use has the lowest demand 11065 m^3. Crops and vegetation have 95%, livestock 4.64% and domestic 0.36% water withdrawal in the watershed area. On the supply side, the estimated water supply of rainfall, ponds and water pumps for domestic and livestock use are 10.79 million, 10632 and 11408 m^3 respectively. Comparison of supply and demand shows that water availability significantly lower than the demand. The supply is covering only 75% of the water demand. Water supply estimates show that rainfall accounts for 99.5% and the remaining 0.5% is from ponds and This indicates that the watershed does not meet the water demand for the production of crops, livestock and domestic water use. The different components of the watershed water balance are presented in Table 13 and 14.

Table 12. Total water supply (m^3) from water pumps in Lenche Dima watershed

Month	**2005 water produced (m^3)**	**2006 water produced (m^3)**	**2007 water produced (m^3)**	**Total water supply (m^3)/2year**	**Mean water supply (m^3)/year**
January		701	941		
February		947	1298		
March		949	740		
April		1192	1273		
May		1498	754		
June		1335	1187		
July		637	637		
August		749	908		
September		754			
October		831			
November	361	1237			
December	594	1388			
Total water supply (m^3)	**955**	**12218**	**7738**	**20911**	**10455**

Table 13. Different components of the water balance for the Lench dima watershed

Water supply components	**Water supply (10^5M^3/year)**	**Water demand components**	**Water demand (10^5M^3/year)**	**Balance (10^5M3/year)**
Effective Rainfall	108	Crops and Vegetations	143	-35
			0.19	-0.08
Ponds	0.11	Livestock drinking water consumption		
Total	**108.13**	**Total**	**143.5**	**-35.09**

Table 14. Proportion of water supply and demand in the Lench Dima watershed

Water supply components	Water supply (%)	Water demand components	Water demand (%)
Effective Rainfall	75.2	Crops and Vegetations	95.28
		Live stock feed production	4.5
Ponds	0.08	Livestock drinking water consumption	0.14
Water pumps	0.07	Domestic use	0.08
Total	**75.35**	**Total**	**100**

Conclusion and Recommendations

The results show that the water demand of the crops and livestock was significantly higher than the water supply. This indicates that water available in the watershed does not meet the demands for the crop and livestock production. The existing ponds and water pumps had insufficient capacity to meet all domestic and livestock drinking requirements during the year. This suggests the need for interventions that could be considered for improving the water supply in the watershed including;

- Develop roof and other in-situ rainwater harvesting systems
- Improved hillside soil and water management and agronomic practices to increase and conserve soil moisture and replenish groundwater resources in the watershed
- Developing additional community ponds and other water sources to fulfill domestic and livestock water needs

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Soil-Water Depletion Changes and Water Requirement Satisfaction Index of Major Crops Grown on Bella-Weleh Catchment, Sekota

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Abstract

Water requirement satisfaction index (WRSI) is 'an indicator of crop performance based on the availability of water to the crop during a growing season' that calculated using a water stress index, which helps to determine whether a given crop has sufficient water to achieve its potential yield throughout the growing season. The objective of the study was to quantify the soil-water depletion of barley, wheat and teff crops, evaluating the crops' performance across the catchment and mapping the catchment based on the WRSI of each crop. The catchment was classified on three strata based on elevation, soil depth and soil texture and in each strata barley, teff and wheat farm lands were selected. Gravimetric moisture content was collected under each crop for soil moisture status in a temporal and spatial manner. The probability of dry (P_{80}), normal (P_{50}) and wet (P_{20}) season occurrence in the area was calculated from the logarithmic regression and the values were 403.24 mm, 515.37 mm, and 733.98 mm.

Overall, barely, followed by wheat, had better WRSI as compared to teff. The overall maximum crop evapo-transpiration of barley was 227.9 mm, 231.6 mm and 227.9 mm in the upper, middle and lower sub-catchment farmlands, respectively, whereas the corresponding actual evapo-transpiration was 195.1 mm, 203.3 mm and 208.2 mm. Similarly, the seasonal maximum evapo-transpiration of wheat was 302.4 mm, 305.2 mm and 306 mm in the upper, middle and lower sub-catchment farmlands, respectively, whereas the corresponding actual evapo-transpiration values were 179.7 mm, 197.5 mm and 226.8 mm. The seasonal maximum and actual evapo-transpiration of teff was 336.2 mm and 139.5 mm, 342.0 mm and 159.3 mm, 344.9 mm and 201.0 mm in the upper, middle and lower sub-catchments, respectively. The yield difference among the farmlands was minimum for barely (0.05 t/ha), intermediate for wheat (0.19 t/ha) and high for teff (0.43 t/ha). In most of the measured parameters, the upper sub-catchment was inferior to the lower sub-catchment, clearly showing the differences in resource base among the sub-catchments. Supplemental irrigation and/or water conservation structures should be practiced during the rainfed cropping system in order to get the potential yield of teff and wheat in the catchment and similar agro-climatic areas, especially in sandy-to-sandy clay loam texture soils.

Key words: Water requirement satisfaction index, Moisture deficit, Catchment

Introduction

Understanding the principles of water movement in the soil profile and continuous evaluation of the storage and balance of soil water are important for efficient soil and water management, crop selection, irrigation scheduling and runoff prediction. Water requirement satisfaction index (WRSI) is 'an indicator of crop performance based on the availability of water to the crop during a growing season' (Senay and Verdin, 2002). WRSI is calculated using a water stress index calculation scheme that helps determining whether an agricultural season has performed well and a given crop has sufficient water to achieve potential yield (Hoefsloot, 2004). WRSI indicates the extent to which the water requirement of a given crop has been satisfied in a cumulative way at any growth stage (Mukhala, 2002). FAO studies (Doorenbos and Pruitt, 1977) have shown that WRSI can be meaningfully related to crop production in semi-arid regions, using a linear-yield reduction function specific to a crop. Senay and Verdin (2001) and Abate (1994) reported that when the index falling below 50%, there is a total crop failure, i.e., it is unsuitable for crop production during that particular season for North Western Ethiopia. The WRSI from 51-75% are considered as moderately suitable, while WRSI values larger than 75% indicate adequately available water for a sorghum grown at a given location during that particular season.

Similarly, Diga (2005) reported that WRSI from 100% to 75% resulted in a 49.7% yield reduction in case of Miesso, 40.8% in case of Melkassa and 24.3% in case of Arsi Negele. Further, when WRSI was reduced down to 50%, there was a total crop failure in the case of Miesso and Melkassa, while the reduction was 48.6% for the Arsi Negele. Similar results were found when WRSI was varied across other input level combinations.

Doorenbos and Pruit (1977) reported that wheat should be irrigated when 55% of the plant available water is depleted in the root zone. They suggested that when crop water use is less than 0.10 inches/day this value should be increased by 30% (to 72% allowable depletion) and when crop water use is greater than 0.30 inches/day this value should be decreased by 30% (to 38% allowable depletion). During ripening, the maximum allowable depletion of plant available water is 90%. The optimum soil water depletion level according to grain yield was 35% for each variety and averaged over varieties. The lowest yield was obtained at 65 and 80% depletion averaged over varieties, and yield at 50% depletion was intermediate.

Materials and Methods

Description of the Study Area

The study was undertaken in Bella-Weleh catchment, which is found in Sekota wereda in the northeast of the Waghimra zone at about 725 km north of Addis Ababa. The catchment extends from 12°27’10.8’’N to 12°35’31.2’’N and 38°59’13.2’’E to 39°04’30’’E and has altitude that ranges between 1976-3600 m asl. The catchment is characterized by a unimodal rainfall pattern, which extends from late June to late August or early September, where crops are cultivated in summer season. Mean annual rainfall varies from 333 to 1016 mm. The mean minimum and maximum annual temperatures are 8 and 21^{o}C, respectively. The major agro-ecological characteristics of this catchment are hot and warm sub-moist to semiarid lowland with tepid to cool sub-moist environment in the Bella Mountain that skies up to 3600 m asl.

The general slope range on which the farmlands occur varies between 0 and 8%, but could be normally found on 0-25 % slope range. The soil type is predominantly alluvial deposits, well drained, light to dark brown in color, and with very shallow-to-shallow soil depth, sandy to sandy clay loam in texture, highly eroded and continuously cultivated, with rock outcrops of basalt and sandstone (Akundabweni, 1984).

For this study, the catchment was divided into four categories as mountainous, upper, middle and lower sub-catchments/strata. The three sub-catchments of the cultivable area were delineated based on selected criteria viz. elevation, soil color, soil depth, soil texture and slope. From each of the selected sub-catchments/strata, three farmlands of *teff*, wheat and barley were selected, making a total of nine farmlands. The farmers themselves managed the selected farmlands. The individual crop cultivars selected, ‘Awragebs’ of barely, ‘Zebenai’ of wheat and ‘Bunie’ of *teff*, were the locally grown ones. The mountainous part of the catchment shares around 45% of the total area followed by the lower sub-catchment (29%), the middle sub-catchment (13%) and the least is the upper sub-catchment (12.5%).

Soil Sampling and Analysis

From the selected farmlands, disturbed (by using auger) and undisturbed (using core sampler) soil samples were collected at four points in each farmland by using traverse sampling technique and composited to make one composite sample per farmland. The soil properties that were determined and/or analyzed included particle size distribution, bulk density, water retention characteristics curve, pH, OM, exchangeable cations (Na^+, K^+, Ca^{++}, Mg^{++}), CEC, EC, total nitrogen and available phosphorus.

Quantification of WRSI and Soil Water Depletion

The decadal water requirement satisfaction index was estimated using the following relationships

$$WRSI = \frac{\sum ET_a}{\sum ET_c} WRSI = \left(\frac{\sum ET_a}{\sum ET_C}\right) \times 100\%$$

Where:

WRSI = decadal water requirement satisfaction index (%),

ET_a= decadal actual evapo-transpiration (mm), and

ET_c= decadal potential crop evapo-transpiration

Since there was no irrigation and the ground water table is too deep to affect the root zone moisture, the decadal actual crop evapo-transpiration was calculated using the water balance equation:

$$ET_a = P + \Delta SW - (R + DP)$$

Where:

P = total precipitation (mm), recorded using rain gauge

ΔSW = soil water contRibbution or discharge in soil water content (mm),

R = runoff losses (mm), and

DP = deep percolation losses (mm).

The decadal soil water contRibbution (ΔSW) was estimated from the following relationships:

$$\Delta SW = \sum_{i=1}^{n} \frac{(\theta_i - \theta_{i-1})}{100} \times D_i$$

Where:

θ_i = soil water content at the time of end of the decade for the i^{th} layer (% mass),

θ_{i-1} = soil water content at the time of start of the decade for the i^{th} layer (%),

D_i= depth of the i^{th} layer (mm).

During wet periods when either the rainfall exceeds evapo-transpiration (i.e., $P > ET_c$) or the moisture content is above field capacity, the moisture storage, S_t, was determined from the addition of the previous day's moisture, $S_{t-\Delta t}$ (mm), to the difference between precipitation and evapo-transpiration, during the time step. Conversely, when evapo-transpiration exceeds rainfall (i.e., $P < ET_c$) and the moisture content of the soil is at or below field capacity (dry conditions), ET_a (mm), decreases linearly from the potential rate at field capacity to zero at the wilting point (Steenhuis and van der Molen, 1986). Under such circumstances, the ETa was estimated using the following relationship:

$$ET_a = ET_c\left(\frac{S_t}{AWC}\right)$$

However, from late August onwards, runoff (R) and deep percolation losses (DP) were also assumed to be negligible since this time corresponds to the end of the rainy season. The crop ET_c was calculated from the ET_o and K_c using CROPWAT model (FAO, 1998). The CROPWAT 8.0 for windows software was used to calculate ET_o by using the FAO modified Penman-Montheith equation from monthly average wind speed, sunshine hours, min and max temperatures and humidity. The individual crop coefficients were obtained from LEAP 2.10 software for Ethiopia (Hoofslot, 2009) as indicated in Table 1.

Table 1: Crop coefficient with fraction of crop cycle of barley, wheat and teff (adapted from LEAP 2.10 software for Ethiopia (Hoofslot, 2009)

Crop	Initial		Vegetative		Flowering		Ripening	
	Fraction of cycle end	Kc	Fraction of cycle end	Kc	Fraction of cycle end	Kc	Fraction of cycle end	Kc
Barley	0.16	0.3	0.41	0.3	0.84	1.2	1.0	0.25
Wheat	0.16	0.3	0.42	0.3	0.84	1.2	1.0	0.25
Teff	0.16	0.3	0.42	0.3	0.82	1.2	1.0	0.25

The soil moisture depletion was quantified using the following relationship:

$$SMD = (\theta_{FC} - \theta_C) \times D$$

Where:

SMD = soil moisture depletion (mm),

Θ_{FC} = volumetric water content (vol/vol),

Θ_C = current or measured water content (vol/vol), and

D = depth of the root zone considered (mm).

The crop moisture deficit (MD), which descRibbes the intensity of the crop water stress, was estimated from the following assumptions:

$$MD = ET_c - ET_a \qquad \text{if } ET_c > ET_a$$
$$MD = 0 \qquad \text{if } ET_c = ET_a$$

The fraction of available water stored (soil water index) in the crop root zone at the end of a particular decade was then calculated as follows:

$$SWI = \left(\frac{SW_i}{WHC}\right) \times 100\% \; SWI = \frac{SW_i}{WHC} X100$$

Where:

SWI = soil water index (%),

SW_i = soil water content at the ith decade (%), and

WHC = soil water holding capacity (%).

The index indicates the soil moisture status at the end of a particular decade and, hence, used to assess the crop water status in the next decade based on the available moisture in the soil.

Moisture and Meteorological Data Collection and Analysis

Temperature (daily max and min), wind speed (ms^{-1}), sunshine hours, and relative humidity (%) were extrapolated from Michew and Lalibela meteorological stations based on Bekele (2006) as:

$$\text{Sekota} = 0.682 \times \text{Michew} + 0.328 \times \text{Lalibela}$$

Six years (2004-2009) daily rainfall data was obtained from the catchment whereas the remaining 18 years' rainfall data were extrapolated from Michew and Lalibela rainfall data for calculation of rainfall probability. An estimate of the respective rainfall data was obtained by computing and plotting probabilities from the rainfall records based on the method stated in http://www.fao.org/nr/water/docs/CROPWAT8.0Example.pdf.

Soil moisture content was recorded in 10 days interval between July 5 and August 4 and in 5 days interval between August 5 and harvest of the respective crops. The gravimetric water content was determined as the ratio of weight loss after oven drying to oven dry weight of the sample. The gravimetric water content was then converted into volumetric water content by multiplying with the dry bulk density of the soils.

Results and Discussion

Climatic Characteristics

The long-term rainfall data analysis indicates that the rainfall is concentrated in the months of June, July and August. The normal (P_{50}), dry (P_{80}) and wet (P_{20}) seasons rainfall values estimated from the rainfall frequency curve, constructed using the 24 years rainfall record, were 403.24, 515.37 and 733.98 mm, respectively based on the proposed criteria of Elias and Castellví (2006) as reported by Ramos and Martínez-Casasnovas (2010). All the normal, dry and wet season rainfall values indicate that more than 87% of the total annual rainfall occurs during the months of June, July and August and decreases afterwards. This implies that, depending on the length of the crop cycle and the available water holding capacity of soils of the catchment, the probability that the crops may experience terminal moisture stress is high, and Tonietto and Carbonneau (2004) have reported similar implications.

The 2009/2010 cropping season total rainfall was 429 mm, which according to the rainfall values approaches the dry season characteristics. The majority of the rainfall that was recorded during this season was in July (206 mm) and in August (205 mm). The seasonal rainfall trend was also in consent with the long-term rainfall pattern. The decadal rainfall distribution shows that there was even a dry spell between the last week of July and first week of August. Further, the rainfall drops below half the reference evapo-transpiration towards the end of the first decade of September. Once again, the survival of the crops depends on the amount of soil moisture reserve stored during the humid months. Because effectiveness of rainfall depends not only on the quantity of rainfall, but also on the distribution (Hatibu et al., 2003).

Spatial Variability of the Soil Properties

The soils are of sandy loam in the upper sub-catchment, sandy clay loam in the middle sub-catchment and clay loam in the lower sub-catchment in texture according to the USDA soil textural classification. Across the sub-catchments, bulk density decreased from the upper-sub-catchment towards the lower sub-catchment. As a result, the highest bulk density values were recorded in the upper sub-catchment, which according to Murphy (1968) is rated as high. The relatively high bulk density values recorded in the upper sub-catchment might, in addition to the compaction caused by plowing, be due to the dominance of the sand fraction, which weighs more per unit volume compared to the silt and clay fractions.

The total available moisture followed the trends of water content at field capacity and permanent wilting point (Table 2). This clearly shows the considerable spatial difference in the available water holding capacity of the soils in the catchment and their suitability to successfully support or not support crop growth after cessation of rainfall. In addition, the upper sub-catchment has a very shallow soil depth, which resulted in total available moisture (TAM) that was approximately half of that held by the clay loam soils of the lower sub-catchment. The upper sub-catchment soils are, therefore, not effective for moisture storage for later use and crops grown on these sandy loam soils might face moisture stress during a dry spell when compared to the sandy clay loam and clay loam soils of the middle and lower sub-catchment, respectively. In general, the soils of the farmlands in all the sub-catchments have low fertility status although soils of the farmlands in upper sub-catchment had the lowest fertility status. The exchangeable sodium percentage (ESP) in all the soils was below 15% and rated as non-sodic according to Landon (1991).

Table 2: Selected physical properties of soils in Bella-Weleh catchment

Section	Profile depth (cm)	Particle size distribution (%)			Texture class	Bulk density (g/cm^3)	Total porosity (%)	Volumetric moisture content (%)			TAM (mm/m)
		Sand	Silt	Clay				FC	PWP	AWC	
USC	0-40	61.9	22.9	15.2	SL	1.63	38	16.24	8.23	8.01	79.54
	40-58	55.2	25.1	19.7	SL	1.66	37	14.58	6.75	7.83	
MSC	0-40	59.2	19.3	21.5	SCL	1.54	42	21.45	11.29	10.16	94.01
	40-70	49.8	21.1	29.1	SCL	1.57	41	17.31	8.92	8.39	
LSC	0-40	33.5	28.0	38.5	CL	1.35	49	31.83	17.01	14.82	145.29
	40-85	33.1	25.2	41.7	CL	1.41	47	30.36	16.09	14.27	

USC = Upper sub-catchment, MSC =Middle sub-catchment, LSC =Lower sub-catchment, SL = sandy loam, SCL = sandy clay loam, CL = clay loam

Moisture Deficit and Water Requirement Satisfaction Index

Barley farmlands

In all the farmlands, relatively low moisture deficit was recorded during the third decade of July (12-23 days after planting) and second decade of August (33-43 days after planting). These are the periods during which there was high rainfall and high soil water index. As a result, moisture deficit was not a problem at this stage of the crop. Furthermore, the moisture deficit increased to relatively high values towards the end of the crop cycle in all the farmlands except the middle sub-catchment farmlands, which showed a decreasing trend. This is because September was a month with limited rainfall and, therefore, the crop relies on the soil water reserve stored during the months of July and August. Towards the end of September, this reserve moisture must have been depleted and therefore high moisture deficit.

Some variations in water requirement satisfaction index were observed among the farmlands in the three sub-catchments although the seasonal trends were similar (Figure 1). This is due to the spatial variability of moisture stored during a growing period as a result of heterogeneous conditions of surface and bedrock topography and soil characteristics as suggested from Penna et al. (2009) findings. In general, the index in all the farmlands showed a decreasing trend towards the end of the crop cycle. In the upper sub-catchment, the index varied from 43.8% during the second decade of September (at harvest) to 99.2% during the second decade of July (12-23 days after planting). In the middle sub-catchment, it ranged from 46.7% at harvest to 99.4% during the second decade of July. Similarly, in the lower sub-catchment it varied from 63.4% during the first decade of July to 99.4% during the second decade of August (33-43 days after planting).

Considering seasonal averages of the crop cycle, the moisture deficit varied from 2 mm/decade in the lower sub-catchment field to 4 mm/decade in the upper sub-catchment field. Similarly, the mean seasonal water requirement satisfaction index of the barely farmlands ranged from 84% in the upper sub-catchment to 86% in the lower sub-catchment. These values fall in the range of ‘satisfactory’ as per the WRSI rating of Senay and Verdin (2002).

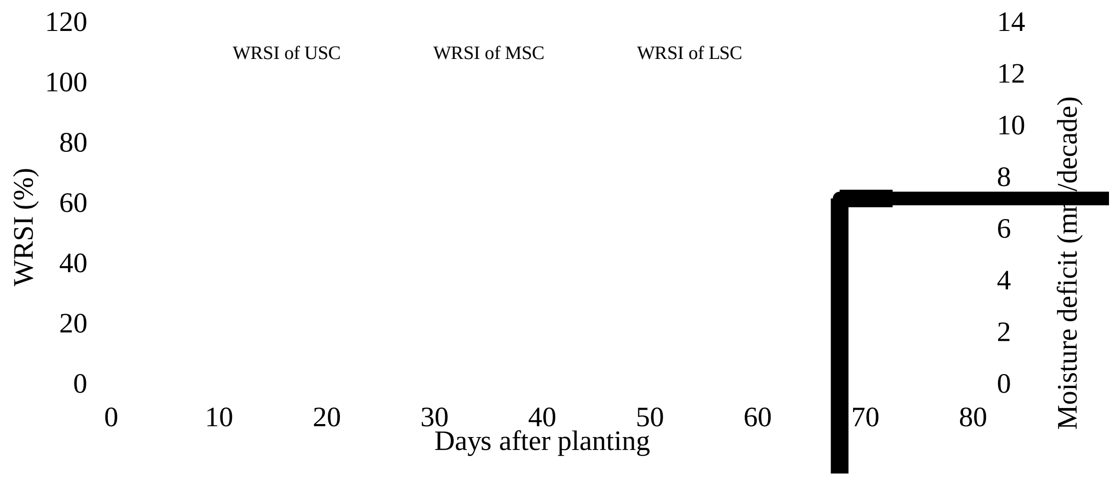

Figure 5: Seasonal variations of water requirement satisfaction index (WRSI) and moisture deficit (MD) of barely farmlands in Bella-Weleh catchment. USC = Upper sub-catchment, MSC =Middle sub-catchment, LSC =Lower sub-catchment

Wheat farmlands

In all the farmlands, the moisture deficit was the lowest during the second decade of July followed by the second decade of August. This was so because there was high rainfall during these decades and expectedly the soil was near saturation. Furthermore, the crop was at its early stage during the second decade of July (only 12 days after sowing) and therefore had low water requirement. On the other hand, the deficit was the highest in all the farmlands during the third decade of September (79 -90 days after planting). This was due to the low rainfall during the decade, no rainfall during the previous decade and then low soil moisture storage. It is also interesting to note that the moisture deficit showed three distinct patterns across the whole of the crop cycle. From 7 to 49 days after planting, there was generally low but irregular pattern of moisture deficit followed by a consistently sharp increase between 49 and 79 days after planting and a consistent decrease between 79 to 96 days after planting. The decrease in moisture deficit towards the end of the crop cycle regardless of low available soil moisture could be related to the low water requirement of the crop at this stage. Within the wheat farmland of the catchment, the average moisture deficit of the season varied from 12.26 mm/decade in the upper sub-catchment to 7.91 mm/decade in the lower sub-catchment.

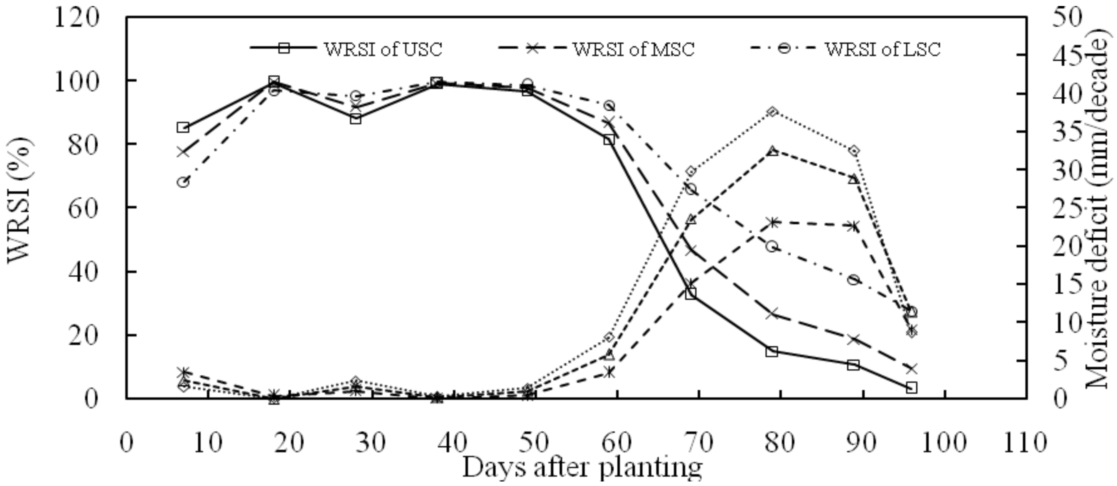

Figure 6: Seasonal variations of water requirement satisfaction index (WRSI) and moisture deficit (MD) of wheat farmlands in Bella-Weleh catchment. USC = Upper sub-catchment, MSC =Middle sub-catchment, LSC =Lower sub-catchment

The water requirement satisfaction indices of the wheat farmlands in the three sub-catchments showed irregular patterns between third decade of July and August (i.e., 7 and 49 days after planting). Between the third decade of August and harvest of the crop (i.e., 49 to 96 days after planting), however, the indices decreased consistently reaching the lowest value at harvest. In all the farmlands, relatively high values of WRSI were recorded during second decade of July and second and third decades of August. Furthermore, the decrease in WRSI was more severe on the farmlands of the upper sub-catchment compared to the middle and lower sub-catchment farmlands.

Another feature observed in Figure 2 is that, until 79 days after planting, WRSI decreases as moisture deficit increases and vice versa. However, between 79 and 96 days after planting, WRSI was decreasing as the moisture deficit was also decreasing. Comparing wheat farmlands in the three sub-catchments, the mean seasonal water requirement satisfaction index was the lowest (61.26%) in the upper sub-catchment and the highest (73.03%) in the lower sub-catchment.

Teff farmlands

The variation in seasonal moisture deficit and water requirement satisfaction index of *teff* farmlands in the three sub-catchments are indicated in Figure 3. The moisture deficit at sowing time in all the farmlands were the lowest as *teff* is used to be sown in a wet soil. The trend of moisture deficit showed two basic features. Between late July and mid August (from sowing to 40 days after sowing), the moisture deficit was nearly zero in all the farmlands. Between mid August and end of November (i.e., 40 to 90 days after sowing), the moisture deficit consistently increased to reach maximum at 90 days after sowing in all the farmlands. This was the period during which the rainfall was about to stop or there was only little to replenish the moisture depleted by evapo-transpiration. During this peak period, the highest and the lowest moisture deficit was 44 mm/decade in the upper sub-catchment and 35 mm/decade in the lower sub-catchment, respectively. The decrease in moisture deficit observed towards the end of the crop cycle, regardless of the low available soil moisture, could be related to the low water requirement of the crop at this stage.

The average seasonal moisture deficit in the *teff* farmlands of the catchment varied between 20.9 mm/decade in the upper sub-catchment and 15.0 mm/decade in the lower sub-catchment. The average seasonal moisture deficit in the middle sub-catchment was 19.0 mm/decade almost equivalent to that of the upper sub-catchment.

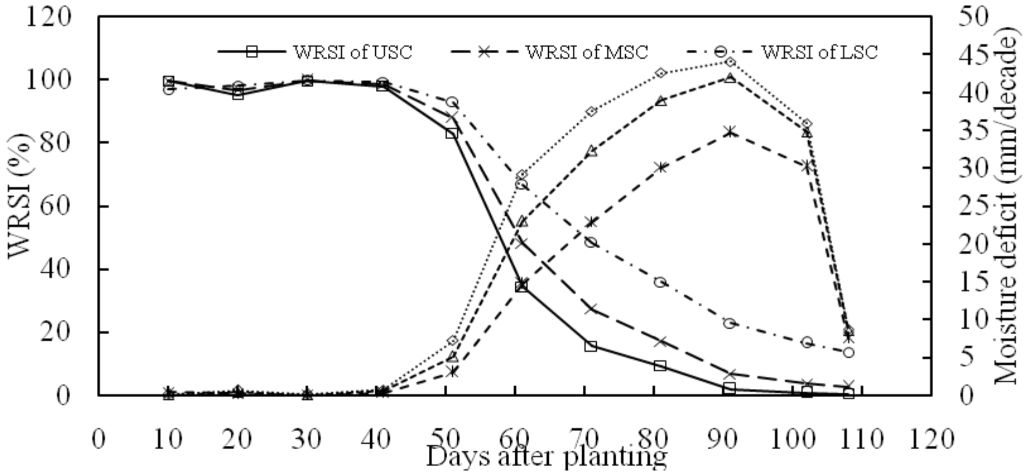

Figure 7: Seasonal variations of water requirement satisfaction index (WRSI) and moisture deficit (MD) of teff farmlands in Bella-Weleh catchment. USC = Upper sub-catchment, MSC =Middle sub-catchment, LSC =Lower sub-catchment

The water requirement satisfaction indices under *teff* farmlands of the catchment followed the trend of moisture deficit but in opposite direction. Between sowing and 40 days after sowing, there was high WRSI in all the farmlands, as this period (between late July and mid August) received relatively high rainfall. Between 40 to 90 days after sowing, the WRSI steadily decreased and reached the lowest value at the end of the crop period. Between 90 to 105 days after sowing, the WRSI of the upper sub-catchment farmlands reached zero before the crop has finished its lifecycle, indicating the presence of critical moisture deficit in the sub-catchment. The farmlands of the lower sub-catchment had relatively better WRSI during the dry periods compared to the farmlands of the other two sub-catchments.

Classification of farmlands based on the barley, wheat and teff WRSI

The values indicate that the WRSI of *teff* and wheat were in the range of 'crop failure' and 'satisfactory' rating, respectively, whereas that of barely was, on average, adequate throughout the crop cycle. The results further signify that the two crops, wheat and *tef*, will face chronic terminal moisture deficit when grown in the three sub-catchments of Bela-Weleh catchment. The classification of the sub-catchments as per their WRSI of the three crops is illustrated in Figure 4.

The results indicate that, as the rainfall distribution is very poor and concentrated in two months, the choice of planting time and the length of the crop cycle are very important scenarios to be considered. Barely had better WRSI because of relatively early planting and shorter cycle of the crop. On the other hand, wheat experienced some terminal moisture stress owing to its relatively late planting and longer crop cycle. Similarly, *teff* had the lowest WRSI due to very late planting and relatively longer crop cycle than barely and wheat.

It would be advisable to look the yield data and yield potentials of the crops. *Teff* and wheat can give above 2 tons/ha (personal contact with Wereda Bureau of Agriculture and Rural Development experts) while in the catchment, they gave even less than 0.5 ton/ha. As a comparison, barley can give reasonable yield with appropriate agronomic practices other than moisture conservation packages as the soil nutrients are depleted. The differences in yield of barley would have been because of the dry spell that has occurred during the growing season and soil nutrient status across the catchment. Next to barley, wheat can give relatively acceptable yield as the WRSI values are satisfactory, but can be enhanced by practicing soil and water conservation technologies and application of supplemental irrigation. For *teff*, especially in the upper and middle sub-catchments, there is a need to apply supplemental irrigation.

The overall maximum crop evapo-transpiration of barley were 227.9 mm, 231.6 mm and 227.9 mm in the upper, middle and lower sub-catchments, respectively. The determined actual evapo-transpiration of barley were 195.1 mm, 203.3 mm and 208.2 mm in the upper, middle and lower sub-catchments, respectively. There was minimum yield differences of barley among the farmlands observed as the range was 0.05 ton/ha.

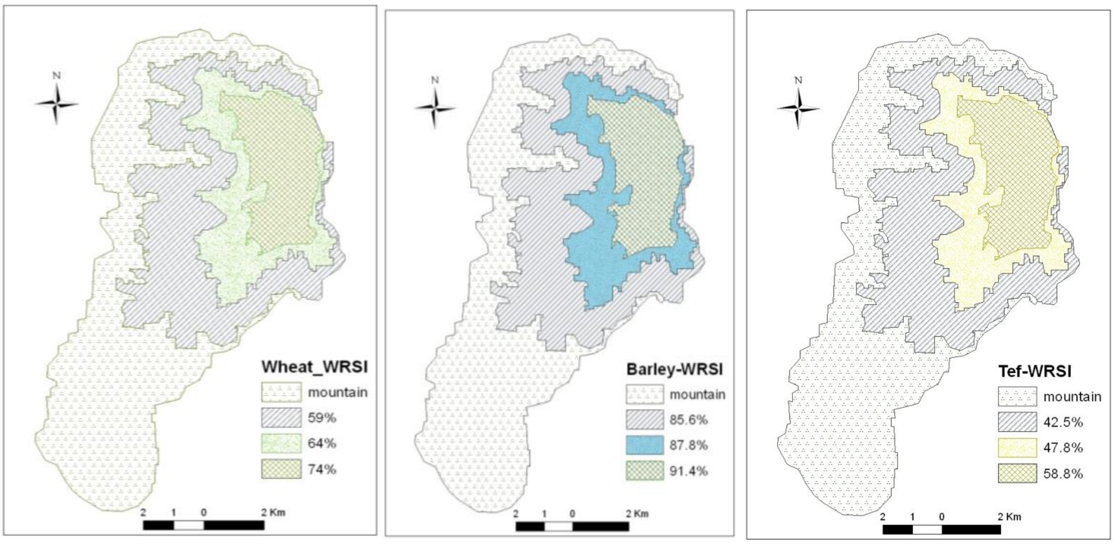

Figure 8: Map of seasonal water requirement satisfaction indices of wheat, barley and *teff*

The actually transpired amount of water by wheat were 179.7 mm, 197.5 mm and 226.8 mm in the upper, middle and lower sub-catchments, respectively. From these differences in the potential and actual evapo-transpiration could result in yield differences in the catchment. There was a moderate yield difference of wheat among the farmlands observed as the range was 0.19 tons/ha.

The seasonal maximum evapo-transpiration of *teff* were 336.2 mm, 342.0 mm and 344.9 mm in the upper, middle and lower sub-catchments, respectively. There was high difference in the actual evapo-transpiration of *teff* across the farmlands and it was 139.5 mm, 159.3 mm, and 201.0 mm in the upper, middle and lower sub-catchments, respectively. When compared with the above two crops, *teff* actually evapo-transpired less than the potential evapo-transpiration. The yield difference of *teff* between the upper and lower sub-catchments was high and maximum as the range was 0.43 tons/ha which doubles the yield obtained in the upper sub-catchment farmlands.

Soil Moisture Depletion with Soil Depth across the Farmlands

The lowest mean difference, which was 4.05 mm and non-significant in mean difference, was observed in the upper sub-catchment farmlands of barley in the 40-58 cm soil depth because of its shallow depth and the associated little capacity to store adequate moisture (Table 3a). Similarly Gregory (1989) and Sharma (1990) reported that shallow root depth has no significant role in moisture retaining for extended dry spell periods for crops. The mean difference among the soil moisture depletion in the farmlands and respective soil layers are significant except in the 40-58 cm and 40-70 cm soil depths of the upper and middle sub-catchment farmlands, respectively. On the other hand, the maximum mean difference at wheat farmlands was 43.18 mm in the lower sub-catchment in the 40-85 cm soil layer, preceded by the upper 0-40 cm depth with a mean difference of 31.51 mm (Table 3b). This result is in line with the work of Penna et al. (2009), who from inspection of soil moisture data time series, reported that hill slope-averaged data over different depths are relatively close to each other after rainfall events, and their difference increases with time during the dry-down. The soil moisture depletion in the *teff* farmlands increased to a maximum from 40 days after sowing to harvesting time and this period indicates the extent to which *tef* crop suffered from the moisture deficit due to exhaustion of the available soil moisture (Table 3c). The 0-40 cm soil layer in the lower sub-catchment farmlands was high and above from all the layers in the soil moisture depletion trend signifying the ability to store and release moisture.

Conclusion and Recommendation

The climate and environmental resource base of crops play a dominant role in their survival, growth, development and ultimate yield production from which almost all food chains start. In the Ethiopian condition, rainfed agriculture plays and will continue to play a dominant role in providing food and livelihoods for an increasing population. The rainfall is very erratic, unpredictable and drought occurs very frequently. Due to continuous cultivation with low input to return the mined nutrients and organic matter content washed by erosion on the northern part of Wollo, soils of this region are shallow in depth, have very low moisture retention capacity and low organic matter. These adversities of climate and soil resulted in the prevalence of soil moisture deficit for most of the year, which led to the loss of crop production.

Considering the average seasonal water requirement satisfaction index of the crops, the WRSI in all the sub-catchments was adequate for barely, satisfactory for wheat and very low resulting in crop failure for *teff*. Soil moisture depletion trends in all the sub-catchments also followed the rainfall trend and were high during dry periods and low during wet periods although there were considerable differences in the level of depletion among the sub-catchments. In this catchment and similar agro-climatic areas, barley can give reasonable yield with rainfed cropping system without practicing water conservation practices and/or supplemental irrigation concerning water shortage and its influence. On the other hand, supplemental irrigation and/or water conservation structures should be practiced during the rainfed cropping system in order to get the potential yield of *teff* and wheat in this catchment and similar agro-climatic areas, especially in the sandy-to-sandy clay loam texture farmlands.

Table 3: One-way sample t-test of soil moisture depletion (mm) with depth under barley (a), wheat (b) and teff (c) farmlands

(a)

	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Mean	Std. Error Mean	95% Confidence Interval of the Difference	
							Lower	Upper
SD of USC 0-40 cm	2.59*	7	0.036	14.16	15.45	5.46	1.24	27.08
SD of USC 40-58 cm	1.73	7	0.127	4.05	6.61	2.34	-1.48	9.57
SD of MSC 0-40 cm	3.25*	8	0.012	21.09	19.48	6.49	6.11	36.06
SD of MSC 40-70 cm	2.03	8	0.076	10.40	15.35	5.12	-1.39	22.20
SD of LSC 0-40 cm	4.64**	7	0.002	45.28	27.59	9.76	22.21	68.35
SD of LSC 40-85 cm	4.18**	7	0.004	67.53	45.72	16.16	29.31	105.75

(b)

	t	Df	Sig. (2-tailed)	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
							Lower	Upper
SD of USC 0-40 cm	3.58**	9	0.006	16.12	14.24	4.50	8.00	28.13
SD of USC 40-58 cm	3.02*	9	0.015	4.84	5.08	1.61	1.57	11.49
SD of MSC 0-40 cm	3.60**	9	0.006	19.65	17.26	5.46	9.69	36.43
SD of MSC 40-70 cm	2.65*	9	0.026	10.48	12.48	3.95	2.81	25.26
SD of LSC 0-40 cm	4.54**	9	0.001	31.51	21.94	6.94	18.10	57.14
SD of LSC 40-85 cm	3.57**	9	0.006	43.18	38.29	12.11	20.89	81.90

(c)

	t	Df	Sig. (2-tailed)	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
							Lower	Upper
SD of USC 0-40 cm	4.46**	10	0.001	19.76	14.68	4.43	10.51	28.86
SD of USC 40-58 cm	3.74*	10	0.004	7.09	6.29	1.90	3.90	12.91
SD of MSC 0-40 cm	4.42**	10	0.001	24.08	18.06	5.45	14.72	37.58
SD of MSC 40-70 cm	3.61*	10	0.005	12.59	11.56	3.48	7.53	25.97
SD of LSC 0-40 cm	5.58**	10	0.001	35.59	21.15	6.38	24.96	56.07
SD of LSC 40-85 cm	5.36**	10	0.001	32.19	19.91	6.00	22.73	69.45

t-values with *,** are significant at 0.05 and 0.01 significant level

USC = Upper sub-catchment, MSC =Middle sub-catchment, LSC =Lower sub-catchment

Acknowledgement

We are very much indebted to acknowledge the Amhara Agricultural Research Institute (ARARI) and the Sekota Dry Land Agricultural Research Center (SDARC) for their all round support of the study. This study was financial supported by the Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA).

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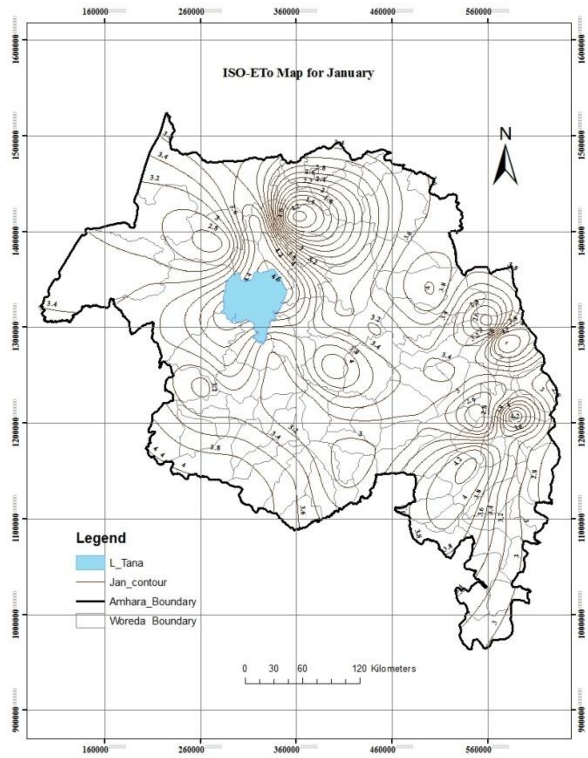
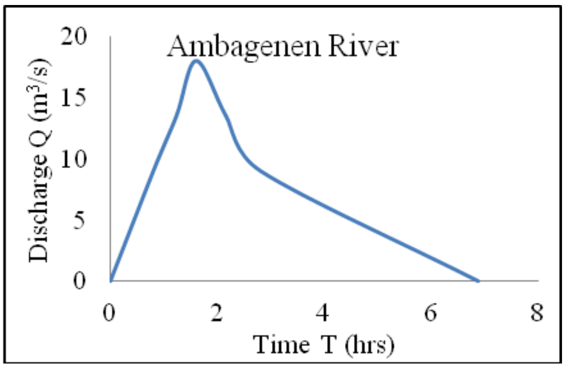
PART 5

REFERENCE EVAPOTRANSPIRATION, HYDROLOGY AND IMPACT OF CLIMATE CHANGE ON WATER RESOURCES





Spatial and Temporal Characteristics of Reference Evapotranspiration in Amhara Region, Ethiopia

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Abstract
The FAO Penman-Monteith equation is the standard method which is commonly used for estimating reference evapotranspiration (ET_o). This method requires use of full weather data measured at the principal stations. Here, we used 25 principal stations in Amhara region to calculate ETo. In addition to this, we tested Hargreave, Thorntwait and Blaney-Criddle techniques to calculate ETo so as to choose best estimating model for the region at 19 temperature stations using Penman-Monteith as a reference. The statistical analysis of the results of these models showed that Hargreave model is the best among the tested techniques. As a result, this model is then calibrated and empirical coefficients at each station were determined for estimating ETo. Finally, Iso-ETo map for Amhara region is developed using thin-plate smoothing splines interpolation method in Geo-statistical analysis based on a total of 44 stations. This work can be used as an input for agricultural research and development in water resource planning, irrigation scheduling, design of irrigation schemes and hydrological studies in Amhara region.

Keywords: Penman-Monteith, Temperature stations, Hargree, Iso-ETo map, Amhara region

Introduction

Design of an irrigation system, estimation of crop water requirement, planning irrigation scheduling, drainage and hydrological studies all critically demand information on reference evapotranspiration (ET_0). The need for development of several approaches for quantification of ETo for a given area may arise from the relative importance of the parameter in both agricultural and hydrological fields. These techniques vary from sophisticated empirical models that employ climatic data as an input to the direct measurement techniques received from instrumentations.

Equation developed by the United Nations Food & Agriculture Organization (FAO) is normally considered to be a standard method for estimating reference evapotranspiration (Allen et al., 1998). This technique requires relatively larger number of data such as relative humidity, sunshine hour, wind speed and air temperature. This technique will be challenged when there are limited measured meteorological parameters which is a common phenomenon in the Amhara region. This calls for development of alternative ETo estimation techniques for wide range of use. In this study three alternative ETo estimating models which require maximum and minimum air temperature data were compared and calibrated against the ETo estimated by Penman-Monteith. Finally, best ETo estimating model was selected that employes temperature data alone in order to develop Iso-ETo map of the Amhara region. This work was designed to meet three objectives: 1) to select appropriate ETo estimation methods for areas of inadequate meteorological information in the region; 2) to generate regional information on spatio-temporal trends and distribution of reference evapotranspiration for water resource planning, irrigation scheduling and hydrological studies; and 3) to develop Iso-ETo maps for the Amhara region.

Material and Methods

Data acquisition

Monthly weather data with five parameters such as sunshine duration, wind speed, relative humidity, minimum and maximum temperatures were collected from 25 principal stations in Amhara Region for the period of 2000 - 2008. In addition to these, temperature data measured over 19 temperature stations in the study area were also collected. The spatial distributions of these meteorological stations are shown in Figure 1.

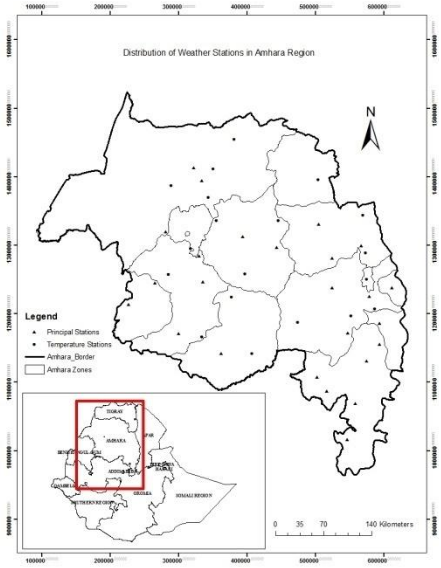


Figure 9. Spatial distribution of the Meteorological stations in Amhara Region

Data Analysis using ETo Models

The Penman-Monteith equation (FAO-PM) of the Food and Agriculture Organization of the United Nations is employed herein to calculate monthly reference evapotranspiration (ETo) over the 25 principal stations for each of the 12 months. This was done using the mean values of the meteorological parameters of each station over the study periods. We introduced the three energy and mass balance models namely Hargreave (E_H), Thorntwait (ET_{Th}) and Blaney-Criddle (ET_B) methods for ETo estimations. These models are the most commonly used and simple to estimate ETo by using only the temperature data. The temperature data at the principal stations was used to evaluate the performance of the three models. To select best method of estimating ETo among the three alternative techniques, the FAO-PM ETo and estimated ETo values were calculated and compared graphically as well as statistically at the 25 principal stations. Finally, the best fit model with the FAO-PM ETo was chosen and calibrated. This model was used to estimate ETo at the temperature stations in the region.

FAO-Penman-Monteith equation

The FAO has proposed FAO-PM ETo method as the standard method for estimating reference evapotranspiration [Allen, 1998] given by,

$$ETo = \frac{0.408 \times \Delta \times (Rn - G) + \gamma \times 900}{(T + 273)u_2(e_s - e_a)\Delta + \gamma(1 + 0.34u_2)}$$

Where, ETo is the calculated reference evapotranspiration (mm/day), Rn is the net radiation at the crop surface (MJ/m^2 day), G is soil heat flux density (MJ/m^2 day), T is air temperature at 2 m height (^{o}C), u_2 is wind speed at 2 m height (m/s), e_s is saturation vapour pressure (Kpa), e_a is actual vapour pressure (Kpa), e_s-e_a is saturation vapour pressure curve (Kpa/^{o}C), γ is psychrometric constant (Kpa/ ^{o}C).

Hargreaves Model

In areas where climatic data such as solar radiation, wind speed and relative humidity data are missing, the Hargreaves model can be employed as an alternative to estimate ETo of a given area [Allen et. at., 1998]. Mathematically Hargreaves Model is given by:

$$ET_H = 0.0023 \times Ra \times (T_m + 17.8)(\mathrm{T_{max}} = T_{min})^{0.5} ,$$

Where, ET_H is estimated reference evapotranspiration (mm/day), Ra is extraterrestrial for daily period (mm/day), T_{max} and T_{min} are the maximum and minimum temperatures, and T_m is daily mean temperature. The monthly estimated ETo can be obtained by multiplying the number of days in a given month. The mathematical method of estimating Ra for a given latitudinal position and month is described by [Allen, 1998],

$$Ra = 0.408 \frac{24(60)}{\pi G_{sc}} d_r[\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_{s\omega}],$$

Where, G_{sc} is solar constant equals (0.0820 MJ/m^2/min), d_r is inverse relative distance Earth-Sun, ω_s is sunset hour angle in radian, φ φ is latitude in radian, and δ δ solar declination in radian.

Thornthwaite Model

Thornthwaite model is one of an empirical method used for estimating the evapotranspiration from mean temperature data. This method was developed principally from rainfall and runoff data of drainage basins. It has been used extensively by agriculturists, foresters, and agricultural meteorologists. The relative simplicity of the methodology is its few data requirement (i.e. only mean temperature and latitude data) contributed for wide usage and acceptance of this technique. Many users proved existence of high correlation between measured evapotranspiration and the Thornthwaite estimate even though the Thornthwaite method is empirical. The equation developed by Thornthwaite which relates the mean temperature to evapotranspiration is given by,

$$EP = 16\left(\frac{10T_m}{J}\right)^a,$$

Where, EP is potential evaporation in mm/month in a standard month of 30 days, J is yearly heat index written as,

$$J = \sum_1^{12}\left(\frac{T_m}{5}\right)^{1.514},$$

Where, T_m is the monthly mean temperature in month m, and a is an empirical exponent given by

$$a=0.000000675\,J^3 - 0.0000771\,J^2 + 0.01792J + 0.49239.$$

According to Thornthwaite for a month with D_m number of days and a mean day light hour N_m, estimated evapotranspiration ET_{Th} can be obtained from,

$$ET_{TH} = EP\frac{D_m N_m}{360}.$$

Blaney-Criddle method

Estimation of reference evapotranspiration (ETo) can also be done by empirical model which is developed by The Blaney-Criddle. Mathematically, it is defined as,

$$ET_B = P(0.46T_m + 8),$$

Where, ET_B in mm/month, P is the mean daily percentage of annual day time hours. The value of ET_B in mm/day can be obtained by dividing the number of days in a given month.

Statistical Analysis

The procedures and calculations of estimation of ETo for the three models were carried out by preparing a MATLAB script, while the FAO-PM ETo is obtained using Instat statistical software. Here, the estimated ETo results of the three models were subjected to statistical analysis by least square technique. This was done by considering the FAO-PM ETo as the dependent variable and ET_{TH}, ET_B, and ET_H as independent variables. Accordingly, a simple linear regression was developed using the following relation,

$$ETo_{est} = a \times [\text{an independent variable}] + \text{b},$$

Where, ETo_{est} is estimated ETo, a is slope and b is intercept of the regression line. Consequently, the values of the regression parameters were determined for each station by using least square. Then the performances of the models were evaluated using statistical parameters (i.e. Root Mean Square Error (RMSE) and Coefficient of Determination (R^2)). According to Gavilan et al. (2005) and Paulo et al (2009), the mathematical equation used for computing these standard parameters are,

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{12}(\text{ETo}-\text{ETo}_{est})^2}{12}}, \quad (\text{ mm/day}),$$

Where, the summation is done over 12 months, ETo_{est} is the estimated ETo using an alternative models for each month.

On the other hand, the coefficient of determination (R^2) is given as ,

$$R^2 = \frac{\textit{explained variation}}{\textit{total variation}} = \frac{\sum_{i=1}^{12}(\text{ETo}_{est} - \overline{\text{ETo}})^2}{\sum_{i=1}^{12}(\text{ETo} - \overline{\text{ETo}})^2},$$

Where, $\overline{\text{ETo}}$ is mean of FAO-PM ETo over the twelve months.

Results and Discussion

Estimation of Reference Evapotranspiration (ETo)

Mean monthly ETo values obtained from the FAO-PM and estimated (ETo_{est}) results of the three alternative models were compared for the study period over 25 principal weather stations with a full data sets. The overall aim of analyzing these techniques is to choose best ETo estimating model for the Amhara Region. The mean monthly FAO-PM ETo in mm/day for the study period is shown in Table 1. Relatively higher values FAO-PM ETo is observed in March, April and May in the western Amhara while in the eastern part this is observed in April, May and June. Graphical analysis was also done to inspect patterns and trends of ET_{TH}, ET_B and ET_H with respect to the FAO-PM ETo in all stations.

It was generally observed that Blaney-Criddle method over estimates ETo values as compared to Hargreaves. On the contrary, Thornthwaite model under estimates ETo values in all stations with the exception of Matema station. Thornwaite model at Matema station showed significantly different pattern for the months of March, April and May. This might be attributed to the limitations of the model. That is, mean monthly temperatures of these months exceed 31^{o}C and the model was recommended only for areas where mean temperature ranges are less or equal to 26 ^{o}C [Paulo C. S. et al., 2009, Yagob D., 2006].

The values of the statistical parameters a, b, RMSE, and R^2 corresponding to the three alternative ETo estimation models were analyzed. The parameter RMSE is used to quantify the differences between the FAO-PM ETo and the ETo*est* for the three models. The value of RMSE varied from 0.03 - 0.12, 0.04- 0.15, 0.07- 0.17 mm/day for the Hargreaves, Thornthwaite and Blaneye Criddle, respectively. Higher value of R^2 and lower value of RMSE are observed in 22 stations out of 25 for the Hargreaves model. The results of these parameters for each station and the value of the slope (a) and the intercept (b) for Hargreaves model (ET_H) are presented in Table 2.

FAO Penman–Monteith versus Hargrave method

Many research outputs have been reported for the calibration of the Hargreaves, the Thornthwaite and the Blaneye Criddle models using FAO-PM ETo as a reference [Gavilan et. al, 2005, Jabloun, 2008, Fooladmand et al., 2008]. In this paper, the statistical analysis presented in Table 2 shows that, Hargreaves model is the best model to choose among the alternatives tested for the region. Hence, in the Amhara

Region at the temperature stations the reference evapotranspiration can be calibrated from Hargraeves model using,

$$ETo_{est} = a \times ET_H + b.$$

Table 2. Mean Reference Evapotranspiration ETo (mm/day) using FAO-PM over Amhara Region (2000 - 2008)

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adet	3.13	3.28	4.19	4.27	4.15	3.42	2.99	2.99	3.44	3.49	3.16	2.59
BahirDar	3.33	3.90	4.41	4.68	4.48	3.78	3.07	3.02	3.43	3.78	3.46	3.07
Chagni	3.62	4.15	4.55	4.81	4.38	3.27	2.86	2.80	3.05	3.23	3.43	3.26
Dangla	3.19	3.73	4.12	4.28	4.12	3.26	2.88	2.84	3.22	3.10	3.04	2.95
Dmarkos	3.54	4.36	4.43	4.42	4.05	3.06	2.58	2.64	3.15	3.70	3.55	3.25
Dtabor	3.28	3.82	4.27	3.91	3.66	3.23	2.79	3.00	3.19	3.26	3.14	3.05
Gondar	3.91	4.59	5.02	4.97	4.75	3.49	3.01	3.21	3.72	3.82	3.75	3.54
Laybir	3.74	4.23	4.80	4.70	4.55	3.52	2.88	2.81	3.03	3.58	3.17	3.44
Metema	4.16	4.82	5.63	6.18	5.96	4.65	3.69	3.65	3.79	4.11	4.17	4.03
Nmewicha	3.18	3.82	3.43	3.49	3.76	3.03	2.46	2.46	2.90	2.97	2.75	2.64
Shahura	4.27	4.94	5.34	5.45	4.97	3.54	2.96	2.93	3.30	3.64	3.77	3.93
A/ketema	4.04	4.63	4.69	4.69	5.02	4.05	2.99	2.85	3.45	4.20	4.06	3.70
D/berihan	3.44	3.97	3.97	3.88	4.08	3.63	2.81	2.84	3.07	3.33	3.26	3.27
Enewari	3.98	4.51	4.49	4.24	4.63	3.62	2.53	2.52	3.26	3.94	3.80	3.60
Majete	3.13	3.94	4.25	4.30	4.92	4.67	4.19	4.02	3.82	3.97	3.57	3.31
M/Meda	3.33	3.86	3.87	3.68	4.28	3.84	3.03	3.01	3.54	3.67	3.28	3.15
Sh/Gebeta	3.27	4.02	4.21	4.10	4.28	3.55	2.81	2.70	3.09	3.62	3.40	3.09
Am/Mariam	3.30	4.05	4.00	4.01	4.37	3.75	2.93	2.95	3.32	3.59	3.31	3.16
Bati	2.91	3.62	4.09	4.31	4.80	4.77	4.18	4.05	3.85	3.72	3.38	2.97
Chefa	3.38	4.49	5.09	4.88	5.35	5.82	4.24	4.39	3.89	4.01	3.80	3.29
Kombolcha	3.14	3.80	4.09	4.31	4.55	4.39	3.94	3.96	3.69	3.49	3.27	3.01
Lalibela	3.96	4.43	4.55	4.65	4.78	3.83	2.74	2.84	3.42	3.95	3.69	3.58
Sirinka	2.87	3.76	4.24	4.47	4.90	4.93	3.87	3.80	3.69	3.71	3.37	2.87
Woreilu	4.02	4.44	4.44	4.50	5.10	4.35	3.09	3.04	3.58	4.21	3.84	3.59
W/Tena	3.26	3.76	4.01	3.89	4.69	3.67	2.79	3.01	3.33	3.45	3.30	3.21

Spatial Distribution of Mean Monthly ETo

To develop Iso - ETo map of the Amhara region, the values obtained at 44 stations (25 principal and 19 temperature stations) need to be interpolated spatially over the region. Use of thin-plate smoothing splines in Geo-statistical analysis is recommended for interpolating climate variables taking into account valued error prediction, data assumptions, and computational simplicity (Hartkamp et al., 1999.). Given one particular interval (x_k, x_{k+1}), linear interpolation in that interval can be given by the formula,

$$f = Af_k + Bf_{k+f}$$

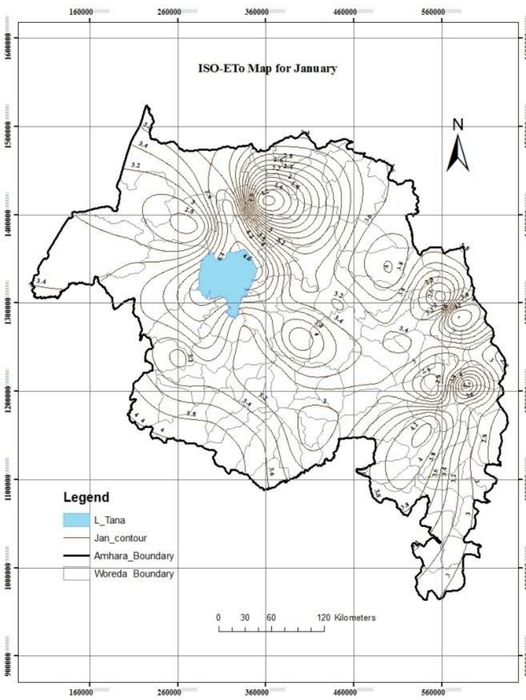
Where, $A = \frac{X_{k+1} - X}{X_{k+1} - X_k}$, $B = 1 - A = \frac{X - X_k}{X_{k+1} - X_k}$

The interpolated values were subject to cross-validation by sequentially omit a point and estimate its value using the rest of the data points, and compare the regression values with the interpolated values. The parameters obtained for a and b as shown in Table 3 are reasonable for spatial interpolation at the temperature stations. Finally, the spatial distribution of monthly ETo for each of the twelve months were developed for Amhara Region.

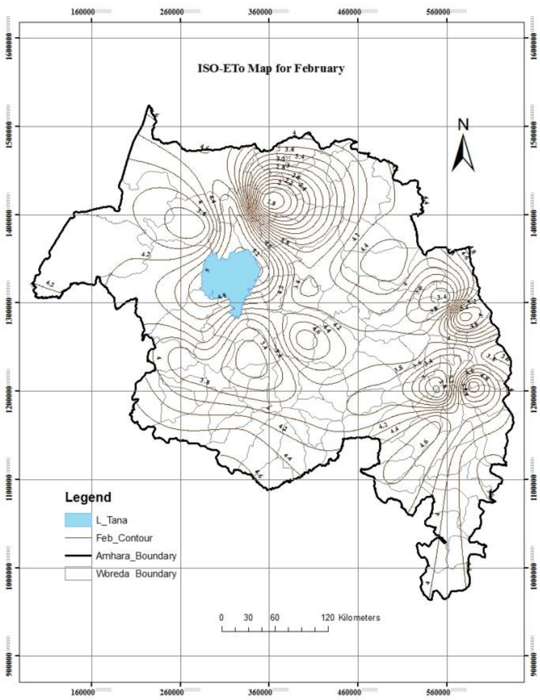
Iso-ETo map showing spatial distribution and trends of mean monthly reference evapotranspiration (mm/day) in the Amhara Region for the months January to December is indicated in the figures 2 ((a) to (l)) below.

Table 3. Values of statistical parameters for each principal station in the Amhara Region

Station name	R^2			RMSE (mm/day)			$ETo_{est}=a*ET_H+b$	
	E_{TH}	ET_B	ET_H	ET_{TH}	ET_B	ET_H	a	b
Adet	0.7591	0.542	0.9245	0.07	0.1	0.04	0.7953	-0.2826
Bahir Dar	0.665	0.4472	0.8736	0.09	0.12	0.06	0.8982	-0.5181
Chagni	0.6434	0.3466	0.9466	0.11	0.15	0.04	0.8290	-0.4668
Dangla	0.5402	0.3628	0.9067	0.1	0.12	0.04	0.8081	-0.3115
Debre Markos	0.6708	0.3644	0.9396	0.1	0.14	0.04	1.1821	-1.1625
Debre Tabor	0.6595	0.373	0.8711	0.07	0.1	0.04	0.8525	-0.0039
Gondar	0.8509	0.4455	0.9683	0.07	0.14	0.03	1.2885	-1.8920
Laybir	0.9627	0.602	0.9678	0.04	0.12	0.04	0.9759	-1.4155
Metema	0.9625	0.689	0.9717	0.05	0.14	0.04	0.8882	-0.7677
Nefas Mewucha	0.7576	0.6456	0.6532	0.06	0.08	0.08	0.5402	1.7166
Shahura	0.9158	0.5153	0.7705	0.07	0.17	0.12	1.6240	-2.3872
Alem Ketema	0.8161	0.489	0.842	0.08	0.14	0.08	1.2106	-1.0719
Debre Birhan	0.1118	0.125	0.7476	0.12	0.11	0.06	1.0699	-0.5780
Enewari	0.4313	0.2035	0.8675	0.15	0.17	0.07	1.3045	-1.1666
Majete	0.76	0.7467	0.9483	0.07	0.07	0.03	0.8390	-0.1116
Mehal Meda	0.292	0.2643	0.5693	0.09	0.09	0.07	1.1062	-0.1836
Shola Gebeya	0.3221	0.2464	0.8165	0.12	0.13	0.06	1.5916	-2.0429
Amba Mariam	0.5169	0.4062	0.765	0.09	0.1	0.06	1.1228	-0.4649
Bati	0.8319	0.8367	0.9694	0.07	0.07	0.03	0.9473	-0.6687
Chefa	0.6706	0.6908	0.8439	0.12	0.12	0.09	1.1003	-1.5550
Kombolcha	0.7838	0.8092	0.9314	0.06	0.06	0.04	0.7921	0.0054
Lalibela	0.92	0.5421	0.884	0.05	0.12	0.06	1.3068	-1.4844
Sirinka	0.7332	0.7557	0.8818	0.1	0.09	0.06	0.9478	-0.4001
Woreilu	0.3121	0.206	0.5387	0.14	0.15	0.12	1.1211	-0.2746
Wegel Tena	0.3877	0.2759	0.713	0.11	0.12	0.08	1.0849	-0.4549


ISO-ETo Map for January
N
Legend
L_Tana
Jan_contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

(a)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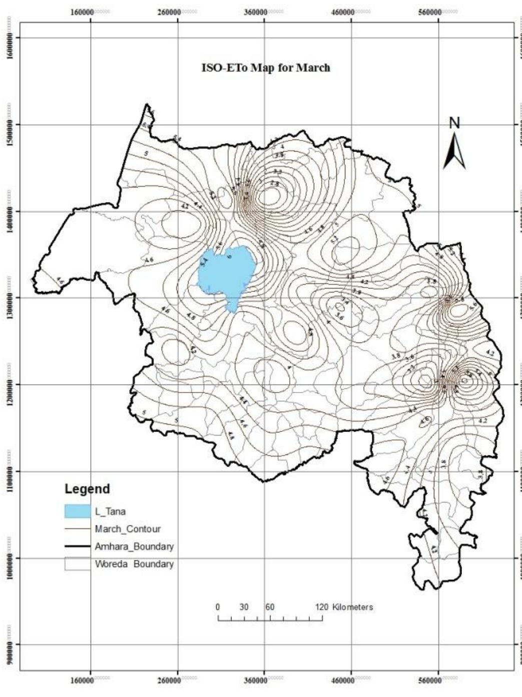
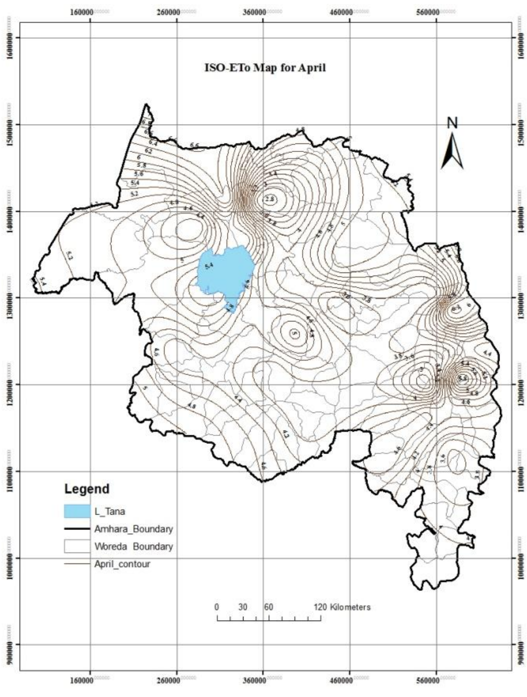
N
Legend
L_Tana
Feb_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

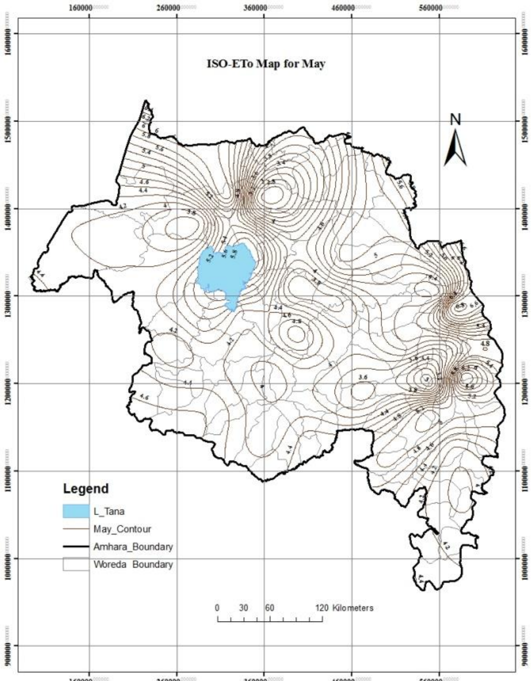
(b)


ISO-ETo Map for March
N
Legend
L_Tana
March_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

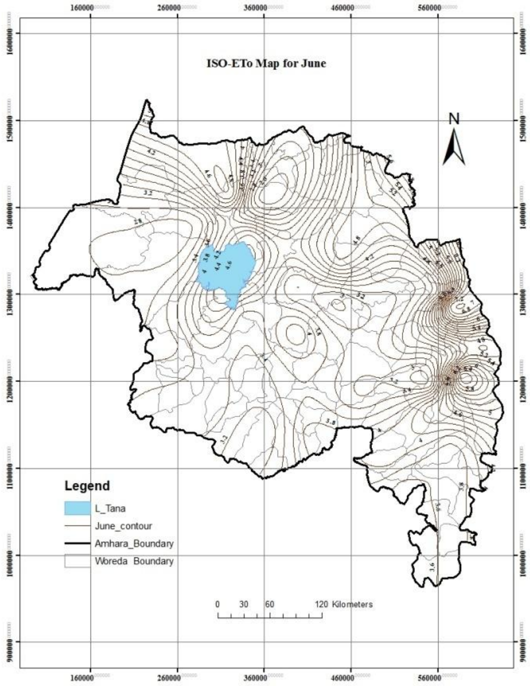
(c)


ISO-ETo Map for April
N
Legend
L_Tana
Amhara_Boundary
Woreda Boundary
April_contour
0 30 60 120 Kilometers

(d)


ISO-ETo Map for May
N
Legend
L_Tana
May_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

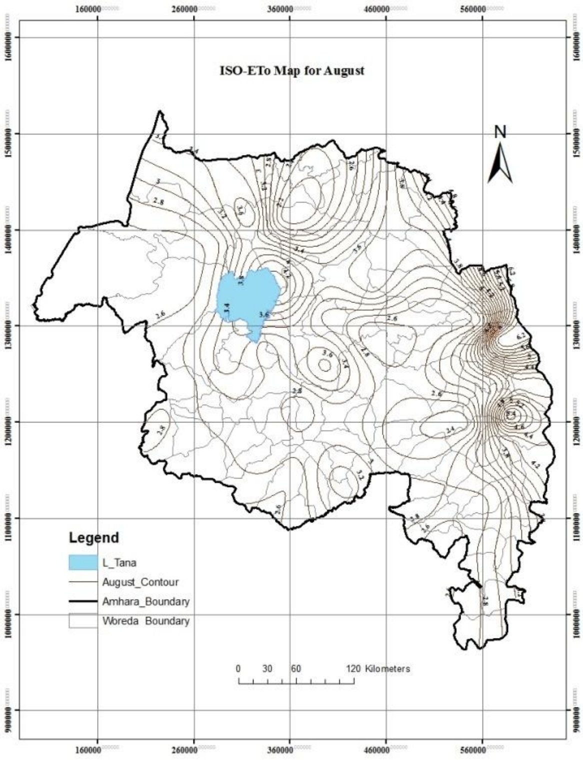
(e)


ISO-ETo Map for June
N
Legend
L_Tana
June_contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

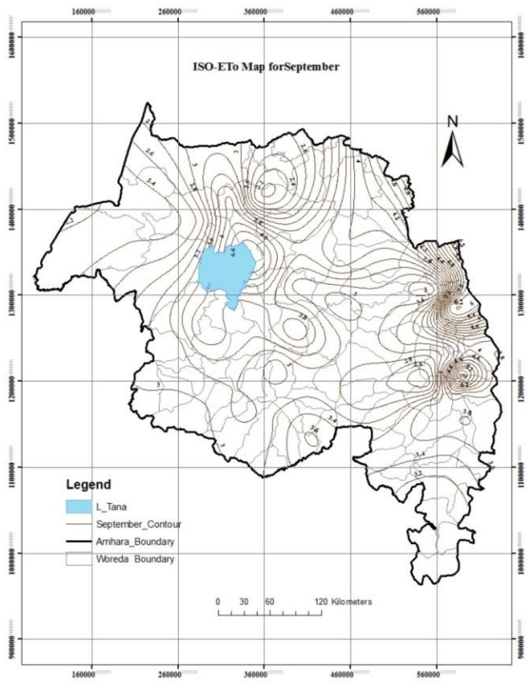
(f)


ISO-ETo Map for July
N
Legend
L_Tana
July_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

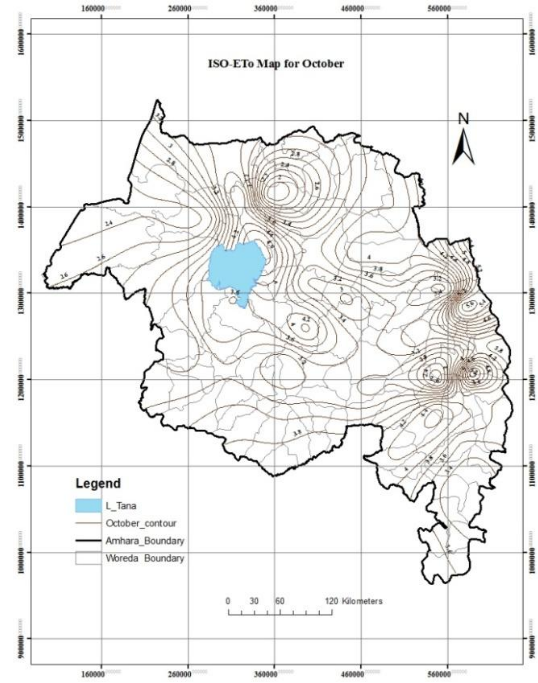
(g)


ISO-ETo Map for August
N
Legend
L_Tana
August_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

(h)



(i)



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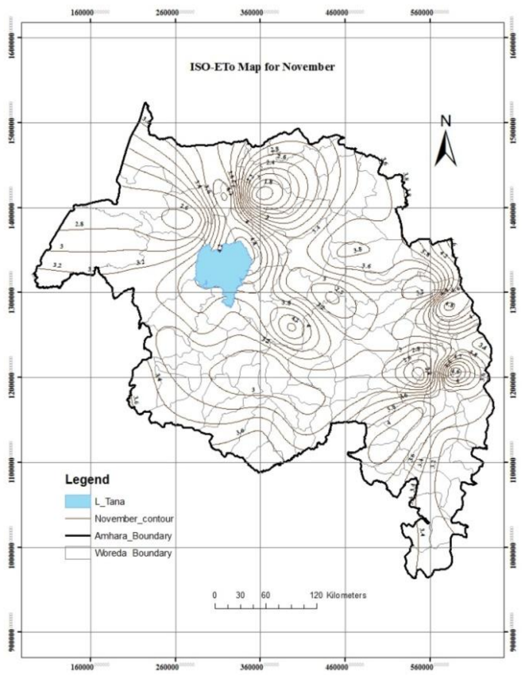
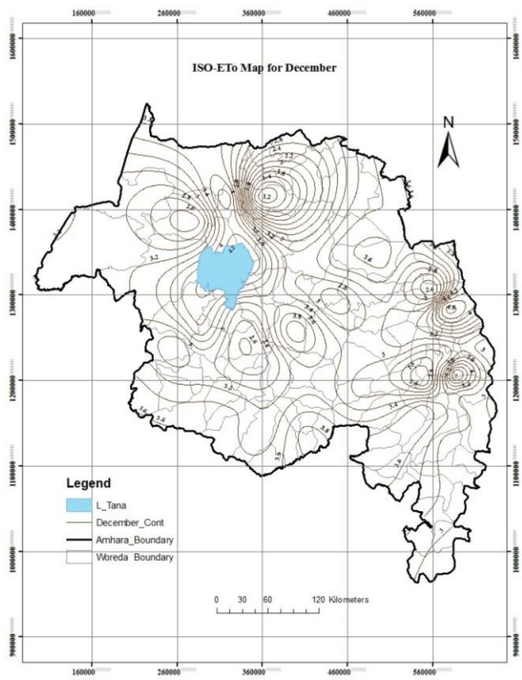


(k)



(l)

Figure 2 Spatial distribution of mean monthly reference evapotranspiration (mm/day) for the months January to December (i.e a to l) of Amhara Region

Table 4. The estimated ETo and the value of regression parameters, a and b, at the temperature stations

Sations	a	b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aykel	1.242	-1.579	2.94	3.85	4.26	4.42	3.94	3.07	2.45	2.87	2.79	2.66	2.77	2.68
AmbaGiorigis	1.250	-1.709	1.48	1.97	2.97	3.15	3.09	2.72	2.25	2.24	2.39	2.08	2.00	1.45
Debark	1.152	-1.155	2.61	3.18	3.68	4.05	3.63	2.77	2.46	2.20	2.53	2.77	2.62	2.14
Adis zemen	0.957	-0.436	4.43	5.15	5.90	4.43	5.54	4.48	4.16	4.21	4.49	4.59	4.36	4.05
Estie	0.812	0.209	4.16	4.71	5.00	5.06	4.92	4.11	3.60	3.65	3.96	4.23	4.24	3.95
Mota	0.864	-0.339	3.17	3.65	3.98	3.99	4.06	3.58	2.86	2.80	3.00	3.13	3.00	2.97
Dembecha	1.023	-1.082	3.58	4.28	4.48	4.48	4.25	3.25	1.76	2.98	3.26	3.62	3.15	3.36
Wotetabay	0.897	-0.581	3.76	4.25	4.71	4.79	4.54	3.80	3.33	3.23	3.72	3.69	3.47	3.70
Zegie	0.934	-0.609	3.86	4.50	5.05	5.26	5.14	4.51	3.72	3.46	3.67	3.61	3.60	3.65
Maksegnit	1.186	-1.410	4.12	4.76	5.67	5.40	5.43	4.34	3.57	3.94	4.27	4.43	4.25	3.81
Yetmen	1.143	-1.059	2.95	4.16	4.52	3.96	4.43	3.82	3.33	3.26	3.59	3.78	3.11	3.82
Sekota	1.069	-0.555	3.68	4.24	4.82	4.99	5.31	4.96	4.04	3.80	4.21	3.84	3.53	3.42
Kobo	1.042	-0.621	3.47	4.37	5.07	5.34	5.99	5.93	5.37	5.14	5.22	4.87	4.21	3.64
AynaBugna	1.185	-0.992	3.51	4.27	5.15	5.00	5.11	4.70	3.70	3.62	3.85	3.96	3.72	3.46
Kabie	0.908	-0.455	2.54	2.85	3.03	2.99	3.05	3.16	2.76	2.60	2.61	2.41	2.41	2.32
Harbu	1.034	-0.401	4.40	5.09	5.77	5.97	6.34	6.42	5.74	5.46	5.41	5.26	4.74	4.40
MekanSelam	0.960	-0.418	3.12	3.70	3.82	3.84	3.53	3.17	2.47	2.45	2.82	3.16	3.06	2.95
Mersa	1.156	-0.598	4.18	5.24	5.70	5.97	6.56	6.80	6.10	5.89	5.74	5.34	4.59	4.37
Haik	0.923	-0.367	3.21	3.88	4.20	4.34	4.54	4.87	4.31	3.90	3.97	3.93	3.69	3.33

Conclusion

Careful analysis of measured weather data with four widely used energy and mass balance models is done to generate regional information on spatial and temporal trends and distributions of mean monthly reference evapotranspiration in Amhara region. Based on results of the linear regression and the statistical parameters of RMSE and R^2, it can be concluded that Hargreaves model can be selected as the most appropriate model for calibration in the process of estimating ETo in the region. The reference evapotranspiration at 44 meteorological stations in the region is produced. Accordingly, spatial distribution of mean monthly ETo map (ISO-ETo Map) is produced for all months using suitable interpolation technique. This work can be used as an input for agricultural research and development in water resource planning, irrigation scheduling, design of irrigation schemes and hydrological studies in Amhara region.

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Development of Synthetic Unit Hydrograph for Watersheds in Lake Tana Sub-Basin, Ethiopia

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Abstract
Unit Hydrograph (UH) is commonly used technique for the characterization and parameterization of watershed hydrology and design of hydraulic structures. UH study was undertaken in four gauged (Megech, Gummaro, Gumara, and Ribb) and two un-gauged (Ambagenen and G/mariam) watersheds of Lake Tana sub-basin, to estimate coefficients and UH parameters for the watersheds. Twenty nine rainfall-runoff events were used and accordingly, twenty nine one hour duration unit hydrographs were developed. Out of the above UHs, twenty five events were used for calibration and the remaining events for validation of Snyder's model. The best single predictor of Ct was found to be Ad, for Cp it was Dd, and for Cb it was Sl. For UH parameters, the best single predictor of Qp was found to be Fr, L for tp, Ad for Tb. Highest R^2 change come about when composite term HKR was added for Ct, Gray for Cp, and S for Cb. For UH parameters Murphy was added for tp and Tb, and Dd for Qp. Statistical and visual comparison between predicted and observed data, revealed that calibrated Snyder's model was suitable for study region under hydro-meteorological similar watersheds and watershed characteristics within the range of model simulation. Therefore, it could be a grant to estimate the required UH parameters for un-gauged watersheds in the region. UH parameter tp (1.60 and 1.31 hr), Qp (18.06 and 13.92 m^3s^{-1}), and Tb (6.87 and 8.86 hr) were estimated for Ambagenen and G/mariam watersheds, respectively. These could be recommended as input parameters during construction of hydraulic structures and hydrological study of the watersheds. However, further studies are needed to be carried out with large number of automatic rainfall data for each watershed including more number of gauged watersheds.

Key words: Rainfall-runoff relation, Un-gauged watersheds, Hydrograph, Snyder's model, Lake Tana sub-basin

Introduction

Ethiopia has 12 river basins with an annual runoff volume of 122 billion cubic meters of water and an estimated 2.6 - 6.5 billion cubic meter of ground water potential (Seleshi *et al.*, 2007). However, due to lack of water storage infrastructure and large spatial and temporal variations in rainfall, there is no sufficient water to produce more than one time per year. Therefore, to overcome shortage of water, construction of earthen dams and hydraulic structures are required at each of the sub basins. In Ethiopia, projects were launched to develop water harvesting structures. Most of them failed due to the utilization of unreliable data during runoff estimation (Daniel, 1997). For determining design discharge for hydraulic structures, a gauged stream flow data and detail information about the rainfall events for that particular watershed is required. However, in many cases rainfall and runoff data are seldom adequate to determine a unit hydrograph of a basin or watershed. This situation is also common in Ethiopia due to lack of gauging stations along most of the rivers and streams. Generally, basic stream flow and rainfall data are not available for planning and designing water management and other hydraulic structures in most watersheds.

Therefore, techniques have been evolved that allow generation of synthetic unit hydrograph. The peak runoff rate and total runoff volume can be obtained from the design storm hydrographs developed synthetically. The best known approach is Snyder's Synthetic Unit Hydrograph method (Raghunath, 2006). Therefore, this model was used for developing synthetic unit hydrographs for un-gauged watersheds in Lake Tana sub-basin. The need for a synthetic method to develop unit hydrograph has inspired many studies (Kull and Feldman, 1998). For calibration and validation of this model basin parameters were collected from DEM with ILWIS software and unit hydrograph (UH) parameters were analyzed from flood hydrograph data collected from Ministry of Water Resource. Besides, coefficients and hydrograph parameters can be modeled in terms of basin characteristics and it will be very helpful for future studies and design works for the hydro-meteorological similar watersheds. Based on the above background, the objective of this study was to develop a synthetic unit hydrograph for selected un-gauged watersheds in Lake Tana sub-basin.

Materials and Methods

Description of the Study Area

Lake Tana sub basin has a catchment area of 15,054 km^2. Geographically it extends between 10.95^0N to 12.78^0N latitude and from 36.89^0E to 38.25^0E longitude. The topography of the study area was generally flat where 60% of the area had average slope less than 10%. However, terrain slope within the basin ranged from 0% to 128%. Major and dominant soil types identified within the sub basin are Luvisols, Fluvisols, Leptosols, Vertisols, Alisols, and Cambisols. Annual rainfall distribution ranges from 964 mm up to 2000 mm in the sub basin.

The selection of un-gauged watersheds in the study area was made on the basis of their irrigation potential and hydraulic structure construction priority given by the regional government. The main criteria considered for the selection of gauged watersheds were the availability of concurrent rainfall and stream flow data. Besides, hydro-meteorological similarity between the un-gauged and gauged watersheds was also part of the se;ection criteria. Based on the above criteria two un-gauged watersheds (Ambagenen and G/mariam) and four gauged watersheds (Megech, Gummero, Gummara, and Ribb) were selected and their drainage maps are given in Figure 1.

Snyder's Model Input

In Lake Tana sub-basin, only a small number of streams are gauged. There are many watersheds for which no stream flow records are available and unit hydrographs may be required for such watersheds. For these reasons Snyder synthetic unit hydrograph generation method was generally adopted. When coefficients are known for watersheds, it is possible to determine any duration unit hydrograph for those watersheds. To develop a unit hydrographs based on Snyder's method, basically five input parameters are required. These are watershed area, length of main stream from outlet to divide, length from centroid of watershed to outlet, and Ct and Cp (model coefficients). Besides the basic five inputs, three regional constants i.e., base time coefficient (Cb), and the time width coefficients of the unit hydrograph at 50% and 75% of the peak discharge, (Cw50) and (Cw75), respectively and a number of watershed characteristics were considered. These model coefficients were determined from four gauged watersheds in the region and transferred to the un-gauged watersheds. Generally, the basic input data used to analyze the regional coefficients of these watersheds were collected in the following ways.

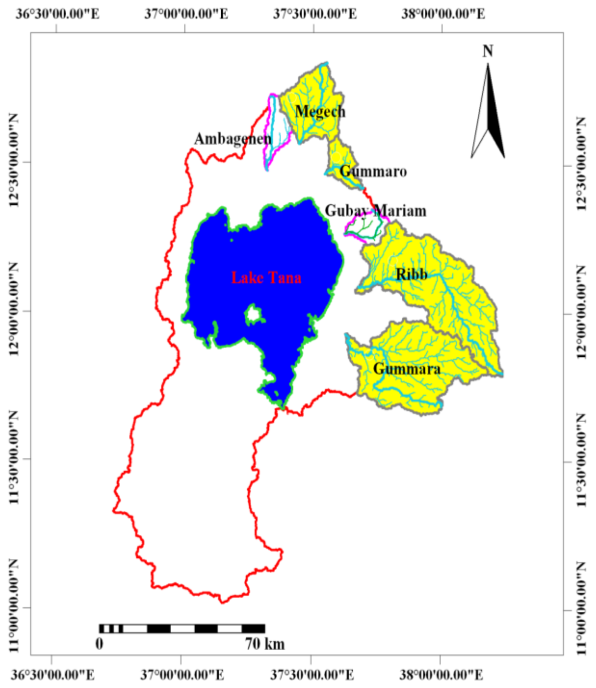

Figure 1. Gauged and un-gauged watersheds used for the study

One of the hydrological data required for this study was the stream flow records taken from automatic continuous water level recorder. The stream flow data for the development of flood hydrographs of the gauged watersheds were collected from Ministry of Water Resources (MoWR) for gauged watersheds. The corresponding rating curve equations were also obtained from the same source. The single peaked water level readings from recording charts were discretized for each gauged river. For this study, twenty nine stream flow data from 1988 through 1995 were used. Out of the twenty nine events only five suitable flood hydrograph events were found at Ribb River, due to frequent siltation problem at the gauging station. For the rest of the watersheds, nine events from Megech River, eight events from Gummaro River, and seven events from Gumara River were generated. Corresponding meteorological data was collected from Ethiopian National Meteorological Service Agency (NMSA). All selected watersheds have rain gauge as per the WMO (1994) recommendation.

The primary elevation data was satellite derived products of the Shuttle Radar Topography Mission digital elevation model data (DEM) with 90 m resolution collected from web site (http:/srtm.csi.cgiar). A multiple step process was enacted in ILWIS

DEM hydro-processing to define watershed characteristics and boundary of the watershed. After the analysis of each step, raster map, segent map, polygon map, and attRibbute table were generated and displayed. The watershed boundary and characteristics were obtained from raster map and attRibbute table generated, respectively. Determining factors which influence the selection of watershed characteristics were requirements to complete the study and extractability with ILWIS DEM hydro-processing. Besides these watershed characteristics, three composite parameters (HKR, Gary, and Murphey) developed by previous researchers (Hickok *et al*., 1959; Gray, 1961; Murphey *et al.*, 1977) were incorporated.

Derivation of Unit Hydrograph from Observed Data

Observed storm hyetographs and their corresponding total runoff hydrographs were studied in detail to derive the required unit hydrograph. Unit hydrographs only model direct runoff hydrographs and they do not account for base flow. The observed hydrographs were separated into base flow and surface flow using straight line base flow separation technique. The total runoff volume for each event was determined by integrating the direct runoff hydrograph. Effective rainfall hyetograph (ERH) was computed by subtracting $\emptyset\Delta t$ from the graph of the observed rainfall, ignoring intervals where ERH is negative. Number of non-zero pulse of rainfall excess (m) was obtained one for all twenty nine events. Thus all unit hydrograph events were one hour duration, since continuous chart was discretized for one hour interval. The ordinates of one-hour unit hydrograph were then computed by dividing the ordinates of direct runoff hydrograph by excess rainfall depth. Therefore nine one-hour UH at Megech, eight one-hour UH at Gummaro, seven one-hour UH at Gummara and five one-hour UH at Ribb were generated. Average unit hydrographs were computed by the arithmetic mean of the peak flows (Q*p*) and times to peak (t*p*) sketching a median line.

Development of Non-Linear Regression Models

A correlation matrix was developed between dependent variables (coefficients and UH parameters) and all single watershed characteristics. Out of all the watershed characteristics, those having high correlation coefficient ($r > 0.8$) were considered for further analysis. Various forms of least square regression equations were tried to evaluate the relationship between individual coefficients and UH parameters, and one of the watershed characteristics. Then parameters which yielded highest value of coefficient of determination (R^2) were considered for final modeling. In the final stage, coefficients and UH parameters were modeled with all watershed characteristics. These analyses were done using SPSS, statistical analysis software package. The dependent variables obtained in the previous step were listed with descending order of R^2 value. Then non-linear regression models were developed with one of the watershed characteristics having highest R^2 first, then another parameter with next lower value of R^2 was added to find out the improvement in R^2. It was used for selection of the best model for the set of data and also the model giving highest value of R^2 was preferred.

Model Validation

How well a model fits with the observed data is determined by pair wise comparisons of model simulated or predicted values with the observed values. Visual observation, coefficient of residual mass (CRM) (Hack-ten Broeke and Hegans, 1996) and student's t-test (Haan *et al.*, 1995) were used to evaluate the performance of the model. The coefficient of residual mass (CRM) was used to measure the tendency of the model to overestimate or underestimate the measured values. A negative CRM indicates a tendency of the model toward overestimation (Xevi *et al.*, 1996). Student's t-test was carried out for finding out significant difference between the observed values and estimated values using the developed models.

Results and Discussion

Coefficients and UH Parameter Modeling with Watershed Characteristics

Correlation matrix

It was found that, watershed area (Ad), drainage density (Dd), longest stream length (L), length from centroid to outlet (Lca), sinuosity (S), main stream channel slope (Sl), basin slope (Sb), fineness ratio (Fr), and three composite terms (HKR, Gray and Murphey) are highly correlated ($r > 0.8$) with coefficients and UH parameters. Since the correlation between main stream length and length from centroid to outlet was very high ($r > 0.99$), the Lca was dropped from further analysis. The correlation matrix is presented in Table 1.

Least square equations of all forms (linear, logarithmic, power, exponential, and polynomial) were developed, taking regional coefficients as dependent variables and individual watershed characteristics as independent variables. It was found that equations developed in the power form had higher coefficients of determination (R^2) as compared to the other forms of equations for the same variables in all cases. So, equations in the power form were used to relate dependent variables with individual watershed characteristics. The best single predictor of C_t was found to be Ad, for C_p it was Dd, and C_b it was Sl. Since these results have not been tested for other regions or basins, they cannot be accepted as general, but still they will provide information about the study region. The best-fit regression equations are listed below.

$C_t = 0.018\ Ad^{0.41}$ ($R^2 = 0.942$)

$C_p = 5 \times 10^{-18}\ Dd^{6.156}$ ($R^2 = 0.923$)

$C_b = 0.139\ Sl^{0.79}$ ($R^2 = 0.955$)

For unit hydrograph parameters, the best single predictor of Q_p was found to be Fr, L for t_p, Ad for T_b. The best-fit regression equations are listed below.

$Q_p = 22.21\ Fr^{1.258}$ ($R^2 = 0.934$)

$t_p = 0.174\ L^{0.666}$ ($R^2 = 0.965$)

$T_b = 1.084\ Ad^{0.336}$ ($R^2 = 0.928$)

Development of non-linear models

The non-linear regression models were developed with one of the watershed characteristics having highest R^2 first, and then another parameter with the next lower value of R^2 was added to find the change in R^2 value. Based on this, it was found that by incorporating Dd, and Sl in the model developed for estimating Ct, the R^2 value increased from 0.942 to 0.995. Similarly the following models were developed for estimating regional coefficient based on highest R^2 value.

$C_t = 0.002\ Ad^{0.436}\ Dd^{0.198}\ Sl^{0.396}$ ($R^2 = 0.995$)

$C_p = 4.571 \times 10^{-14}\ Dd^{4.667}\ (Gray)^{-0.004}$ ($R^2 = 0.980$)

$C_b = 0.063\ Sl^{1.115}\ S^{0.452}$ ($R^2 = 0.989$)

Similarly, the following models were developed for estimating unit hydrograph parameters based on the highest R^2 value.

$Q_p = 2.432 \times 10^{-7}\ Fr^{1.006}\ Dd^{3.105}$ ($R^2 = 0.988$)

$t_p = 0.198\ L^{0.908}\ (Murphey)^{0.186}$ ($R^2 = 0.968$)

$C_b = 1.072\ Ad^{0.368}\ (Murphey)^{0.033}$ ($R^2 = 0.999$)

Table 1. Correlation matrix between dependent variables and independent variables for gauged watersheds

	Q*p*	**t*p***	**T*b***	**Cp**	**Ct**	**Cb**	**Ad**	**Dd**	**L**	**Lca**	**S**	**Sl**	**Sb**	**Fr**
Q*p*	1.00	0.96	0.98	0.97	0.99	-0.28	0.96	0.95	0.96	0.94	0.53	-0.38	-0.82	0.97
t*p*		1.00	0.96	0.92	0.96	-0.42	0.97	0.95	0.99	0.96	0.55	-0.49	-0.84	0.89
T*b*			1.00	0.90	0.99	-0.45	0.99	0.88	0.98	0.98	0.68	-0.54	-0.91	0.98
Cp				1.00	0.95	-0.05	0.86	0.99	0.88	0.84	0.29	-0.15	-0.65	0.88
Ct					1.00	-0.34	0.97	0.93	0.97	0.96	0.58	-0.43	-0.85	0.98
Cb						1.00	-0.55	-0.11	-0.52	-0.58	-0.90	0.99	0.77	-0.38
Ad							1.00	0.87	0.98	0.96	0.72	-0.63	-0.94	0.94
Dd								1.00	0.90	0.85	0.28	-0.19	-0.65	0.83
L									1.00	0.99	0.68	-0.60	-0.92	0.93
Lca										1.00	0.75	-0.66	-0.95	0.94
S											1.00	-0.99	-0.91	0.67
Sl												1.00	0.84	-0.48
Sb													1.00	-0.88
Fr														1.00

Model Evaluation

Visual comparison

The calibrated models performed fairly well at both tails except for Ribb watershed (Figure 2). In Ribb watershed, the synthetic time base is quite very long as compared to the observed ones and this may be for various reasons. One possible reason could be the uncertainty in the observed data from the watershed due to siltation problem and breakage of recording instrument. At the initial tail before peak discharge “hump” hydrograph shape was observed in all watersheds. For all watersheds the calibrated models did not perform well around hydrograph peak. It showed far too little attenuation of peak discharge for Gummaro and Megech watersheds and slight over prediction of peak discharge for Gummara and Ribb watersheds. Besides, slight delayed time to peak than observed hydrograph was observed for Gummara watershed. In general calibrated Snyder's models are acceptable for the study watersheds based on the graphical comparison as per the guidelines of ASCE Task Committee (1993), except slight under estimation and over prediction of basic UH parameters.

Statistical evaluation

As indicated in Table 4.5, low positive values of CRM for t_p, T_b, W50, and W75 show that the calibrated Snyder's model has a slight tendency of under prediction, whereas it has slight tendency of over prediction for estimating Q_p. Student's t-test results indicated critical t value is greater than the t-calculated value, which revealed that all predicted UH parameters had no significant difference to the observed UH parameters at $P > 0.05$.

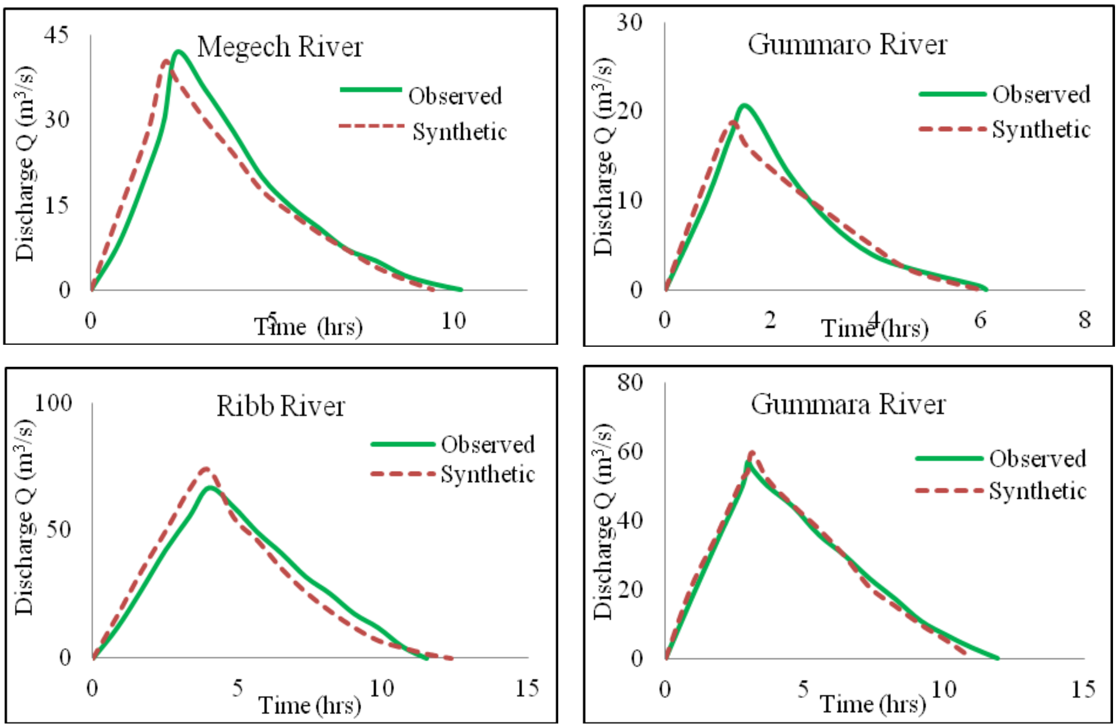

Figure 2. Observed Vs Synthetic unit hydrograph for gauged watersheds

Development of One Hour Duration UH for Un-gauged Watersheds

Snyder's synthetic unit hydrograph parameters for Ambagenen and G/mariam un-gauged watersheds were estimated in accordance to Ramirez (2000) and Arora (2004). As shown in the Figure 3, the estimated peak discharge was to be 18.06m^3/s and 13.92m^3/s their respective time to peak was 1.6hr and 1.31hr for Ambagenen and G/mariam watersheds, respectively. Ambagenen and G/mariam un-gauged watersheds had a time base of 6.87hr and 8.86hr, respectively. Time width of hydrograph at 50% of peak discharge was estimated to be 1.74hr and 1.95hr for Ambagenen and G/mariam watersheds, respectively. Time width of hydrograph at 75% of peak discharge was the estimated time width at 75% of peak discharge to be 0.73hr and 0.95hr for Ambagenen and G/mariam watersheds, respectively.

Table 2. Performance evaluation of developed models using different statistical tests

Name of watersheds	Unit hydrograph parameters									
	t_p		**Q_p**		**T_b**		**W50**		**W75**	
	Obs.	**Syn.**	**Obs.**	**Syn.**	**Obs.**	**Syn.**	**Obs.**	**Syn.**	**Obs.**	**Syn.**
Megech	2.35	1.97	42.05	40.19	10.12	9.38	2.86	2.59	1.43	1.22
Gummaro	1.57	1.25	20.48	18.71	6.11	5.90	1.89	1.81	0.79	0.84
Gummara	2.94	3.11	55.64	60.79	11.91	11.21	4.53	4.45	2.27	2.06
Ribb	4.00	3.84	66.27	73.54	11.50	12.71	4.35	4.24	2.12	1.96
CRM	0.064		-0.048		0.011		0.040		0.080	
t-calculated	0.223		-0.141		0.056		0.150		0.294	
Critical table value ($t_{0.99,6}$) of t-distribution = 3.707										

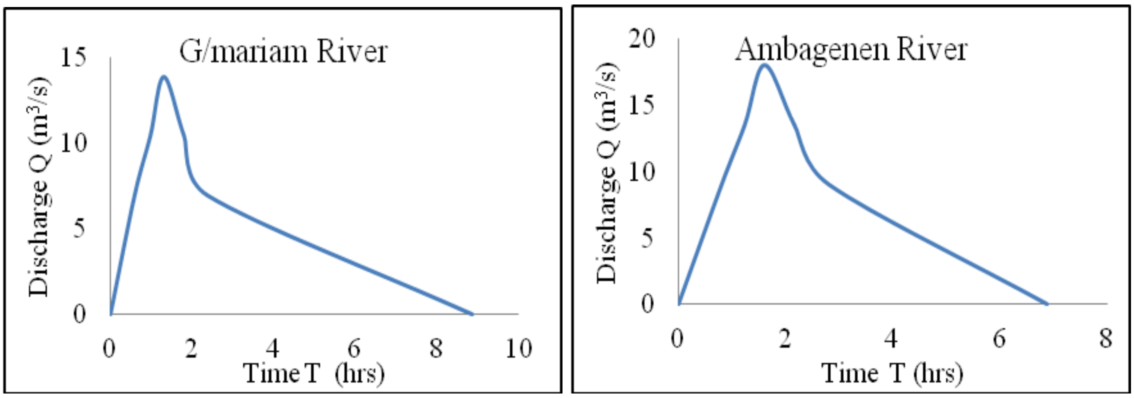

Figure 3. One hour duration synthetic unit hydrograph for un-gauged watershed

Conclusion and Recommendations

This study provided a unique opportunity to estimate unit hydrograph parameters for un-gauged watersheds and the relationship between regional coefficients and unit hydrograph parameters with watershed characteristics in northern and eastern part of Lake Tana sub-basin. The following conclusions had been drawn on the basis of results obtained from the study for the prevailing sub watersheds

1. Values of the coefficients of the Snyder's synthetic unit hydrograph (SUH) equations estimated in this study were seen to have quite considerable variation from values obtained by other investigators in some other regions.
2. Regional coefficients (C_t, C_p, and C_b) and respective unit hydrograph parameters having high variation among gauged watersheds could be modeled with geomorphologic parameters, which could subsequently be used to generate unit hydrographs for un-gauged basins of similar hydrologic condition.
3. Bothe visual and statistical test revealed that the calibrated Snyder's model have well performed, except slight under estimation and over estimation of basic unit hydrograph parameters
4. Synthetic unit hydrograph developed for Ambagenen and G/mariam watersheds based on mean value of time width coefficients, borrowed coefficients and equation would contribute a lot in water resource management and planning works.

In developing such models it is very important to have adequate and reliable sets of hydrological and meteorological data. Unless these data are reasonably sufficient and reliable it is difficult to have better estimate of the required coefficients as they vary quite considerably from region to region. Thus it is recommended that:

- Applying the equations may result in reliable synthetic unit hydrographs, as long as the physical characteristics of the watersheds under consideration are within the range of these characteristics for the gauged watersheds considered in this study. However, for more reliable results the coefficients and equations should be tested on hydro meteorologically similar gauged catchment, which has reliable data set and can be modified accordingly.

- The conclusions from this study are based on four stream flow and three automatic recording rainfall station data. For future studies, large number of station data, specially automatic rainfall recording data should be incorporated to achieve better result.
- In this research empirical equation to estimate regional coefficients and unit hydrograph parameters are modeled with only physical watershed characteristics. However, both rainfall and watershed characteristics should be studied together to improve explanation power of the model.

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Climate Change Impact Assessment on Water Resources of Gumara Watershed, Upper Blue Nile Basin

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Abstract
Recently, there is growing scientific evidence that the global climate has changed, is changing and will continue to change. Climate change is also expected to aggravate current stresses on water resources availability due to rapid population growth and economic development. The major uncertainty in water resources management is the variability of water supply and demand pertaining to changes in climatic variables and in dynamics of river basins. Therefore, the water supply potential of a river basin is sensitive to land use and climate change. Hence, in many river basins steady climatic (stationary) conditions are no longer considered a valid assumption for sustainable water resources management. The case study was carried out on Gumara River where the government has proposed to construct a dam and diversion weir to irrigate 14100ha of land. The aim of this study was to assess the potential impact of climate change on the water resources of Gumara watershed using reliability, resilience and vulnerability indices. Generally, projected maximum and minimum temperature shows an increasing trend for the next century for all scenarios studied. However, the precipitation shows decreasing trend in case of the A2a and B2a scenarios and an increasing trend for the RegCM3-A1b scenario. It is also observed that the reliability index for all climate scenarios reveal above 91%, resilience index of above 96% and vulnerability of less than 30%. Hence, it is concluded that the proposed Gumara irrigation project has high capability to meet the required target demand in 2030s and 2090s, and also it recovers quickly from a failure to meet the demands and satisfying them. Based on the result of performance indices, the decision makers, concerned persons or any water users in the area can be assured that the proposed irrigation project has very good potential to irrigate the required area under 2030s and 2090s climatic condition.

Key words: Climate change, Water demand, Downscaling, HEC-HMS, Gumara watershed

Introduction

Recently, there is growing scientific evidence that the global climate has changed, is changing and will continue to change (NRC, 1998). The latest Assessment Report

(AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) projected that global average temperatures in 2100 will be 1.4-5.8°C higher than the 1980-2000 average. Sea levels are projected to rise 0.18-0.59m by 2100. In Ethiopia, the trend analysis of annual rainfall over the last 50 years shows that a declining trend has been observed over the Northern half and South-Western Ethiopia. It also reveals that there has been a warming trend in temperature. The average annual minimum temperature over the country has been increasing by about 0.25°C every ten years while average annual maximum temperature has been increasing by about 0.1°C every decade. It is interesting to note that the average annual minimum temperature is increasing faster than the average annual maximum temperature (MoWR and NMSA, 2001).

A major uncertainty in water resources management is the variability of water supply and demand pertaining to changes in climatic variables and in dynamics of river basins. The water supply potential of a river basin is therefore sensitive to land use and climate changes. Rapid population growth and economic development are also expected to put extra pressure on demand for water (Solomon, 2002). Hence, in many river basins, steady climatic (stationary) conditions are no longer considered a valid assumption for sustainable water resources management. Therefore, despite its significant computational effort, water resources studies at the river basin level are increasingly linked to regional climate studies. In addition to natural variability, which is incorporated in existing water planning methods, new water projects will have to deal with uncertainty associated with population growth and trends in climate change (Mohamed *et al*, 2005).

Despite its economic importance to the national economy and for the survival of the people around, the design study of the Gumara irrigation project does not consider the future climate impact on the proposed irrigation scheme. Although climate change is expected to have adverse impacts on socio-economic development globally, the degree of the impact will vary across nations. It is expected that climate change impacts are going to be most severe in the developing world like Ethiopia, because of their poor capacity to adapt to climate variability (Gosain *et al*, 2006). Besides, a large part of Ethiopia is arid and semiarid, and is highly prone to desertification and drought; climate change and its impacts are a cause for concern (MoWR and NMSA, 2001). In addition, both observed and Global Climate Models (GCMs) future scenarios suggest a recent amplification of climate contrasts across the globe (IPCC, 2007). Furthermore, most (Conway, 2005; Kim *et al* ,2008; Mohamed *et al*, 2005; Soliman *et al*, 2009 and Soliman *et al*,2008) of the studies made so far are mainly at the basin level. It is advisable to study the impact of climate change in sub-basin level (Yihun, 2009). Moreover, previous climate change impact studies in the Nile Basin have mostly focused on the effect on runoff and the consequences for downstream countries. However, climate change can affect multiple features of water resources, e.g., quantity and quality, high- and low-flow extremes, timing of events, etc (Kim *et al*, 2008).

Hence, assessing vulnerability of water resources to climate change at a watershed level is crucial, which gives an opportunity to plan appropriate adaptation measures that must be taken ahead of time and also to consider possible future risks in all phases of water resource development projects. The main objective of this study is to evaluate the impacts of future climate change on both hydrologic regime and water resources of the Gumara watershed. This study has used a statistical downscaling technique to downscale HadCM3, Dynamical downscaled RegCM3 outputs and a HEC-HMS hydrological model to simulate the possible impacts of climate change on the Gumara watershed. This technique may provide a valuable tool for future water resources management if climate trends, both observed and modelled, can be translated into hydrological impact.

Materials and Methods

Description of the Study Area

The Gumara River is located to the east of Lake Tana and has a total drainage area of about 1893km^2 and 1394km^2 above the gauging station at Gumara. After flowing for a length of 132.5 km, the river joins Lake Tana. It falls between latitude 11^{o}45’ and 11^{o}55’ N and longitude 37^{o}30’ and 37^{o}50’ E. The watershed consists of rugged and undulating topographies with different ridges, valleys and steep slopes which vary from 1790 up to 3700 m asl. The land-use of the study area is categorized as agricultural, agro-pastoral, pastoral and urban which constitutes 59%, 36%, 3.4% and 0.1% respectively. With regard to soil type, Vertisols and soils with vertic characteristics are the dominant soil groups. Chromic Luvisols, Orthic Luvisols, Chromic vertisols and Lithosols covers 56%, 26%, 14% and 2.2% respectively. The annual rainfall is relatively high in the watershed, ranging between 1145 mm and 1523 mm. The maximum and minimum monthly temperature varies between 23^{o}C-29.9^{o}C and 7^{o}C-14^{o}C respectively. Total population of the sub-catchment is 1.1 million (MoWR, 2008).

An earthen dam and a diversion weir will be built on the main tRibbutary of the Gumara river, the Sendega River before its confluence with the main stream for irrigation. The dam has a total catchment area of 385 sq. km at the proposed dam site and a capacity of 24Mm^3. The proposed diversion will be located about 28km below the proposed dam and has an area of 1166km^2. The diversion weir consists of 16.5 m long scouring sluice bays and 75m long ogee shaped weir, with a 2m wide divide wall in between. The full supply discharge is 19.7m^3/s. The cultivable command area is 8940 ha on the left bank and 5160 ha on the right bank, total being 14,100 ha, which is 84% of the gross command area that can be irrigated by the proposed irrigation project.

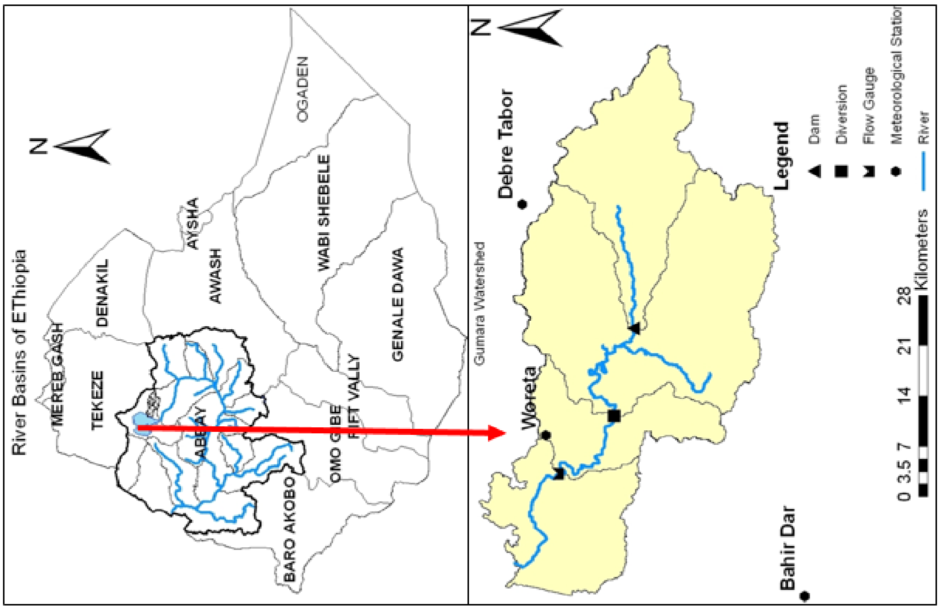

Figure 10-Location of the study area

Methods

The general steps followed in the study of climate change impact on the water resources of the study area are described below:

First, analysis was made of the observed data for the reference-period (1971-2000), checking the absence of trends and the stability of the mean using TREND-program (Simple and reliable time series analysis program to evaluate homogeneity, consistency and independence of data); filling in missed data using Autoregressive (AR) model and generate data using Long Ashton Research Station Weather Generator (LARS-WG) to extending records for stations that have a limited length of data. LARS-WG is a stochastic weather generator which can be used for the simulation of weather data at a single site (Semenov and Brooks, 1999; Semenov *et al*, 2002), under both current and future climate conditions. These data are in the form of daily time-series for a suite of climate variables, namely, precipitation (mm), maximum and minimum temperature (°C) and solar radiation ($MJm^{-2}day^{-1}$).

Then temporal climate change scenarios of precipitation, temperature, and Potential Evapotranspiration (PET) were developed using Downscaling Model from large-scale predictor variable information of GCMs. Based on the availability of public domain GCMs and time, the study used GCM scenarios of HadCM3 from UK Hadley Center and Regional Climate Model (RegCM). HadCM3, running under A2a and B2a emission scenarios (where A2a is referred as the medium-high emissions scenario and B2a as the medium-low emissions scenario), represent rainfall patterns in East Africa relatively well (McHugh, 2005). The main reason for the selection of this model for impact study is that the GCM output is available together with the downscaling tools called Statistical Downscaling Model (SDSM). Among the widely applied statistical downscaling techniques, the multiple linear regressions based model called Statistical Downscaling Model (SDSM) is used in this study. Statistical downscaling is based on the view that the regional climate is conditioned by two factors: the large scale climate state, and regional/local physiographic features (e.g. topography, land-use). From this perspective, regional or local climate information is derived by first determining a statistical model which relates large-scale climate variables (or “predictors”) to regional and local variables (or “predictands”). Then large-scale output of a GCM simulation is fed into this statistical model to estimate the corresponding local and regional climate characteristics. One of the primary advantages of these techniques is that they are computationally inexpensive, and thus can be easily applied to output from different GCM experiments. Another advantage is that they can be used to provide site-specific information, which can be critical for many climate change impact studies. The major theoretical weakness of statistical downscaling methods is that their basic assumption is not verifiable, i.e. the statistical relationship developed for the present day climate also holds the different forcing conditions of possible future climates (Wilby *et al*, 2004)

Besides, the RegCM3 model nested with the ECHAM5 GCM were applied. The RegCM3 predictor variables are available for the A1b experiment. Soliman *et al* (2009) and Soliman *et al* (2008) calibrated and validated RegCM3 over the Blue Nile basin domain. While comparing the model results with different observational data sets, they found that the model was able to accurately simulate the climatology of the Blue Nile. The observed spatial and temporal pattern of temperature and the seasonality and spatial pattern of precipitation were well represented by the model outputs.

The predictand for statistical downscaling using SDSM are mean areal precipitation and temperature derived from Bahir-Dar, Debre-Tabor and Woreta stations using Inverse Distance Weight (IDW) method for the base period from 1971-2000, and PET calculated from the temperature using FAO Penman Monteith method. However, dynamically downscaled RegCM3 outputs are available only for the period 1991-2000, 2031-2040 and 2091-2099 at daily time steps. These data have been collected from IWMI-Ethiopia.

After selecting the hydrological model using the criteria of Cunderlik and Simonovic (2007) and Beven (2000), the HEC-HMS hydrologic model has been set-up and calibrated with climate and stream flow data that represent the current climate. Then, simulation of stream flow corresponding to future climate change scenarios has been made. Moreover, the simulated stream flow corresponding to the different time periods are analyzed to see if there is a trend in flow.

The impact of climate change on water consumption for some of these water uses is not yet clearly known. It is projected however, that climate change will increase irrigation water requirements due to increased potential Evapotranspiration for the doubling of CO_2 scenario. The Gumara irrigation project has been planned for cultivation of cereals, pulses, oil seeds and other horticultural crops. Therefore, the Irrigation requirement has been calculated based on the proposed percentage of land allocated for the different crops using CROPWAT by assuming that the proposed cropping pattern is the same in its design period whereas environmental flow requirement of the area is adopted from MoWR (2008). Finally, the climate impact is assessed for the period 2030s (2031-2040) and 2090s (2091-2100) using indices, these are *Reliability*, *Resilience and Vulnerability indices.*

Climate Impact Assessment Indices

The analysis of potential climate change impact on the water supply system requires simulation of the water balance under different climate scenarios. There are different measures for assessing system performance. This study used three performance indices that will be used to evaluate the climate change impact on reservoir comparatively, these are; *Reliability*, *Resilience and Vulnerability indices.*

1. *Reliability*

Reliability is defined as the probability that a water supply system will be able to meet, within the simulation period, the target demand in any given interval of time (often a year or a month). There are several measures of reliability, which are defined by Thomas et al (2004) as follows.

Time-based Reliability considers the proportion of intervals during the simulation period that the reservoir can meet the target demand. A general expression for estimating this metric is:

$$Rt = \frac{Ns}{N}; 0 < Rt \leq 1 \quad (1)$$

where Rt is the time-based reliability, Ns is the number of intervals that the target demand was fully met and N is the total number of intervals covering the historical or simulation analysis period. When the time interval is monthly or annual, we speak about a monthly or an annual time-based reliability, respectively.

Volumetric Reliability is defined as the volume of water supplied to a demand divided by the total target demand during the entire simulation period, i.e.

$$Rv = 1 - \frac{\sum_{i=}^{n}(D_i - D_i')}{\sum_{i=}^{n} D_i} = 1 - \frac{\text{Total Shortfall}}{\text{Total Target Demand}}; \ 0<Rv<1 \quad (2)$$

where Rv is the volumetric reliability, D_i is the target demand during ith period, D_t' is the volume actually supplied during the ith period and n is the number of time intervals in the simulation, so that Rv=1 if D_i is totally satisfied, i.e. $D_i' = D_i$ for all i. It should be noted that Rv will always be equal to or greater than Rt because during a time interval in which a failure is recorded some release, although lower than the target demand, may still be made.

2. Resilience

Resilience is a metric defining how quickly a reservoir will recover from a failure. The measure adopted in this study is:

$$\varphi = \frac{fs}{fd}, \ fd \neq 0 \quad (3)$$

where φ is resilience, *fs* is the number of individual continuous sequences of failure periods and *fd* is the total duration of all the failures, in other words, φ is the inverse of the average failure duration. Resilience is the probability of a year of success following a year of failure.

3. Vulnerability

The metric known as vulnerability measures the average volumetric severity of failure during a failure period.

$$\eta' = \frac{\sum_{j=1}^{fs} \max(S_j)}{fs} \tag{4}$$

Where η' is the vulnerability, S_j is the volumetric shortfall during j^{th} continuous failure sequence and *fs* is the number of continuous failure sequences.

Because Eq. (4) averages out the maximum shortfall over all the continuous failure periods, then a reduction in fs will cause η' to increase when the numerator in Eq. (4) remains unchanged. A practical situation where this may occur is when the reservoir capacity is increased, with all other factors remaining constant. One way to avoid this anomaly is to remove the averaging in Eq. (4). Another point to note about Eq. (5) is that η' is in volumetric units; a more useful expression of vulnerability is its dimensionless form given by:

$$\eta = \frac{\eta'}{Df}, \ 0 < \eta \leq 1 \tag{5}$$

Where η is the dimensionless vulnerability metric, known as the vulnerability ratio in this paper, and *Df* is the (constant) target demand during failure. (Note that *Df*=*D*, i.e. target demand is the same for drought and non-drought periods.)

Results and Discussion

Statistical Test and Weather Generation

Statistical tests were carried out for observed annual rainfall and temperature data (1971-2000) for absence of trend with Spearman’s rank-correlation method and by t-test for stability of mean using TREND-trend/change detection program. The result shows that minimum and maximum temperature shows an increasing trend whereas precipitation does not show any significant trend.

Because of the short record (1985-2000), data are generated for Woreta station using LARS-WG for the period 1971-1984 to fit the 30 years base period criteria. To evaluate the performance of LARS-WG model, the Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Percent Bias (PBIAS) indices are used as shown in Table 1. Singh *et al* (2004) state that RMSE and MAE values less than half the observed standard deviation (SDev) of the measured data may be considered low and that either is appropriate for model evaluation which is valid for this study. Moreover, Moriasi *et al* (2007) also indicates PBIAS less than or equal to ±15 is very good for model evaluation. Since all indices are within acceptable range, LARS-WG has shown a good performance that indicates representative weather data can be generated from limited data for the study area. Hence, precipitation, maximum temperature and minimum temperature for Woreta meteorological station are generated using LARS-WG for the period 1971 to 1984.

Table 5. Summary statistic and error indices for LARS-WG generated data

Error index	Minimum Temperature	Maximum Temperature	Precipitation
SDev	3.66	2.95	7.58
RMSE	1.65	1.29	3.13
MAE	1.80	1.38	3.42
PBIAS (%)	3.40	0.16	8.90

Future HadCM3 and RegCM3 Outputs

Once the downscaling model has been setup and validated, this model is used to downscale the future climate change scenario simulated by GCM. The statistically downscaled outputs from A2a and B2a scenario of HadCM3 and Dynamically downscaled outputs of RegCm3 are shown in Table 2. The study will not give any conclusion towards a preference for one or the other as the output comes from different GCMs with different downscaling techniques. Here, the 1990s observed scenario is used for comparing the GCMs and downscaling techniques performance whereas the 2030s and 2090s scenario are used to predict the future climate trend.

Table 6. HadCM3 versus RegCM3 future scenario

Scenario	Climate Variables	Changes in	
		2030s	2090s
HadCM3-A2a	Precipitation	-6.3%	-10.6%
	Maximum Temperature	0.50°C	0.98 °C
	Minimum Temperature	0.32 °C	1.17 °C
	PET	1.6%	2.8%
HadCM3-B2a	Precipitation	-5.1%	8.2%
	Maximum Temperature	0.27 °C	0.8 °C
	Minimum Temperature	0.31 °C	0.73 °C
	PET	1.6%	2%
RegCM-A1b	Precipitation	4.7%	3.0%
	Maximum Temperature	2.61 °C	5.89 °C
	Minimum Temperature	1.96 °C	5.11 °C
	PET	8.6%	17.8%

Note: the negative sign (-) shows that decrement

Hence, Table 2 shows that future precipitation may decrease at increasing rate in statistically downscaled HadCM3-A2a and HadCM3-B2a. However, it may increase at decreasing rate in RegCM3-A1b. Future Temperature and PET increase at increasing rate for all scenarios although the rate is higher for the RegCM3-A1b. It is also observed that precipitation is shifting towards October in the case of RegCM3.

HEC-HMS Hydrological Model Development

HEC-HMS calibration performed from 1993-2004, and validation was carried out from 1985-1990 using both daily and monthly time step. The flow data at Gumara gauging station was collected from hydrological department of Ethiopian Ministry of Water Resources. Model validation is used to determine the effectiveness of the parameterization and calibration methodologies. Moreover, efficiency criteria such as Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2), percent difference (D) and RMSE-observations standard deviation ratio (RSR) were used for evaluation of the performance of the model. A summary of HEC-HMS hydrological model development using a combination of Deficit constant loss, Clark's unit hydrograph transformation, monthly constant baseflow and Muskingum routing method is shown in Table 3. In general the model performed reasonably in simulating flows for periods outside of the calibration period, based on adjusted parameters during calibration.

Table 7. The result of model performance criteria

	NSE	R^2	D (%)	RSR
Calibration (1993-2004**)**	0.70 (0.88)	0.72 (0.89)	0 (0)	0.55 (0.35)
Validation (1985-1990**)**	0.73 (0.91)	0.73 (0.92)	-3.4 (-3.42)	0.52 (0.29)

Note: The value outside the bracket is for daily time step and those in brackets is for monthly time step

Hydrological Model Simulation corresponding to Climate Scenarios

The inflow to the Gumara gauge-station is generated by using the downscaled climate variable as an input to the HEC-HMS hydrological model. For comparison purpose the generated flow is compared with the current (1991-2000) mean monthly observed flow.

Table 8. Changes in flow and climate variables

Period	Flow (%)	Precipitation (%)	Temperature (^oC)	PET (%)
	HadCM3-A2a Scenario			
2030s	-9.1	-6.3	0.31	1.6
2090s	-16.4	-10.6	0.97	2.8
	HadCM3-B2a Scenario			
2030s	-8.3	-5.1	0.29	1.6
2090s	-14.2	-5.7	0.63	2.0
	RegCM3-A1b			
2030s	4.1	4.7	2.3	8.6
2090s	3.2	3.0	5.5	17.8

Relative to the 1991-2000 (1990s) condition, the simulated future inflow to the gauge, based on the HadCm3-A2a scenario, shows an average annual decrease in volume by 9.1% in 2030s and 16.4% in 2090s. This may be due to the increment of future temperature, and reduction in future precipitation. In case of HadCM3-B2a scenario, the inflow projected to decrease by 8.3 % in 2030s which exhibits an average annual absolute temperature increase by 0.29^{o}C, PET increased by 1.6% and the precipitation decreased by 5.1% in the same time horizon, While in 2090s, the inflow volume decreases by 14.2% where the absolute annual average temperature increased by 0.63^{o}C, PET increased by 2% and the precipitation decreased by 5.7%. Considering RegCM3, the inflow projected to increase by 4.1% in 2030s which exhibits an average annual temperature increase by 2.3^{o}C, PET increased by 8.6% and the precipitation increased by 4.7% in the same time horizon, while in 2090s the inflow volume increases by 3.2% where the absolute annual average temperature increased by 5.5^{o}C, PET increased by 17.8% and the precipitation increased by 3% as shown in Table 4.

Climate Impact Evaluation: the Performance Indices

The values of the performance measures were computed after generating the inflow to the Gumara storage dam and Diversion weir. It is examined under the standard operation policy of the reservoir i.e.the target demand is fully supplied whenever sufficient water exists; otherwise all the available water is put into supply and the reservoir is left empty. Based on the availability of dynamically downscaled RCM outputs, both current (1990s) and future (2030s and 2090s) generated inflow are considered when quantifying the performance indices. The target demand consists of irrigation water demand and downstream release or environmental demand for the same period.

The averaged time-based reliability and volumetric reliability of the Gumara Irrigation Scheme reveals a value of about 90% and above 92% for all scenarios in both time periods respectively. The result value of above 80% tells that there exist very good potential at the site to meet the demand in terms of time as well as volume. Resilience indicates how quickly a system will recover from a failure. The resilience analysis result in Table 5, value about 100% for all scenarios and time periods, shows that the irrigation scheme recovers quickly for all scenarios in its design period. The volumetric vulnerability, which indicates the average of maximum volumes of shortages, reveals that the shortage is found within the ranges from 3.33Mm3 to 3.44Mm^3 for A2a and B2a scenarios, and 3.45 to 4.4Mm^{3}for the RegCM3 scenario. Comparing the scenarios, the maximum shortage occurred in RCM scenario where the temperature exhibits average increase.

Table 9. Results of performance indices

Scenario	**Period**	**Rt(%)**	**Rv(%)**	***φ*(%)**	***η*(Mm3)**	***ή***
Current	1991-2000	83.8	95.0	100	2.92	0.33
HadCM3 A2a	2030s	91.7	97.0	100	3.41	0.28
HadCM3 B2a	2030s	91.7	97.1	100	3.35	0.27
RegCM3-A1b	2030s	91.7	95.1	100	3.45	0.30
HadCM3-A2a	2090s	89.1	92.4	100	3.44	28.7
HadCM3-B2a	2090s	89.1	93.0	100	3.33	27.5
RegCM3-A1b	2090s	91.7	95.1	100	4.40	0.33

Conclusion

The performance of the Gumara reservoir and diversion weir under the climate change is quantified by using the reliability, resilience and vulnerability indices (RRV-criteria). Based on the study, the following conclusions are drawn as: LARS-WG has shown a good performance that indicates representative weather data can be generated from limited data for the study area. In addition, projected temperature shows an increasing trend for the next century. However, the precipitation shows decreasing trend for A2a and B2a outputs whereas it will increase in case of the ReCM3 output. It is also concluded that the HEC-HMS model is able to capture daily and monthly patterns that can be proven by NSE, R^2, D and RSR values. Hence, HEC-HMS is able to accurately explain the hydrological characteristics of the Gumara watershed. with regard to the inflow of the proposed dam. The average annual inflow volume will decrease for the A2a and B2a scenarios but increase for the RegCM3 scenario for both the 2030s and 2090s. Since a Reliability of about 90% and a Resilience of 100% is found, it is concluded that Gumara reservoir and weir has high capability to meet the required target demand in the 2030s and 2090s in terms of time as well as volume. Moreover, the supply system will recover quickly from a failure to meet the demand to satisfying the target draft. Hence, the proposed scheme has very good potential to irrigate the required area in its life period's climatic condition with the consideration of described limitations.

Based on the findings and limitations noted in this study, the following research gaps were drawn. The GCM outputs, the emission scenarios and the downscaling methods used have certain level of uncertainty. Therefore, further study should reduce the uncertainty by using additional GCMs, downscaling methods and emission scenarios for longer period (rather than only for 2030s and 2090s) to get better result. Besides, the study can be extended by considering change in land use, soil type and other climate variables in addition to temperature and precipitation. Future research should also include adaptation options to climate change. Finally, to make the evaluation of climate change impact more complete, it is appreciable to use addition of other performance indices, such as ratio of AET to PET, Drought Risk Index (DRI) and Sustainability Index (*K*).

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Synthesis of Papers

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The rapid changes in food demand, urbanization and industrial development of Ethiopia along with changing climate are having direct impact on the water access and management. The rapid pace of these changes means that there is a great challenge to meet the water demand of various sectors and achieve at the same time water security, and food and nutrition security. These increased competition for water lead to the reduction of agricultural water use.

With the increased pressure on water resources that have occurred in the past decades, there are changes in the enabling policies and development strategies. The most important changes are:

- Following the Ethiopian water policy development in 1999, formulation of strategies, proclamations and regulations have been made. The water sector strategy in 2001, water sector development program in 2002, water resources management proclamation in 2000, Councils of Ministers regulation in 2005, and River Basin Councils and Authorities Proclamation in 2007 have been developed. Consequently, the Amhara National Regional Water Resource Development Bureau was separately conceived and autonomously established by the Regional Proclamation No.99/2004 and subsequently by the Proclamations No.120/2006, No.167/2009 and No.176/2010 in order that it would be able to fully and exclusively focus on such demanding and inter-related activities as the development, utilization, conservation, protection and control of the region's surface and ground water resources far and wide in an integrated and systematic manner.

- Small scale irrigation sourced from rain water harvesting, hand dug wells, spring development, river diversion, is expanding very fast. This expansion has enabled some smallholder farmers to move away from irrigation of traditional food grain crops and enter to produce high value vegetable and fruit for such crops as tomato and onion and some fruits for market.

- Introduction and widely adopted irrigation technologies such as motorized pumps, rope and washer pumps, threadle pumps, low cost drip irrigation systems enable farmes to access water and expand area under irrigation.

- Extensive medium and large scale irrigation projects and hydro-power development are on the move. This change requires river basin plans and effective and sustainable joint management by relevant stakeholders of the water resources of the basins under the framework of integrated water resources management approach.

These changes are likely to result in much improved utilization, management and protection of the scarse water resources of Ethiopia and Amhara region in particular and increase the benefit of the users.

This proceed cover issues of unclear institutional boundary for service provision and regulatory functions in the water sector, poor water governance and participatory irrigation management, capacity gaps of irrigation extension service, challenges of irrigated vegetable market, low technical and financial performance of irrigation schemes and unequity of water distribution, low storage efficiency and productivity of water harvesting ponds, unbalanced supply and demand of water in rainfed production, and lack of knowledge on hydro-climatic information and impact of climate change.

Part 1 introduces the overall context regarding smallholder irrigation in Amhara region. This section covers range of issues in the areas of water policy and regulations, concepts and practices of integrated water resources management, community participatory irrigation management, extension service, value chain and market, and performance of schemes. The lessons that need to be learned from the context and past experiences of smallholder irrigation development in Amhara region are;

- Though it has been stated in the legal instruments, the focus given to management and protection of water is very much low. Continuous and more use of water for different purposes has been grown from time to time for the last two decades and scarcity of water is becoming an important issue of governance. Therefore, such issues can be solved by strictly focusing on the management and protection of the resources which again requires the way how the legal instruments are set up and enforced. Review of the capacity of implementing institutions and the creation of awareness about the legal instruments and how these tools can be practiced in the community is therefore essential.

- The roles and responsibilities of the MoWE and/or Basin Authorities and the Regional Bureaus as a supervising body must have been clearly set in the proclamation rather than keeping it centralized both the regulatory and service provision functions. In other words, functions of national and sub-regional bodies are not clearly devolved and have blurred boundaries. In addition, the priority for water allocation to different uses such as domestic, environmental and socio economic activities depending on the availability of water resources was not strongly stated either in the proclamation or regulation. There is no detail directive to implement it. The procedures of permit for waste water discharge in to the water bodies, construction along water body banks, dry waste dumping along the water bodies is indicated in the proclamation but the offence settlement is not stated.

- The performance of the existing irrigation schemes is below expectations mainly due to low participation of the users in planning, design and construction process. In view of the increased focus on O and M and Participatory Irrigation Management, SWHISA developed an implementation guideline that describes PIDM procedures and resulting outcomes based on four new small scale irrigation schemes as case studies in the Amhara region. To develop a sense of ownership and responsibility for O and M among the water users, it is required that the users are involved in all the stages of the development of an irrigation system. Especially during the design of the scheme, maximum users' participation is a prerequisite for successful scheme development. Because it is important to consider the elaboration of the design as a step-by-step process during which farmers' priorities and preferences are matched with technical and financial possibilities and it also enhances farmers' sense of ownership. It is also recommended that there is a need to establish a platform comprising an inter-disciplinary Scheme Development Team comprising the three main stakeholders, i.e. IDDP, IADP and CPA

- Irrigation extension service plays an important role in the dissemination of improved irrigation technologies to water users. Despite this, the performance of extension services at most irrigation schemes in the region is below expectation. Experiences in SWHISA indicated that the current level of knowledge and skill gaps of the irrigation extension officers and water users are the areas to be focused for the improvement of existing irrigation extension services in the region.

- The case study on tomato value chain analysis at Kobo district indicated that irrigated vegetable producers earn the least benefit (13.3%) out of the total benefits. Much of the benefits (86.7%) accrue to Mekelle whole sellers. This implies that in the absence of effective market linkages, encouraging farmers to produce commercial vegetables become futile effort for subsistence farmers. Therefore, regulating market of vegetables is critically important to minimize the burdens of imperfect markets from the shoulders of those producers who struggle to shift from subsistence production and enter to smallholder commercial production.

- Case studies on scheme performance evaluation against standard indicators prove that the schemes are operating below the expected performace both in terms of efficiency and effectiveness. Moreover, the impacts of unequal, unreliable, or unscheduled water distribution have long term and short term effects on users. In a short term effects it can clearly reduce yields; arise conflicts between farmers or expose farmers to additional costs, like renting/buying pump to get irrigation water, then finally deterioration of the irrigation infrastructures as a whole. Further more in a long term effects of water distribution changes, farmers have been leaving their villages to seek a job outside the scheme; the remaining farmers are changing their cropping patterns; and deterioration of the system. Siltation of canals and poor maintenance can deteriorate performance of irrigation schemes even if a well established large scale schemes like Gezira in Sudan. Water distribution based on the crops need and the canal capacity balance, as well as; the experience of crop rotation and uniformity throughout a tertiary unit are very important for the equal water distribution among users. Continues follow up of a system; employ soil conservation measures on upstream parts; and continuous maintenance of irrigation canals as well as, creation of hydraulic property concept to farmers - through full participation and cost recovery - are important lessons drawn from Gezira that need actions on the existing and future schemes that we are going to develop in our country and Amhara region.

- Survey study on diseases, insect pests and parasitic weeds of irrigated crops at Ribb irrigation scheme indicates the need to design periodic pest and disease monitoring strategies.

In Amhara region, irrigated agriculture is expanding since recent years. However, farmers are growing most of the irrigated crops with very limited use of improved technologies, which kept the production and productivity of the irrigated system not much better than the rainfed system. For instance, out of the total households that cultivated using irrigation only 14% and 4% of them applied chemical fertilizers at Megech and Ribb areas respectively. On the other hand, the current irrigated agriculture development encourage farmers to produce high value and marketable crops with efficient soil and water management.

To support this effort, part 2 looks at irrigation technologies and knowledge generated and developed such as variety adaptation, improved water management and utilization, and improved soil fertility management. Some of the most important implications of these technologies are;

- Potato and banana are important horticultural crops grown in the high and mid altitude areas of Western Amhara, and mid and low altitude areas of Eastern Amhara respectively. Variety adaptation under irrigation production in Amhara region resulted in yield improvement of 44-50%, 160-175%, and 55-80% over the productivity of local cultivars for potato, desert and cooking type banana, respectively. Moreover, being high value crops introduced into the irrigation system, mungbean varieties which have suitable quality for export are also adapted and produced up to 16 tons per hectar.

- In the irrigated agriculture, farmers experience no or direct adaptation of the recommended fertilizers used in the rainfed agriculture. To fill this gap, nitrogen (N) and phosphorus (P) fertilizer applications are determined for some of the vegetables at different irrigation schemes in Amhara region. For irrigated onion production, application of 150 kg N ha^{-1} and 20 kg P ha^{-1} as first option and 250 kg N ha^{-1} and 20 kg P ha^{-1} as a second option; application of 100 kg N ha^{-1} and 60 kg P ha^{-1} as the first option and 50 kg N ha^{-1} and 60 kg P ha^{-1} as a second option; application of 100 kg N ha^{-1} and 60 kg P ha^{-1}; and application of 200 kg N ha^{-1} combined with 20 kg P ha^{-1} are recommended, respectively for Ribb, Koga, Megech, and Gurumbaba irrigation schemes. The economic optimum fertilizer application of 189 kg N ha^{-1} followed by 162 kg N ha^{-1} for potato production at Koga irrigation scheme can be used. At Megech, application of 150 kg N ha^{-1} and 60 kg P ha^{-1} are found high yielding and economically feasible rates for tomato production.

- CropWat is often used to determine irrigation requirement and irrigation schedules. Using estimations from the CropWat, onion can be irrigated with 33mm water at 7 days interval and 38 mm water at 7 days interval at Ribb and Kobo irrigation areas respectively in order to attain an optimum yield and water use efficiency. Irrigation water requirements of onion are also found to be 462 mm and 570 mm at 14 and 15 irrigation frequencies at Ribb and Kobo respectively. To produce tomato under irrigation in Jarie, South Wollo, application of 14mm depth of irrigation (i.e. 75% of cropwat generated depth) at 11 days interval with a total seasonal irrigation requirement of 168 mm is recommended. Deficit irrigation is also becoming an important strategy to optimize agricultural water use in arid and semiarid regions. In the dry areas of Lalibela, cultivating mung bean under irrigation are advised to apply either 25% ET_c (75% deficit) by creating one period stress at initial or development or late growth stages or 75% ETc (25% deficit) throughout the growth stages. Consequently, these studies imply that verification and validation of the CropWat model need to be done to better estimate the crop water requirement and optimum irrigation scheduling under local conditions.

Part 3 addresses the issue of low storage efficiency and productivity challenge of individual water harvesting systems. Capture potentially damaging rainfall and runoff makes clear sense where rainfall is limited, uneven or unreliable with pronounced dry spells. Yet despite these rainfall limitations, runoff occurs due to high intensity rains and the low water holding capacity of agricultural fields. And with the impacts of climate change already with us, here is water harvesting approach to better use a local resource for livelihood sustenance. The productivity of water harvesting ponds can be improved by increasing the storage efficiency and through integrated production. Storage efficiency of small scale water harvesting ponds can be improved by spreading table salt at rate of 2 kg/m2 in ponds. It improves the storage efficiency from 0.24 to 0.87. One of the purposes of water harvesting ponds is for fish farming (aquaculture). Fish fingerlings have been stocked in water harvesting ponds integrated with backyard vegetable production to supplement family food source. In most farm ponds tested in two zones of Amhara region, fish were successfully grown and the 70 g size fingerlings reached the recommended table size (180 g and more) within 7 months of time. Rectangular ponds were very suitable due to their larger surface area exposed to sunlight.

Part 4 examines issues of demand and supply of water under rainfed conditions. A major uncertainty in water resources management for both rainfed and irrigated agriculture is the variability of water supply and demand pertaining to changes in climatic variables. The rainfall is not dependable to meet the water demands for human, crop and livestock. The results of the case study at Lench Dima watershed in North Wollo show that the water demand of the crops and livestock was significantly higher than the water supply. This indicates that water available in the watershed does not meet the demands for the crop and livestock production. This suggests the need for interventions that could be considered for improving the water supply and sustainable intensification of the rain fed agriculture in the watershed including roof and other in-situ rainwater harvesting systems, hillside soil and water management and agronomic practices to increase and conserve soil moisture and replenish groundwater resources, growing low moisture demanding crops, improving the vegetation cover, and community ponds.

Speciifc to crop water balance study in Sekota area following topo-sequence of the catchment indicate similar results. The water requirement satisfaction index (WRSI) in all the sub-catchments was adequate for barely, satisfactory for wheat and very low resulting in crop failure for teff. Spatial distributions of soil moisture depletion in watersheds followed the seasonal rainfall pattern. The results imply that analysis of spatial distribution of farm water balance support to determin suitability of specific crop production with rainfed alone or with the practice of water conservation practices and/or supplemental irrigation.Therefore, the WRSI tool helps determining whether an agricultural season has performed well and a given crop has sufficient water to achieve potential yield.

The water supply potential of a river basin as well as the design and planning of water resource development and hydraulic structures are also strongly related to the rainfall supply. Understanding the water balance in watersheds and water resource potentials of river systems under changing climate is thus support to plan sustainable water management interventions that would improve the water supply and use of efficient demand management options. Part 5 presents papers related to potential evapotranspiration, unit hydrographs and impact of climate change on water potential. For designing an irrigation system, estimation of crop water requirement, planning irrigation scheduling, drainage and hydraulic structures, and water harvesting structures detail spatial and temporal information on evapotranspiration, rainfall and runoff is required. Developing reference evapotranspiration (ET_0) and unit hydrographs as input parameters for water resources planning, design of structures and hydrologic studies is important.

The FAO Penman-Monteith equation which requires use of full weather data is the standard method which is commonly used for estimating reference evapotranspiration (ET_o). However, there are only 25 principal stations in Amhara region to calculate ETo and develop iso-ETo map for the whole region. With reference to the Penman-Monteith equation, Hargreave is tested and found that it is the best among other tested empirical models to calculate ETo using temperature stations. Hargreave is then calibrated and empirical coefficients at each station are determined for estimating ETo. Finally, Iso-ETo map for Amhara region is developed based on a total of 44 stations-both principal and temperature stations. This map can be used as an input for agricultural research and development in water resource planning, irrigation scheduling, design of irrigation schemes and hydrological studies in Amhara region.

Snyder's Synthetic Unit Hydrograph method applied to estimate coefficients and unit hydrograph parameters of ungauged watersheds in Lake Tana sub-basin from the design storm hydrographs of four gauged watersheds - Megech, Gummaro, Gumara, and Ribb. The model estimated the required UH parameters such as tp (1.60 and 1.31 hr), Qp (18.06 and 13.92 m^3s^{-1}), and Tb (6.87 and 8.86 hr) for un-gauged watersheds in the region. These could be recommended as input parameters during construction of hydraulic structures and hydrological study of the watersheds.

A case study was conductd at Gumara River where the government has proposed to construct a dam and diversion weir to irrigate 14100 ha of land to assess the potential impact of climate change on the water resources of Gumara watershed using reliability, resilience and vulnerability indices. Projected maximum and minimum temperature shows an increasing trend for the next century for all scenarios studied. However, the precipitation shows decreasing trend in case of the A2a and B2a scenarios and an increasing trend for the RegCM3-A1b scenario. It is also observed that the reliability index for all climate scenarios reveal above 91%, resilience index of above 96% and vulnerability of less than 30%. Hence, it is concluded that the proposed Gumara irrigation project has high capability to meet the required target demand in 2030s and 2090s, and also it recovers quickly from a failure to meet the demands. Based on the result of performance indices, the decision makers, concerned persons or any water users in the area can be assured that the proposed irrigation project has very good potential to irrigate the required area under 2030s and 2090s climatic condition.