Integrated water and land management research and capacity building priorities for Ethiopia

Proceedings of a MoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia
2–4 December 2002

Ethiopian Ministry of Water Resources

Ethiopian Agricultural Research Organization

International Water Management Institute

International Livestock Research Institute

ILRI Proceedings

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Acknowledgements

This work was carried out with the aid of grants from the International Development Research Centre (IDRC), Ottawa, Canada and from the Global Mechanism (GM) of the United Nations Convention to Combat Desertification (UNCCD).

Outcomes of the workshop

The workshop emerged from a joint mission of the International Water Management Institute (IWMI) and the International Livestock Research Institute (ILRI) to Ethiopia in February–March 2002, at the invitation and enthusiastic support of various Ethiopian government ministries and other institutions for developing long-term collaborative research and capacity building in integrated water and land resources management. Other visits and missions, including a workshop-planning mission in August 2002 by a senior IWMI staff member followed. The Ministry of Water Resources (MoWR) and the Ethiopian Agricultural Research Organization (EARO) along with IWMI and ILRI later agreed to hold a 'Workshop on research and capacity building priorities 2002–2020'. This workshop was organised by representatives from the MoWR, EARO, ILRI, and IWMI and was held at the ILRI Addis Ababa campus in early December 2002.

The workshop brought together about 80 professionals, both researchers and practitioners drawn from a wide range of institutions in Ethiopia, in addition to the international participants. Twenty-five papers were presented and discussions conducted on land and water management research. The participants worked in five discussion groups to prepare the workshop outputs.

Well-targeted and good quality research is essential to develop Ethiopia's natural resources and to reduce poverty and promote development. A range of important research issues were identified, which will be useful for guiding future research projects in Ethiopia. These research issues need further prioritising. Carrying out the research will require co-operation among Ethiopian research institutions and partnerships with federal ministries and regional governments, and can be strengthened through partnerships with international institutions. They can facilitate collaborative research among the countries sharing the Nile and other river basins, and exchange of experiences with other regions and basins.

The workshop made it clear that there is considerable research and development capacity in Ethiopia. However, this capacity is fragmented among diverse institutions. Integrated water and land management research must be interdisciplinary, including the social, physical and biological sciences. The human, institutional and financial resources for carrying out research are well short of the level required to meet the needs of the country.

Substantial financial resources over a period of time will be required to build the necessary capacity for land and water management research. Such resources can be raised from many sources, including government, private sector, non-governmental organisations (NGOs), bilateral and multilateral partners, and regional sources such as the Nile Basin Initiative (NBI). A joint effort by Ethiopia and international partners to raise the necessary funds is needed.

The workshop recommended the implementation of the Ethiopian Science and Technology Commission (ESTC) proposal to establish an institutional framework for supporting and strengthening water research and development. It also recommended establishing strong linkages with appropriate international networks and institutions. The International Water Management Institute (IWMI) could play a role in developing this institutional framework.

An Ethiopian Consultative Committee for Water and Land Management Research should be established to serve as an interim mechanism to support water research in collaboration with the planned research department in the Ministry of Water Resources. This Committee will help prioritise research issues and facilitate co-operation between Ethiopian institutions and international bodies such as IWMI and ILRI.

A Memorandum of Understanding (MoU) between the Government of Ethiopia and IWMI should be prepared and adopted as soon as possible to facilitate co-operation. Several projects are already in the pipeline and an MoU would facilitate their implementation and the development of a strong collaborative programme. Posting of IWMI staff in Ethiopia, if desired, will be under ILRI's agreement with the Government of Ethiopia.

Finally, the Organising Committee wishes to thank the International Development Research Centre (IDRC) of Canada and the Global Mechanism for Combating Desertification for their support, which made the workshop possible.

Gulilat Berhane (MoWR), Paulos Dubale (EARO), D. Merrey (IWMI) and D. Peden (ILRI)

Welcome address

Gulilat Birhane
Ministry of Water Resources

His Excellency, Ato Shiferaw Jarsso, Minister of Water Resources
His Excellency, Mr Samuel Nyambi, UNDP Resident Representative and UN Resident Coordinator
Honourable Guests
Respected Participants
Ladies and Gentlemen

It is a privilege and honour for me to welcome you all on behalf of the organising committee and on my own behalf to the workshop on 'Integrated water and land management research and capacity building priorities for Ethiopia'.

The workshop was conceptualised during the first visit by the high-level experts of the International Water Management Institute in February 2002. Since then efforts have been made to organise this workshop in a manner that enables it to give the best opportunity to all stakeholders in the field of water and land, which are the most important factors of production in an agrarian economy. In the last ten months, invitations have been forwarded for public and private institutions, non-governmental organisations (NGOs) and professionals to present papers and participate in the workshop. Funds were also raised from the International Development Research Centre (IDRC) and the Global Mechanism (GM) of the United Nations Convention to Combat Desertification (UNCCD).

As a result, today we have more than 75 participants from 24 government institutions, 8 private institutions, 3 NGOs, 10 bilateral and 8 multilateral institutions and freelance experts.

In the coming two and a half days, 23 papers will be presented and plenary discussions will also be conducted.

Ladies and Gentlemen

For the benefit of our respected guests, who may not able to be with us in the subsequent sessions, I now call upon Dr Doug Merrey to give us a brief highlight on the goal and expected outputs of the workshop.

I thank you.

Workshop objectives

D.J. Merrey
Director for Africa, International Water Management Institute (IWMI)

Friends and colleagues

I am very pleased that this workshop has materialised so quickly, and that there are so many participants here today. I welcome everyone on behalf of the International Water Management Institute (IWMI).

The main objectives and expected outcomes of the workshop are to:

- identify priority research issues in land and water management research in Ethiopia
- identify priority capacity building needs related to land and water management in Ethiopia
- advise on the niche and roles of various partners in the research and capacity building programme, including the Ethiopian partners who must take the lead, IWMI, International Livestock Research Institute (ILRI), and other international and regional partners
- advise on the governance framework for partnership among the various parties and
- outline a resource mobilisation strategy to make it possible to implement the programme.

We all agree that improved land and water management is essential for sustainable development and poverty reduction in many African countries including Ethiopia. Ethiopia has considerable research capacity already, but perhaps it is not always as effectively mobilised as it could be. The intention of the proposed long-term programme is to help mobilise and focus these capacities, and help Ethiopia further strengthen its research capacities and its policies and management strategies in natural resource management.

I am sure that this workshop will be an important milestone in achieving this objective and Ethiopia's long-term development goals.

Thank you.

Welcome address

D. Peden
Director, Ethiopia, International Livestock Research Institute (ILRI)

Your Excellency, Ato Shiferaw Jarsso, Minister of Water Resources
Your Excellency, Ato Mesfin Tegegne, Vice Minister of Water Resources
Colleagues from the Government and the universities of Ethiopia, the Global Mechanism of the CCD, the United Nations Country Team, Embassies, NGOs, IWMI and ILRI
Visitors and Guests

Dear Friends

It is a great pleasure to welcome each and every one of you to ILRI, the International Livestock Research Institute, and to this opening session of the workshop on 'Integrated water and land management research and capacity building priorities for Ethiopia'. We are delighted and honoured to host this event on ILRI's Addis Ababa campus in collaboration with the Ethiopian Ministry of Water Resources, the Ethiopian Agricultural Research Organization (EARO), the Ministry of Agriculture and the International Water Management Institute (IWMI). We are particularly happy to have so many participants from partner organisations across the country and from abroad. You are very welcome.There is a family of 16 international agricultural research centres that work with many partners to improve agriculture and natural resources management around the globe. These are known as Future Harvest Centres. For those of you who can access the web, you will find more information about the Future Harvest Centres at www.futureharvest.org. ILRI and IWMI are parts of Future Harvest. Shortly, you will also learn more about IWMI and Future Harvest's priorities for research and management of water resources.

ILRI was established in 1995 through the merger of the International Livestock Centre for Africa (ILCA, a well-known institute in Ethiopia) and the International Laboratory for Research on Animal Diseases (ILRAD) that was located in Kenya. What Ethiopians used to know as ILCA is now ILRI. In collaboration with many partners, ILRI conducts livestock related research in Asia, Africa and Latin America and it maintains close ties to many advanced research institutions in the more industrialised countries. It seeks to strengthen ties with non-governmental organisations (NGOs) and civil societies whenever and wherever appropriate.

Reducing poverty is a goal that we all share in common. As its goal, ILRI and its partners intend to reduce poverty and make sustainable development possible for livestock keepers, their families and the communities in which they live. It can become the unifying principle that drives future collaboration amongst all of us. Our vision is a world made better for the poor people in developing countries by improving agricultural systems in which livestock are important and or could become so. Evidence shows that, in Ethiopia, livestock production plays an important role in bringing people out of poverty. We believe that well managed domestic animals can make agricultural systems in this country more productive and more sustainable. However, livestock production is not possible without adequate quality water. When people mismanage livestock, degradation of already scarce water resources often follows. Thus, ILRI is committed to working with you to help improve the lives of the poor through integrated water and livestock management.

This is an exciting day because this workshop will enable us to learn more about you and the organisations that you represent. It will allow us to merge our comparative and collaborative advantages to better enable us to collectively bring great benefit to the millions of the poor in Ethiopia and to contribute to the conservation of Ethiopia's natural resources, a country of unique inherent value and importance. Improving water, watershed and river basin management is vital to poverty reduction. The knowledge gained in Ethiopia will benefit the world.

For example, the Secretary General of the United Nations, Kofi Annan, specified in the targets for the recent World Summit on Sustainable Development that: 'Unless we take swift and decisive action, by 2025 as much as two-thirds of the world's population may be living in countries that face serious water shortage. We need to improve access. We need to improve the efficiency of water use, for example by getting more *crop per drop* in agriculture which is the largest consumer of water.' ILRI believes that 'crop per drop' must include animals feed crops and those intended for direct human consumption.

Together, we can make a difference. We hope this workshop will mark new strengthened partnerships that will lead to better natural resources management in Ethiopia.

Your Excellencies

On behalf of ILRI, I wish to extend a warm welcome to each and every one of you. We thank you all for coming, and we look forward to a rewarding workshop. In the course of the next three days, please do not hesitate to let any member of the ILRI team know if there is anything that we can do to make your time here enriching and enjoyable.

Thank you.

Keynote address

Girma Hailu
Assistant Resident Representative (P)
Energy, Environment and Water, UNDP Ethiopia

Honourable Guests
Colleagues, Workshop Participants
Ladies and Gentlemen

UNDP is highly honoured to be invited to make a statement on this important meeting entitled 'Integrated land and water management research and capacity building priorities for Ethiopia' organised by the Ministry of Water Resources in collaboration with the International Water Management Institute (IWMI), the Ethiopian Agricultural Research Organization (EARO), and Ministry of Agriculture from 2–4 December 2002 at the International Livestock Research Institute (ILRI), in Addis Ababa, Ethiopia.

Availability of increased water resources is the key to sustainable development. The Ethiopian Government has now committed itself by including water as one of its national priority agenda and formulated a 15-year comprehensive Water Resources Development Programme that outlines:

- water supply and sanitation
- small-scale irrigation
- hydropower and
- water resources management needs of Ethiopia.

Together with education, health and infrastructure, water resource development is now one of the chapters that have been included in the sustainable development and poverty reduction programme.

UNDP financed the preparation of the Water Sector Development Programme (WSDP) by the Ministry of Water Resources that has now been finalised and efforts are being made to start implementation. This workshop is very timely since it builds on the research and capacity building aspect that is well recognised as a means to increase the availability and efficient management of water in Ethiopia. The fourth component of WSDP, water resource management, calls for expanded land and water resources studies and capacity building to meet the growing water demand of the population, as well as for crops and livestock.

UNDP chairs and coordinates the development partners' group on water established to promote constructive dialogue with government counterparts. The substantive input of this group has been well appreciated by the Government during the WSDP formulation and subsequent Poverty Reduction strategy discussions. This forum not only helps to raise awareness and information exchange on water related issues but also serves as a critical vehicle to mobilise resources to implement the activities of the WSDP as well.

Let me once again reassure the workshop participants that UNDP will continue to support the water sector and hope this workshop will map out the way forward regarding land and water resource development research and capacity building in the country.

Opening address

Shiferaw Jarsso
Minster of Water Resources, Federal Democratic Republic of Ethiopia

Honourable Guests
Respected Participants
Ladies and Gentlemen

On behalf of the Ministry of Water Resources and on my own behalf it gives me a great pleasure to be here with you at the opening of this important workshop on 'Integrated water and land management research and capacity building priorities for Ethiopia'.

As it is widely known, Ethiopia is blessed with huge water resources potential but due to adverse problems, the country couldn't benefit from these rich resources. The major factors constraining the use of our water resources include:

- lack of finance
- poor management of water and land
- transboundary nature of most rivers and
- shortage of skilled manpower.

Climate change, population growth, environmental degradation and lack of harmonised intervention have also been affecting both the water and land resources adversely. This is actually the challenge we face and hence need immediate intervention from all stakeholders including government, external support, non-governmental organisations (NGOs) and others.

To tackle the challenges in a systematic way, the Ministry of Water Resources has started the water sector reform some seven years back. After a rigorous consultative process involving all stakeholders from the grassroots level, the Ministry of Water Resources has completed the preparation of a visionary water management policy, water sector strategy and water sector development programme. The United Nations Development Programme (UNDP) has played a key role in supporting these programmes.

In addition, the Ministry of Water Resources has completed carrying out Integrated River Basin Master Plan Studies in five of the twelve basins. The basic objective of the Master Plan Studies carried out by the Ministry have been to 'prepare an investment plan which would contribute to sustainable development and poverty reduction through optimum possible adverse environmental impacts taking water resources at the centre of development'. Conducting such studies would no doubt provide sufficient information on the optimum use of our water resources.

In addition to the commitment of the Government of Ethiopia to provide limited support, high expectations are foreseen from our external partners to help the implementation of the recommendations of the studies.

The Ministry of Water Resources is in the process of establishing the Basin Authority through the necessary legal arrangements, considering this as an excellent tool useful for implementing the master plan studies.

Moreover, positive developments are being observed on the use of the Nile water for the benefit of all the riparian countries.

Ladies and Gentlemen

Capacity building has been given top priority by the Government of Ethiopia. Without building our capacity, it would be difficult to implement any programme on a sustainable manner. Coupled with building capacity, undertaking of research activities becomes extremely important to share experiences from others, analyse our situation and come up with valuable recommendations.

We realise that this is an important instrument to develop our sector, and to this effect, the Ethiopian Science and Technology Commission together with the Ministry of Water Resources have conducted a thorough study and research in the water sector. We will soon start implementing the programme. The Ministry of Water resources has also newly organised a Research and Development department to better address the related problems of our sector.

Ladies and Gentlemen

Before I conclude my remarks, I would like to take this opportunity to forward my sincere appreciation to the staff of the International Water Management Institute and the International Livestock Research Institute, who have devoted their time and shown keen interest to make this workshop a reality. I also hope that this spirit of co-operation would continue in a sustainable manner. I would also like to assure you that the support of the Ministry of Water Resources would definitely continue in the years ahead.

Furthermore, I would also like to thank all other institutions and colleagues who have greatly contributed to the success of this workshop.

Finally, wishing you a happy discussion time I declare the workshop officially open.

I thank you.

Research and development in land and water resources

Research and development in land and water resources

Admasu Gebeyehu
Freelance Consultant

Introduction

The rapid increase in population necessitates an adequate management of Ethiopia's land and water resources. Agriculture is unthinkable without land and water. Agriculture could be effective only when it gets sufficient water at the right time. Therefore, to ensure sustainable agricultural development, there should be reliable supply of land and water as well as land and water management systems. If people engaged in agriculture get sufficient water throughout the year, it is possible to harvest higher yields from a smaller size of land and keep labour busy on production throughout the year.

Ethiopia is a country of great geographical diversity with high and rugged mountains, flat-topped plateaux, deep gorges, incised river valleys and rolling plains. Altitude ranges from the highest peak at Ras Dejen, 4620 metres above sea level (masl), down to the depression of the Kobar Sink, about 110 masl. Physical conditions and variations in altitude have resulted in a great diversity of climatic conditions, soils and vegetation cover.

The physiography of the country gives rise to a wide array of climatic zones, which range from tropical to temperate. Rainfall regimes of the country show that the mean annual rainfall varies from more than 2500 mm to less than 60 mm. Places such as the Afar Depression experience the highest mean annual temperature in the country at 45°C from April to September. The lowest mean annual temperature in some highland areas is observed to be around 0°C or lower.

The altitudinal ranges of Ethiopia provide a variety of climatic conditions, which permit the cultivation of a variety of agricultural crops and land uses. About 43% of the country is classified as highland (above 1500 masl), where most of the population (about 88%) practice mixed crop–livestock agriculture. The largest proportion of the country are the lowlands, where pastoralism is the main activity of the people.

The Ethiopian Rift Valley separates the Nile drainage system, the Indian Ocean drainage system and other drainage systems, which have no outlet to the sea. Ethiopia has a substantial amount of potential water resources, though its distribution and occurrence through time and space is erratic. On average, the surface water potential amounts to over 110 billion cubic metres per annum. Ethiopia, known as the 'water tower' of north-eastern Africa, is faced with the fact that all its large rivers (except Awash) flow into neighbouring countries. About 90% of the annual runoff goes to the rivers that flow into The Sudan, Egypt, Somalia and Kenya.

The irrigation potential of Ethiopia is estimated to be about four million hectares of which only about 5% is developed. Since irrigation development is associated with heavy consumption of water, this may cause serious conflict with riparian states as it certainly reduces the quantity of the trans-boundary waters. There is a need to continue the present effort of establishing the principles of co-operation for the use of regional and trans-boundary waters for irrigation.

Hydropower potential has been estimated to be 170 thousand GWh/yr, whereas less than 1.5% of the potential is used. Although there is a large, untapped potential for hydropower production, access to electricity is low and it is a constraint to economic growth.

Ethiopia is one of the poorest and least developed countries in the world. The current population is estimated at 66 million with an annual growth rate of about 3%. The economy is highly dependent on agriculture consisting of crop production and livestock rearing.

Poverty is the central issue of the economic problem. Major indicators of poverty in Ethiopia could be lack of farm land or small size of farm land per household, lack of the major means of production, households with large numbers of dependants, low nutritional status of rural communities particularly that of children and the wide spread prevalence of infectious diseases.

Ethiopia had been self sufficient in staple food and was classified as a net exporter of food grains till the late 1950s. However, since the early 1970s, domestic food supply failed to meet the food requirements of the people. Even though sufficient quantities of food have been produced in most of the good years, the average food production during the last decade remained almost stagnant. In the 1960s, the average per capita food production was about 280 kgs per year; however, it has fallen to about 160 kgs per year during the last 30 years.

More than half of the population is food insecure. Food insecurity problems of the country mainly emanate from limitations of rural land holdings, where more than one-third of the households cultivate less than 0.5 ha of land under rain-fed agriculture with minimal agricultural inputs.

Ethiopia's livestock population is the largest in Africa and the tenth largest in the world. Livestock are an integral part of nearly all the farming systems and are the principal capital of the farmer. Cultivators own about three-quarters of the livestock, and pastoralists own the remaining quarter. The recurrent droughts severely affected livestock and crop production. The deteriorating environmental conditions have also adversely affected feed resources.

Watershed management

Ethiopia has varied landscapes, ranging from rugged highlands in the central part, to the wetland areas of Gambella, and to the deserts of the Afar and the Ogaden area. Rainfall is highly variable across the country, from season to season, and from year to year. This variability subjects the country to frequent droughts and famines. Deforestation, population growth, overgrazing, and use of marginal lands have intensified erosion. Land degradation is serious in the highlands, contributing to low soil productivity and poor agricultural production. High erosion also causes downstream sedimentation, which can significantly decrease reservoir life.

The objective of watershed management is to improve the standard of living of the population living within the watersheds, decrease population pressure, and increase land productivity so that sustainable livelihoods and land use practices can be secured for the target populations. Without action, the challenges of food insecurity and famine, environmental degradation, and rapid population growth will intensify. Yet, through co-ordinated efforts of different stakeholders, production of food and energy, mitigation of droughts, arresting watershed degradation, reducing sedimentation, and improving the environment can be achieved. It is possible to capture these opportunities in a sustainable manner to benefit the people.

Any watershed management intervention for Ethiopia must address the root causes of land degradation, soil erosion, sedimentation and loss of soil fertility. Population pressure, fuel wood demand, lack of alternative sustainable livelihoods, and illiteracy are some of the root causes. In view of the multi-sectoral nature of the problems, a comprehensive and integrated approach is required. Treating the symptoms, as opposed to addressing the root causes, will lead to a downward spiral of degradation and poverty.

The first benefit of appropriate watershed management is to reduce soil erosion and the subsequent siltation rate of reservoirs thereby maximising the benefits of irrigation and hydropower projects. The second important benefit will be an overall increase in land productivity, which will yield higher agricultural outputs and thus enhance food security and alleviate poverty.

Widespread and high rates of soil erosion are serious problems in Ethiopia. The severity of the geological erosion is due to a combination of an aggressive climate, steep topography, and erodible soil types. Human activities in the catchments, including land clearing for agriculture and particularly overgrazing and firewood stripping, have resulted in a rapid acceleration of the erosion processes. The rapid population growth has further exacerbated the soil erosion and deforestation. An annual average sediment yield of 10 to 1500 t/km^2 in the south-western, northern and eastern parts of the country is observed. Unless proper conservation measures are taken high sediment loads in the rivers continue to cause siltation problems in reservoirs and lakes.

During drought times, many springs and streams dry up, and crop production becomes practically impossible. During the severe drought Ethiopia experienced in 1984 affecting both The Sudan and Egypt, the annual yield of the Nile River at Aswan dam fell to only 42 billion cubic metres, which is half of the mean. The prevalence of drought forced people to look for opportunities for survival including abandoning their home and migrating to temporary camps. Those who were unable to move or cope were doomed to perish. The deterioration of the natural environment compounded the human and livestock death toll.

Various factors, such as human and livestock population growth, poverty, expansion of agriculture and demands of wood, are threatening the management of land and water resources in Ethiopia. Comprehensive and integrated programmes and inter-disciplinary approaches are critical to fully use land and water resources and to safeguard those resources against deterioration.

Sustainable management of land and water resources is essential for the alleviation of poverty, economic development and the enhancement of the well-being of the Ethiopian people. Poor people depend heavily on forest products. They collect and sell forest products to obtain cash for purchasing basic needs and services. In addition, wood is the only affordable, and often the only, fuel.

Investments, policy related strategies, and regulations related to land and water resources need to be formulated in the context of a broad resources strategy, which takes the long-term view and considers the ecosystem and socio-economic structure that exist in river basins. The key element is the need to develop a comprehensive framework based on a multi-sectoral approach that reflects the country's social, economic and environmental objectives.

The country needs to build its technical, institutional and organisational capacities to effectively manage its land and water resources. In many cases, the institutional and organisational capacities will need to be developed at national and local levels. More support is needed from international agencies in capacity building including training and research. Strengthening the institutions dealing with land and water resources in Ethiopia, building their managerial capacity and improving co-operation and co-ordination between federal and regional governments are vital for sustainable development in the country. In addition, user participation will be important in creating a sense of ownership among land and water users and as a means of improving operations and cost recovery.

Identified research and development (R&D) programmes in the water sector

Higher Education Institutes (HEIs) that are involved in water sector research and development activities include: Addis Ababa University (AAU), Arbaminch Water Technology Institute (AWTI), Alemaya University of Agriculture (AUA), and Mekelle University (MU).

There are national institutions (non-HEIs) that carry out R&D in collaboration with universities, or institutions carrying out applied research, or institutions conducting strategic research. The most important organisations include: Ethiopian Agricultural Research Organization (EARO), National Meteorological Services Agency (NMSA), Geological Survey of Ethiopia (GSE), and Engineering Design and Tool Enterprise (EDTE)

For research to contribute to the national development, the potential users' capacity to appreciate and actually use the relevant technology made available by research is decisive. Equally decisive are the planning, organisation and management of research in the research institutions, and its development and promotion. Any water sector R&D organisation has to serve not only government organisations but also the private sector. The major beneficiaries of water related R&D results include: Ministry of Water Resources (MoWR), Ministry of Agriculture (MOA), Environmental Protection Authority (EPA), Regional Irrigation Development Offices (RIDO), private sectors involved in the water sector (such as

Consultants, Contractors etc.), and non-governmental organisations (NGOs) involved in water development.

R&D efforts in the land and water sector, particularly by the HEIs, become ineffective and inconsequential due to several factors such as:

- lack of a defined responsibility and accountability for charting out R&D programmes based on centrally determined objectives, policies and priorities and
- lack of transparency at every level of the higher learning organisational set up.

The objectives of most HEIs are too general, too vague and lacking clarity and focus. Clear objectives and optimisation of a productive research linkage between the HEIs, government organisations and the private sector is highly desirable.

R&D in the water and land sectors is faced with problems related to institutional development, funding, human resource development, information management, adequate planning as well as effective dissemination and adoption of research findings.

Information gathering on land and water R&D being undertaken by scattered institutions is extremely scanty, haphazard and no comprehensive database is available on the ongoing and completed research. There is a need to know what land and water R&D projects are being carried out, what they lead to, where they take place, when they are likely to be completed and their expected findings. There is a further need to know which personnel are involved in what projects, their capabilities etc. This key deficiency of the present information management leads to less than satisfactory planning, monitoring and evaluation of research programmes.

Recruiting for research involves strategies for attracting well-qualified staff. It also involves devising strategies for providing quality research training. Lack of sufficient local capacity in graduate training forces the country to depend on external training, which has its own risks and shortcomings including high cost, appropriateness of training for local needs, disassociation from the home environment, and brain drain.

MCE (2002) carried out a study on research and development activities in the water sector to assess the existing situation and proposed alternatives for future action. The study has identified four divisions with a total of 23 R&D programmes.

- Water resources assessment and management which consists of five R&D programmes such as: climatic characteristics, surface water hydrology, groundwater hydrology, water quality management, and watershed management
- Water resources development which consists of eight R&D programmes: water supply, sanitation, water supply for livestock, irrigation, drainage, rain water harvesting, hydropower, and multi-purpose projects
- Engineering and technology which consists of six R&D programmes: construction site and materials investigation, hydraulic structures, traditional technology, technological development, choice/selection of technology, and technology management
- Socio-economics or social sciences, which consists of four R&D programmes: finance and economics, institutions and stakeholders, capacity building, and policy and legislative issues.

This classification allows R&D activity in the water sector to be categorised according to the field of research to be undertaken. While this classification includes individual specialised fields of national interest, it generally reflects the overall structure of disciplinary fields and related subfields taught at universities or tertiary institutions.

Since R&D activities within the area of land and water are inter-disciplinary in nature, all the identified R&D programmes could be involved depending on the nature of the specific problems. However, the R&D activities relevant to land and water shall concentrate on issues that would produce relevant practical results and significantly contribute in:

- promoting practices of efficient and appropriate watershed management to maximise water yields and quality and minimise sediment yields
- incorporating environmental conservation and protection requirements as integral parts of land and water resources management
- minimising and mitigating as much as possible, the negative environmental impacts associated with land and water resources development
- promoting and enhancing traditional and localised water-harvesting techniques in view of the advantages provided by the schemes dependence on local resources and indigenous skills
- introducing and transferring rainwater-harvesting techniques that have been successful elsewhere for agricultural purposes
- providing sustainable and objective-oriented training on the relevant areas of land and water resources management and develop and implement effective means to efficiently utilise and sustainably retain trained manpower and,
- building and strengthening the capability to search, select, negotiate, transfer, use and modify appropriate technologies for prospecting and development of land and water resources.

Proposed organisational arrangement

The need for a R&D organisation (institute) in the water sector, is not only apparent, but is also becoming more urgent as sectoral objectives and planned development programmes are receiving enhanced attention from the government, the public and concerned international bodies.

As competition between uses and users increase, the requirements for water are also growing. The competition between countries sharing a water source will be addressed through equitable allocations that are bound to include factors such as economic viability, cost effectiveness, and non-harmful impact, all requiring practical solutions to the various constraints. The environmental dimension of water resources development, both negative and positive, at the local and international levels, will require intelligent solutions based on scientific and practical research.

The existing national R&D capability in the water sector can only be described as minimal. These capabilities have so far demonstrated little impact on the development of the sector. The need for a comprehensive and integrated management of R&D is critical.

The overall review and analysis of the national water sector R&D capabilities and its limited achievements have led to the conclusion that the establishment of a water resources R&D institute is of crucial national importance. The institute should be an autonomous organisation having the overall responsibility and powers regarding all national R&D efforts in the water sector.

The overall objective of the proposed water sector R&D organisation (institute) is to contribute towards the implementation of the country's long-term policies and development objectives within the sector itself, and other related development programmes. The specific objectives include:

- contributing towards strengthening the national capability to undertake R&D activities in all fields of the water sector
- undertaking, and cause the undertaking of, multi-disciplinary research to resolve problems, alleviate constraints and maximise opportunities in the development of the country's resources
- promoting the use of research results to enhance sectoral development and
- operating as depository and documentation centre for data, information and research undertakings related to the water sector.

The major duties and responsibilities of the institute include:

- initiating and conducting R&D on water resources particularly in the field of assessment, management, development, engineering, technology and socio-economics
- guiding, planning, co-ordinating, integrating and monitoring R&D activities in the water sector
- studying the application of various research results carried out in other countries to this end, the preservation of a collection of related materials, literature and scientific data
- co-operating with and providing consultative services to the different agencies on questions falling with the functional sphere and capability of the institute
- disseminating research findings through reports, publications and other appropriate media, and acting as a forum for constructive dialogue on water resources development and management
- operating as depository and documentation centre for all research in Ethiopia that are related with water resources development
- training personnel involved in specialised data collection, investigation, research methods and applications
- strengthening the existing R&D executing and support institutions in the water sector and establishing new ones as necessary
- undertaking effective training of R&D manpower locally and abroad as necessary and on the basis of the sub-sectoral need and plan to produce the desired quality and quantity
- promoting efficient and sustainable relationship and interaction among the R&D, higher learning and development institutions
- providing the necessary support and incentives to strengthen the participation of the private sector and the community at large, especially women, in the R&D activities of the sector
- encouraging and supporting the participation of professionals engaged in the R&D of the water sector in relevant national, regional and international conferences, symposia and workshops to enable them to acquire knowledge and experience essential to their work

- creating a conducive working condition to workers engaged in R&D activities of the water sector and establishing a system for the provision of incentives, recognition and protection of rights for those that achieve satisfactory results
- establishing and strengthening R&D co-operation with international organisations and foreign governments in such a way that it contributes to national water sector R&D capability building
- building and strengthening national capability in project studies, design and other engineering works and consultancy services in the water sector and,
- allocating the required budget for undertaking the R&D activities of the sector and creating suitable conditions to encourage the private sector to contribute to the sectoral R&D through its own initiatives.

Issues for discussion

1. It is a well-known fact that Ethiopia is the 'water tower' of north-eastern Africa since 90% (about 110 billion cubic metres per annum) of the annual runoff that originates in Ethiopia flows to neighbouring countries. However, the maximum amount to which Ethiopia is entitled (or eligible) to use is not known.
2. Although the residents of Addis Ababa have relatively better access to alternative energy sources such as electricity, gas, kerosene as well as alternative construction materials such as stone, blocks and bricks, more than half of the residents use firewood, charcoal and dung as energy sources and about 80% of the housing construction material is wood. Why?
3. Deforestation, high population growth, overgrazing and use of marginal lands have intensified land degradation through the process of erosion. Another way of looking at the problem is by making assumptions on whether poverty is the root cause of land degradation or vice versa. What strategy should thus be adopted to solve the problem?

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Present and future water resources development in Ethiopia related to research and capacity building

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Background

Ethiopia with a total area of 1.13 million km^2 has a total population of 63.5 million in 2001 out of which about 54 million are rural while 9.5 million are urban. The rate of population growth is in the order of 3% per annum.

The economy of the country is highly dependent on agriculture, which is in turn dependent on the availability of seasonal rainfall. Although the country's renewable surface and ground freshwater amounts to 123 and 2.6 billion cubic metres per annum, respectively, its distribution in terms of area and season does not give adequate opportunity for sustainable growth to the economy. The intensity of recurrent droughts affects the livelihoods of agricultural communities and the whole economy. Even in a year of good rain, the occurrence of floods affects the livelihoods of riparian residents with little capacity to neither protect themselves from the seasonal flood nor mitigate the impact.

Excess water is also responsible for the soil erosion in the highlands. Recent studies show that the sediment yields in different rivers range between 180 and 900 t/year per km^2 (Rodeco 2002). It is estimated that the transboundary rivers alone carry about 1.3 billion tonnes of sediment each year to neighbouring countries (MoWR 1993). Poor watershed management and farming practices have contributed to these rates.

Sustainability of the management of water supply schemes is also a challenge for the sector. Poor co-ordination among stakeholders is aggravating the situation and constraining the economic returns on investment. Lack of research and development in the sector has hampered the contribution of the sector to the socio-economic development of the country.

Basin studies were first undertaken in the country in the 1950s, and the United States Bureau of Reclamation (USBR) conducted the Abay River basin study in 1964. Subsequently, basin level studies have been carried out in the northern basin (Tekeze, Mereb-Gash and Guang) and the Wabi Shebele River basin. Basin development studies have been carried out recently in a more comprehensive and integrated manner in five of the twelve major basins in the country, and studies in two more basins are underway. To date, the implementation of these studies has been limited.

1. This document is prepared on behalf of the Ministry of Water Resources. However, all the views in the document are those of the author. If at any circumstance there is any deviation the author is liable for the views reflected.

Seven years ago, realising the prevailing problem, the Ministry of Water Resources began work on water sector reform. This started with developing integrated water resources management policies and was subsequently followed by the creation of strategies and development programmes, which included extensive stakeholder consultations. This process included drawing on experiences from other developing and developed countries.

This paper presents an overview of the resource base of the country, existing practices and, based on the planning efforts discussed above, future directions of development with regard to research and capacity building.

Resource base and issues on the ground

Out of the total water resources, about 75% drains to neighbouring countries (MoWR 2001a). The country is divided into 11 climatic zones ranging from equatorial desert to hot and cool steppes, and from tropical savannah and rain forests to warm temperate and cool highlands. The mean annual rainfall varies between about 100 mm in the north-east to 2800 mm in the south-west (Lemma 1996). However, rainfall is generally erratic and irregular. The fluctuation of the rainfall is closely related to the occurrence of the El Niño Southern Oscillation (ENSO) that occurs on a 2–7 year cycle.

Table 1 presents the surface water resources available against the landmass of the major basins of the country. Two of the basins, Ogaden and Ayesha, which make up 7% of the country's landmass and serve as home to a number of pastoralists and their livestock, have no water. On the contrary, there are also basins with high ratios of water. The question is how do these people live in these water-deficient areas? What sort of remedial measures can be taken to reduce the risk in their traditional life styles? The integrated master plan studies have identified potential solutions in the investment plans where financing allows.

On top of the general water scarcity in these areas, frequent droughts further affect the socio-economic features of the country. In the history of the country, more than 42 great droughts and famines had been recorded (NMSA 1996). In the 1972–74 drought and famine events alone, more than 140 thousand people were displaced. The incidence of the 1984–85 draught was not much different from the former in terms of migration to neighbouring *woredas* (Admasu 1996) even though the drought was not as severe. In any given year, on average, more than four million people face food shortages and need relief assistance. The incidence of poverty is also high with 45, 37 and 42% at the rural, urban and national levels respectively (MoFED 2002). Nevertheless, no major action has been taken to overcome the problem in a sustainable way, and environmental degradation is now aggravating the problem.

In previous water resource development projects, the issue of environmental impact was not well addressed. A few studies were conducted. However, major mitigation measures were not carried out and beneficiaries were not trained to implement the programmes. In a country like Ethiopia, the worry should have to be on two important facts: the social and the economic opportunity. Unfortunately, these issues are not well articulated.

The potential irrigable land in Ethiopia is about 3.6 million hectares out of which only 5% has been developed. The water sector development programme concluded that the production of feed, fibre and sugar could not meet local demands with rainfed agriculture and the current rate of irrigation development. To close the food gap, it is estimated that a further one million hectares of irrigated land has to be developed in the next 15 years, which, even if it was possible, is considered not to be sustainable (MoWR 2001b).

Table 1. *Ethiopian surface water resources by major river basins.*

No.	River basin	Catchments area (km^2)	Annual run off ($\times 10^9$ m^3)	Specific discharge (litres/km^2)	Share out of total
1	Abay	199,812112,00	52.6	7.8	43.05/17.56
2	Awash	112,700	4.6	1.4	3.76/9.9
3	Baro-Akobo	74,100	23.6	9.7	19.31/6.51
4	Genale-Dawa	171,050	5.88	1.2	4.81/15.03
5	Mereb	5900	0.26	3.2	0.21/0.52
6	Omo-Ghibe	78,200	17.96	6.7	14.7/6.87
7	Rift Valley	52,740	5.64	3.4	4.62/4.63
8	Tekeze	90,000	7.63	3.2	6.24/7.9
9	Wabi-Shebele	200,214	3.16	0.5	2.59/17.59
10	Danakil	74,000	0.86	0	0.7/6.5
11	Ogaden	77,100	0	0	0/6.77
12	Aysha	2200	0	0	0/0.19
Total		1,138,016	122.19		

Ground water resource potential is approximately 2.6 billion cubic metres.
Source: Different master plan studies.

The total hydropower potential of the country is estimated to be around 650 million TWH, of which about 160 million TWH is economically exploitable. Presently the generation capacity is less than 450 MW, and is expected to rise to 670 MW when Fincha II and Gilgel Ghibie hydropower projects join the Interconnected system (ICS).

Water quality is a critical issue in a number of areas, including the groundwater in the Rift Valley basin, which is high in florides. In other areas, iron deposits are problematic. The lack of information on water quality makes it difficult to determine appropriate strategies in a particular locality.

Despite its importance to water management, there is limited water quality monitoring in Ethiopia. Upstream activities in a number of basins are polluting the water bodies with little consideration for stakeholders downstream. Without improved management, the situation will further deteriorate and could lead to conflict.

Water allocation will also be another area of concern. So far, there is no major record of conflicts. Nevertheless, there are some cases, such as the issue of abstraction and pollution by upstream residents, which beneficiaries have started to complain about. This is actually an international phenomenon that relates with population growth and resource scarcity (Abernethy 2000).

For Ethiopia, which has an economy highly dependent on agriculture and high population growth, it is prudent to effectively manage its water resources, build capacity and link development efforts with practical research findings. Development efforts made so far were not supported by empirical research findings; rather they have relied on theoretical ideas or imported experience, which do not fit the prevailing conditions on the ground.

The Ethiopian Water Resources Management Policy (EWRMP) that was developed in 1999 attempted to address all the issues highlighted above (MoWR 1999). The policy is detailed on various issues, including research. However, since the document is holistic in nature, there are certain issues still to be examined at a local level. Some of the relevant parts of the policy will be presented later when the development approach is discussed. The sector strategy also addressed the issue of research as one of the important inputs to the success of the water sector programme implementation.

Conventional ways are not working

Returns to date have been disappointing. Economic growth is jeopardised by agricultural market fluctuations, such as the fall of the coffee market and recurrent droughts. Part of the solution lies in diversification of the production systems that fully utilise the available water resources. The utilisation may range from rainwater harvesting to construction of big dams, and from bucket pouring to large-scale irrigation systems. The economic justification would have to be proved through research and studies. In a country with abundant unskilled labour, low-tech labour intensive investment scenarios seem rational. Nevertheless, it has also its own cost inefficiency, low return on investment and even lack of sustainability. The traditional development of the sector is highly characterised by most, if not all, of the following:

1. Lack of sustainable and reliable water resources management strategy
2. Lack of efficient utilisation of water resources
3. Non-objective-oriented programmes and projects
4. Uncertainties and ambiguities in planning
5. Prevalence of intensive centralism of management that does not focus on rural development
6. Lack of institutional sustainability
7. Lack of operation and maintenance activities of water schemes
8. *Ad hoc* development practices lacking coherent objectives and continuity
9. Highly subsidised and considered as any other social good
10. Lack of stakeholder participation and belongingness to the development of the sector
11. Relatively low attraction of the private sector
12. Low investment on research and development and
13. Transboundary nature of the rivers and the conflict that comes along.

The country has considerable experience in drought alleviation, but, so far, it has been unable to avert the situation. As part of the broad water sector reform programme, the Ministry of Water Resources has sought to incorporate drought alleviation in water sector management and investment, thereby addressing drought in a more systematic way, rather than react to drought when it occurs.

Basin studies were first undertaken in Ethiopia some 45 years back. However, the study was not comprehensive and little of it was implemented. Because of the lapsed time, these studies are of limited value. Without immediate implementation and updating, such efforts are a waste of meagre resources. Given this, the Ministry of Water Resources is striving to implement some of the projects identified under the present basin studies. The establishment of basin authorities is also in process to support and monitor the implementation of the studies. There are also efforts to establish a department in the Ministry that facilitates and co-ordinates research efforts in the sector.

Development approach

Change is always a challenge. In entering into change, it is always difficult to get real partners and forecast external influence. Internally the sector had institutional problems in developing a coherent vision. But because of the 1995 re-organisation of federal institutions, the sector had an opportunity to be organised under a unified organ— the Ministry of Water Resources—and establish the foundation for reform.

The reform starts from setting clear goals, objectives and principles, which are presented in Boxes 1–3. The vision of the sector has been spelt out in a way that enables it to alleviate the prevailing problems (FDRE 2000). Detailed regulations are under preparation. The policy has three broad parts, which are the general policy, cross-cutting issues and sectoral issues. All the parts have further sub-divisions. The issue of research and development and capacity building is addressed under the cross-cutting issues (MoWR 1999).

Box 1: Goal of water resources management policy

The overall goal of the water resources policy (WRP) is to enhance and promote all national efforts towards the efficient, equitable and optimum utilisation of the available water resources for significant socio-economic development on a sustainable basis.

Box 2: Objectives of the water resources management policy

1. Development of the water resources of the country for economic and social benefits of the people on an equitable and sustainable basis.
2. Allocation and apportionment of water based on comprehensive and integrated plans and optimum allocation principles that incorporate efficiency of use, equity of access, and sustainability of the resource.
3. Managing and combating drought through, *inter alia*, efficient allocation, redistribution, transfer, storage and efficient use of water resources.
4. Combating and regulating floods through sustainable mitigation, prevention, rehabilitation and other practical measures.
5. Conserving, protecting and enhancing water resources and the overall aquatic environment on a sustainable basis.

Box 3: Fundamental principles of water resource management policy

1. Water is a natural endowment commonly owned by all the peoples of Ethiopia.
2. As far as conditions permit, every Ethiopian shall have access to sufficient water of acceptable quality, to satisfy basic human needs.
3. In order to significantly contribute to development, water shall be recognised both as an economic and a social good.
4. Integrated framework of water resources development as a rural-centred, decentralised management and the participatory approach shall underpin.
5. Management of water resources shall ensure social equity, economic efficiency, system reliability and sustainability norms.
6. Promotion of the participation of all stakeholders, particularly women and user communities in the relevant aspects of water resources management.

Considering water as a social and economic good, the principle of cost recovery, acceptance of the basin as a unit of planning, decentralised management, equitable and reasonable water allocation, capacity building, and research and development are the most important concepts incorporated in the policy.

After the endorsement of the policy and before the development programme was launched, the sector strategy was prepared. Since it is defined and agreed as a means of translating the policy into action it sets a road map on how to make meaningful contribution towards:

- realising food self-sufficiency and food security in the country
- improving the living standard and general socio-economic well-being of the people
- improving environmental health conditions
- generating additional hydropower
- enhancing the contribution of water resources in attaining national development priorities
- promoting the principles of integrated water resources management and
- enhancing water supply coverage (MoWR 2002).

Environment, watershed management, water resources protection and conservation

This is one area that was not given much emphasis in past efforts to develop, utilise and manage water resources and yet it has been found to be very important and the experiences of other countries justify the same.[2]

2. The author observed the Yellow River Commission of China during a short-term visit in 2000. There are also a number of experiences throughout the globe.

The inclusion of environmental protection in all development efforts is a recent phenomenon that emerged from the Rio De Janeiro World Summit. Immediately after that, Ethiopia established a specialised governmental institution that prepared policies and strategies. The Ministry of Water Resources has also addressed the issue of environment in its policy and strategy. In both documents, environment was included as an integral part of projects and programmes. This means that environment has to be included in the process of preparation and implementation of all projects. The issue is to determine the impact of the intervention on the environment, its cost effectiveness, sustainability, the standards to be met etc. Research is vital in comprehending these issues.

Watershed management is also another area of focus. What has been done so far locally is not encouraging. The practice of water and soil conservation has been in place for more than five hundred years in Konso,[3] but this effort was not developed and duplicated elsewhere in the country, especially in areas that have similar problems with Konso. Recently, encouraging efforts have been made in Amhara and Tigray regional states to adopt bund construction for water and soil conservation through food-for-work programmes. With certain modifications it would definitely be acceptable in other parts of the country. There are also certain research-oriented efforts carried out by the Ministry in two projects. The first project financed by the European Union (EU) is called the 'Assessment and monitoring of erosion and sedimentation problems in Ethiopia', and its objective is to control erosion. The outcome is encouraging and can be duplicated elsewhere. The second one is an on-going study under the umbrella of the Environmental Support Project. The focus of this project is on environmental assessment and sustainable resource utilisation in North Wello Zone. The purpose of the project is to facilitate decision-making on improved natural resources management.

The policy has addressed the issue of basins development by giving due emphasis and showing a direction for its inclusion as an integral part of the overall water resources management. In the policy the 'Basin' is the planning unit, and projects initiated since have watersheds as an integral part of the focus. The items discussed in this section have been addressed in the policy and the strategy. However, there is much to be refined and checked against the socio-economic framework. Research and investigation is required for further elaboration and verification.

Stakeholders' issues

Experience shows that programmes with high community participation rates greatly improved their sustainability. The policy and strategy of the sector has provisions for stakeholder participation and even the process of the document preparation itself was consultative and open to partners. Now, the outstanding issues with respect to stakeholder participation might be the extent and mechanism of choosing the appropriate ways of participation.

3. Konso is a special district in the Southern Nations, Nationalities and Peoples' Regional Government. The traditional way of bund construction and soil conservation of the Konso people has been recorded as one of the national heritages of the country.

If we take the case of beneficiaries alone, especially in a country like Ethiopia where there is diversified cultural and social conditions, adaptation of a unilateral mode of stakeholder participation may not be appropriate. The lifestyle and religious thought of the sedentary highlanders cannot be the same as that of the lowland pastoralists. Even the life style of the eastern pastoralists is not the same as that of the southern and western pastoralists. To get appropriate participation it is necessary to have the appropriate social researchers and capacity building.

Transboundary waters

Water is a source of life regardless of its location, culture or ownership. That is why it remains a source of conflict and suspicion for some countries (Wondimneh 1979). Of course, there are cases where countries have been able to manage their shared water and mutually use it (Mokuoane 2000). Since 75% of the rivers that originate in the highlands of Ethiopia cross the border and feed neighbouring countries, co-operation is not only important but a must. That is why the Ethiopian Government in its water resources policy had made its commitment clear towards the principle of equitable and reasonable use of water resources.

International efforts and the policy direction have brought together the partners in the Nile basin under the umbrella of the Nile Basin Initiative (NBI). It is clear that this is a start of a long journey, which could collapse at any time unless otherwise supported by all the necessary instruments, including empirical research results on the benefits that could be achieved from the co-operation and the mechanisms to strengthen it.

Capacity building and dialogue among all stakeholders have to continue to facilitate research and co-operation. With respect to Ethiopia, which contributes about 86% of the Nile waters and the sources of other trans-boundary rivers, the lack of capacity both at regional and national levels is evident.

Finance and economics

One of the most challenging areas of the policy is finance and economics. As a tradition, water is considered simply as a natural resource and even most of the people may not be aware of its economic value. On the contrary, the investment requirement of water is high while the time requirement to get returns is long.

Even some of the outcomes from providing water are not also easily understood, which complicate water pricing. Unless there is some justification (social or political), any investments made must be paid back, which is also the direction of the water policy. The policy and strategy provisions address the issue of cost recovery and water pricing. Urban water supply and irrigation projects are required to cover investment, operation and maintenance costs. Rural water supply projects are only required to cover the cost of operation and maintenance. Water pricing is done in order not to harm the beneficiaries and yet discourage misuse of the resource. To this end, tariff setting is site specific.

The two primary challenges are: affordability and the willingness to pay. Since about 45% of the people have a daily income of less than US$ 1, it is very difficult to get returns from a huge investment. Even those who have better incomes might not be willing to pay back the cost of water, unless special training is extended.

To overcome the challenges, care has to be taken in the choice of technology and efficiency has to come into the whole process from inception to operation. His Royal Highness the Prince of Orange, in his 'No Water-No Future' initial contribution to the panel of the UN Secretary General in preparation for the Johannesburg Summit, has come up with a recommended target and actions towards financing water projects (see Box below).

Recommended target

Have at least 20% of all water infrastructure investments funded by alternative forms of financing by 2015.

Recommended actions

Build capacity in local government to assess alternative forms of financing for infrastructure, including capacity to identify, develop and negotiate sound projects that are feasible and environmentally sustainable as alternative solutions to large-scale investments.

Research and development

As mentioned above, in the past research related to water was not well incorporated into development efforts. Currently the Ministry has a policy direction aimed at integrating the research as part of development efforts. In line with this, the Ministry considers the following points as key areas for research (MoWR/ESTC 2002).

- the occurrence and state of resources in the entire hydrological cycle
- the application and utilisation of resources for various end users
- resource management and environmental aspects including watershed
- engineering and infrastructure aspects with respect to water resources regulation and management.

The specific research activities may include but are not limited to:

- definition of engineering design parameters and standards for water development
- identification of suitable and appropriate irrigation methods for different scale of irrigation schemes
- development of different water conservation and management options for surface and sub-surface water

- setting water quality standards
- removal of fluoride from drinking water
- inventory and characterisation of indigenous water management practices
- selection of appropriate technologies in the water sector
- quantification of runoff and soil loss under different climatic conditions
- crop water requirement
- drainage for different soil types
- desalination of lake water
- loss of water through conveyance systems
- recent development and technologies in water resource surveys
- reservoir, canal, river bed sedimentation
- efficient water use methods in arid and semi-arid areas
- recycling of waste water
- solar energy for different water related uses
- wind mill energy for different water related uses
- development at the village level.

Conclusion

The issue of water is the issue of life. Societies that are able to use their water resources in an efficient and sustainable manner have succeeded in being food self-sufficient, reducing the incidence of water-borne diseases and minimising adverse effects of the resource. Unfortunately, this has not happened in Ethiopia. If we take population growth and environmental degradation into account, the way ahead will be even more complicated.

To avert the problem, intervention in the sector has to be intensified and implemented in a manner that is efficient in terms of resources and capital. To achieve this efficiency requires, among other things, that research activities be an integral part of development efforts.

The policies and strategies for the water sector clearly support research. However, harmonised activities have yet to be framed and initiated. Now is the time to look into all possible options for research and capacity building in the water sector.

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Present and future trends of natural resources (land and water) management in Ethiopian agriculture

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Abstract

Agriculture depends fundamentally on natural resources and has an important role in their conservation. The deteriorating land and water resources in Ethiopia present a concern to rural land users, and wider public awareness of environmental issues is bringing urgency to conservation issues. Water depletion and land (natural resources) degradation, themselves the result of ever-increasing ecological imbalances, caused the recurrent drought and famine. Sustainable agriculture plays the central role in poverty reduction efforts of the country.

Meeting food security and food self-sufficiency in Ethiopia require, among other things:

- integrated land and water development planning and implementation
- increased efficiency of water use in agriculture giving due attention to the popular participation and empowerment of local governments and marginalised and resource-poor community groups and
- enhanced capacities and capabilities of integrated land and water users and their development partners, local governments, i.e. lower decentralised unit—*woreda*—for designing and executing development programmes.

Scientific land and water use planning and implementation are the fundamental processes needed to achieve these results. Nevertheless, it has to be founded on the basic principles of community-driven development and fully supported with participatory and applied research activities on the major biophysical and socio-economic land resources. The practice has to be enhanced with smallholder level rainwater-harvesting techniques in areas with relatively better length of growing period (LGP), followed by the huge dam construction works in lowland areas. This measure will be the basis for sustained productivity in the continuous and iterative process of producing and disseminating alternative land use options equipped with alternative land use technology packages to farmers/pastoralists in the specific agro-ecological settings. In addition, the proper involvement and participation of all stakeholders prior to huge investment works is essential. The human resources development (HRD) and training and education (TE) establishment gearing towards the efficient implementation of integrated land and water planning should not be overlooked.

Background

Land degradation and water depletion has been recognised as a serious problem in the Ethiopian highlands. The fear of losing the fertile topsoil has driven experts, planners and decision-makers to tremendous efforts focused on soil conservation measures.

Land and water resources are limited and finite. The wise use of rural land and water resources with the best technologies, in the most rational and beneficial way possible, is crucial for the social and economic well-being of the country and its people.

Land refers not only to soils, but also to land forms, climate, hydrology, vegetation and fauna, together with land improvements (terracing, irrigation, drainage works) and unsustainable land use practices (including all land using community).

Because of relatively better climate, rainfall amount and frequency and less health hazards, most of the Ethiopian farming communities live on the highlands (>1500 metres above sea level, masl). Areas extensively inhabited by pastoralists whose subsistence is dependent on extensive grazing also indirectly rely on the cereal productions of adjacent highland regions.

Although Ethiopia has an estimated area of 1.12 million km^2 with a wide ecological diversity, the uneven spatial and temporal occurrence of water resources are still the causes of underutilisation of arable land for agriculture. Between 80–90% of the country's water resources is found in four basins (Abay, Tekeze, Baro-Akobo and Omo-Ghibie) where the population is not more than 30–40%. The water resources in the other basins (east and central) are only 10–20% whereas the population in these basins is over 60% (MoWR 1995).

This clearly depicts that 'moisture stress' in most of the agricultural potential areas is the major constraint. According to FAO (1994), the total irrigated area in Ethiopian river basins amounts to 161,790 ha, which is only 4.4% of the predicted 3.4 million hectares of potentially irrigable land.

Faced with this situation and a poverty driven depleted resource base, the risk averting strategy that has been adopted by the rural community is increasing unsustainable pressure on natural resources through:

- over utilisation of the available land
- encroachment on wildlife and forest priority areas
- overgrazing etc.

These actions lead to land and water depletion and degradation and/or 'forced' migration to urban areas.

In addition, the absence of off-farm income in rural areas has also contributed to the high population pressure on arable land, which leads to fast deterioration of natural resources.

This situation will remain a challenge until a high rate of agricultural transformation coupled with maximum and sustainable agricultural productivity (per unit area of land-intensification) takes off from the present crisis. Realising the present socio-economic situations, it is evident that Ethiopia cannot meet its food security and food self-sufficiency objectives using the prevailing land and water use systems.

Taking into consideration the catchment areas of each river basin of Ethiopia *vis-à-vis* the population census of 1997, it can be observed that more than 129 persons/km^2 live in the Rift Valley, while the bulk of the lowlands are scarcely populated with as few as 8.3 persons/km^2.

Agriculture in Ethiopia contributes 40% of the total gross domestic product (GDP) and 85–90% of export earnings. It also accounts for 85% of the total employment. However, agricultural productivity is characterised by low productivity. The causes are various, diverse and often interlinked with poverty.

As most of the poor are living in the rural parts of the country, agricultural development will still play the central role in poverty reduction efforts. This implies that an increased productivity in agriculture will have a powerful dynamic general socio-economic equilibrium effect benefiting the poor.

Increased productivity in agriculture should be driven by technology and investment for sustainable productivity and agricultural transformation. The most prominent social benefits that can be brought by the increased productivity are elimination of hunger, fast economic growth, reduction of poverty and proper development and utilisation of natural resources.

Again, sustainable agriculture needs integrated land and water planning, implementation and management, which increase the efficiency of water use in agriculture. This process has to be led by the community and their development partners, i.e. local governments.

Land and water development can be undertaken for settlement and irrigated agriculture. The co-ordinated effort and consent of stakeholders plays an important role in minimising mistakes, which are very costly. Training and education are also important tools to achieve the desired productivity level for the rural poor.

Capacity building priorities in community driven land and water management

Experiences suggest that decentralisation will not work without vibrant, participatory communities, with *woreda* (local government) and also for sustainability. The two can evolve together dynamically, strengthening one another (Alkiire et al. 2001).

Learning-by-doing is an important way of creating capacity in communities and local governments. Technical schemes in the past often failed because they did not correspond to communities' needs and priorities (Esmail 2002).

Once communities and local governments are given the power and resources, they can choose and implement projects.

Community driven land and water management that relies directly on resource-poor land users has the potential to make poverty reduction efforts more inclusive and cost effective than programmes traditionally run by governments.

Though community-led development programmes are relevant across many sectors, they have the greatest potential for goods and services that are small-scale and not complex and which require co-operation, such as common pool goods best represented by the management of surface water irrigation systems, management of communal land (pasture, grazing), and management of public forestry etc. (Manor 1999).

Why community-driven land and water management?

- enhances social acceptance and confidence
- compliments public sector activities, improves efficiency, effectiveness and equitable utilisation of infrastructure
- makes development more inclusive of the interests of resource-poor, vulnerable and minority groups
- empowers poor people, builds social capital and strengthens good governance and
- allows poverty reduction efforts to work at the appropriate scale.

Technical assistance and skill-oriented education and training should be given to all people involved in and responsible for land and water management, planning, implementation and execution, i.e. communities, land users, decision-makers and technocrats.

Moreover, the installation of major data/information structures like mini-meteorological stations in specific agro-ecological settings with the necessary human resources should not be overlooked.

Regarding the above notion, the following important points are raised for discussion and verification for enhancing the capacities of communities and the lowest levels of local government.

1 Education and training

a. Surveying and mapping and database management with special reference to cadastral for land registration, certification of land title and deeds.
   This measure is important in ensuring security on land use rights and regulations.

b. Decision-supportive role in land/water use planning, management and enhanced local capacity in sustainable (rain, ground and irrigation) water use efficiency.
   The Agricultural Technical, Vocational Education and Training (Agri-TVET) programmes (rainwater harvesting and small-scale irrigation curricula) can be used as an opportunity to all people involved in land and water use management, i.e. *woreda*-level decision makers, technocrats and water users associations.

c. Develop institutional structures of irrigated agriculture and capacity building both at land (arable/grazing) and water use associations and local governments.

d. Enhance capabilities of local governments and community-based organisations in designing local land use planning standards, strategies and enforcement regulations.

e. Develop mechanisms for enhancing the capacities and ensuring the participation of private investors in direct investment, construction etc. of land and water planning.

f. Build capabilities of local governments in assessing the natural resources and undertaking of Environmental Impact Assessment (EIA) studies prior to any investment.

g. Develop demonstration facilities (rainwater harvesting techniques) in the Agri-TVET institutions where all stakeholders should be responsible.

2 Expansion of supportive institutional structures (access)

a. Meteorological stations in specific agro-ecological settings as much as possible and upgrading the services for practical application and applied research.
b. Training and education (TE) facilities in land and water management for human resources development (HRD)
c. Development of applied trial and research stations in specific agro-ecological settings.

Initiatives for future applied research on land and water management

Ethiopia gets an annual rainfall apparently adequate for rainfed food and fodder production. However, moisture stress prevails in most parts of the country due to the uneven and unpredictable occurrence of rainfall both spatially and temporally.

Moreover, the ever increasing unsustainable use of all bio-physical natural resources coupled with overwhelming rural poverty and mismatch between uncontrolled population growth and food and fodder production have been attributed to the ever increasing ecological imbalances. This ecological disturbance has in turn been attributed to the recurrent famine occurring every 3–5 years.

Furthermore, the traditional and backward agricultural practices and the absence of applied research and extension services to alleviate local situations also contribute to insufficient exploitation of the available rainfall amount. In addition, most of the available data are obsolete and not suited to local conditions.

The little efforts made to use the water resources by the government, non-governmental organisations (NGOs), farmers etc. are concentrated only on the natural courses of rivers on available plains and do not give due attention to resource-poor farmers and pastoralists. Moreover, investment on river diversions, levelling and other reclamation efforts are almost negligible.

The major reasons can be summarised as follows:

- total dependence on rainfed agriculture and traditional land use practices
- insufficient technical service from the government and other relevant institutions
- poor characterisation of the agro-ecological settings to enhance organic farming and alternative agriculture and the absence of alternative technology packages (extension) on homogeneous land units—intensification efforts build upon what farmers are already doing
- absence of coherent land and water information systems
- irrigation efforts are observed only in natural courses of rivers
- no investment by the government to alleviate constraints of potential areas for re-distribution of land and opening up of new settlement areas

- near spontaneous approaches in allotting land to private investment without prior and thorough attention to Environmental Impact Assessment (EIA) and the absence of land use policy on leased lands accompanying investment.

Despite the above shortcomings, the success exhibited in the production of cotton in the Afar Regional State can be cited as an indication for the potentials and opportunities for development of land and water harmonisation.

Shortage of rains and population pressure are blamed for food insecurity and low productivity of agriculture and the deterioration of natural resources. However, if strategies are designed to alleviate the above problems and water resources are developed to cater to irrigation, it would be possible to attain agricultural surplus enough for domestic consumption and external markets.

As the main problem of agricultural productivity even in the rainfed areas calls for mitigating moisture stress, rain, ground and surface water resources have to be made to contribute to agricultural development through supportive applied research on all crop–environmental interactions within specific agro-ecologies.

The main aspects for future land and water management research initiatives could be the following, but should be exhausted in the succeeding forums.

i. Agro-ecology characterisation on a larger scale for each regional state.

ii. The design of land use policy strategy, regulations at each level of planning and mechanisms of harmonising them.

iii. Crop–environment interaction within a given agro-ecology, i.e.:

- soil nutrient status and fertiliser recommendations
- minimum irrigation requirement
- irrigation frequency (with respect to soil quality and crop requirements)
- areas with relatively better rainfall amount but needing supplementary irrigation
- water balance calculations
- soil moisture storage capacity
- reference (potential) evapotranspiration and crop coefficient (Kc value)
- minimum climatic data/information needed
- length of growing period (LGP)
- rainfall amount, probability, intensity, frequency and distribution
- available water capacity of soils and other physical properties
- crop rotation and organic farming
- socio-economic studies (indigenous knowledge, attitude of the community towards land and hydrology)
- agro-industry and marketing, and other post-harvest technologies
- soil and water conservation requirements
- specific land and water management options
- other constraints and opportunities to development—exhausting all issues and assumptions in specific areas within a period of time.

iv. Major land use (irrigation, rainfed, specific crop, grazing, livestock) requirements, i.e.:

- rainfall amount, moisture availability and other land qualities

- nutrient requirements
- climatic requirements (temperature, humidity etc.)
- harvest index and yield response factors
- growing cycle
- slope and landscape
- salinity/alkalinity tolerance
- calcium carbonate ($CaCO_3$) and Gypsum ($CaSO_42H_2O$) tolerance
- soil physical properties requirements (texture, structure, infiltration capacity etc.).

Recommendations

Despite the challenges and setbacks, there is a window of opportunity for progress. There is no blue print for achieving progress. Strategies and interventions should reflect the actual situation and need thorough thought on how they might be used.

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Present and future trends in natural resources management in agriculture: An overview

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Abstract

Agriculture is the backbone of the Ethiopian economy engaging more than 85% of the population and accounting for nearly 52% of the country's gross domestic product (GDP). Natural resources like land, water, vegetation, climate and topography and relief play a significant role in the success of agriculture. As a result of population pressure, climate change and poor management of natural resources, components of this sector have been threatened by chronic degradation, recurrent droughts, shortage of skilled manpower and improved technologies.

Efforts have been made to combat natural resources degradation by generating technologies in soil and water conservation and re-forestation, but the result was gloomy because of different reasons. Emphasis to develop the water resource was given top priority only in recent years. The potential for irrigated agriculture is estimated at more than 3.7 million hectares. The major direct threats to the development of water resources for agriculture in Ethiopia include sedimentation of rivers and water reservoirs, reduced infiltration and recurrent drought. The Ethiopian Agricultural Research Organization (EARO) has formulated a strategic research plan for the sector on its mandate area and also for setting priorities to generate technologies for different agro-ecologies. Emphasis is given to water harvesting *in situ* and *ex situ* and the management of irrigation water and drainage at all levels.

Background

Agriculture accounts for more than 85% of the country's work force, 51.6% of the gross domestic product (GDP) and 90% of export earnings (CSA 1999). Proper management of some of the natural resources is vital for the healthy development of the sector.

The country's economic development policy aims at:

1. ensuring food security
2. increasing production of sufficient export products

3. increasing supply of raw materials for the local industries and,
4. ensuring conservation-based development of natural resources.

In recent years, agricultural development has been highly affected by mismanagement of the natural resources. The Ethiopian highlands where most of the population lives have undulating topography and relief. Although stressed by high population density, the highlands have relatively better moisture, economic activities and infrastructure. The lowlands (<1500 metres above sea level, masl) have low and erratic rainfall and, hence, low soil moisture and severe erosion, as well as vector-born diseases that affect both humans and livestock. However, the lowlands have very high potential for the development of irrigated agriculture if water is available and infrastructure can be improved.

Trends of vegetation cover

There is no reliable figure on the trends of forest cover in Ethiopia. However, as some historical sources indicate high forests might have once covered about 35–40% of the total land area of the country (EPA/MEDaC 1997; EARO 2000a). Deforestation accelerated towards the beginning of the 20th century and in 1960, closed natural forest was estimated to cover only about 3.37%. It is believed that, in Ethiopia, agricultural activities must have started about 5000 years ago (EPA/MEDaC 1997) and wide spread deforestation started about 2500 years ago (Hurni 1988). In 1981, the estimated rate of deforestation stood at 200 thousand hectares per year and it is expected that this figure will be much higher today and may continue like this unless some alternative options are made available to the rural population. It has been estimated that high forests covered 16% of the land area in the early 1950s, 3.6% in the early 1980s (IUCN 1990) and only 2.7% in 1989 (EARO 2000a).

There are convincing indications of a downward spiral of forest resources degradation. Some of these are:

1. persistent deterioration of the quality of cultivated land
2. expansion of gullies
3. poor yield
4. poor water holding capacity of the soils, and measured/estimated values of the annual soil loss due to erosion ranging from 10 to 130 t/ha, with a generally accepted average of 42 t/ha (Hurni 1988).

Some re-forestation activities are underway but compared with the deforestation that is taking place it is only a small percentage and most of the replanted species are eucalyptus and cupressus with very low replanting of indigenous species. Re-forestation is a planned activity with a targeted area to be covered each season whereas almost every household in the rural part of the country does cutting of trees as it wishes. Compared with the long years tree species take to reach a productive stage on degraded environment and against an increasing demand and the slow effort in re-forestation, the future for vegetation cover is gloomy.

Sustainable smallholder land and water management

Traditional small-scale irrigation innovations

Because of increasing trend of population growth in the last six decades, (from 17 million in 1940 to 63 million in 2000) (EPA/MEDaC 1997), and increased exploitation of land resources, the balance of water resources has also been negatively affected. Although traditional small-scale irrigation practices existed in a few places, scaling-up activities must have started since the 1960s. The traditional irrigation practices by the farmers have some setbacks like:

- high labour requirement to build canals
- loss of productive land due to soil and stone ridging as well as tree cutting for construction purposes
- gully formation as a result of deep canals
- lack of water control to each canal resulting in poor water distribution to the stakeholders
- because of the lack of extension advice on water management, the impact from such practices has been small and should be improved through improvement of the technologies.

However, farmers use simple tools available at their disposal. Today some small-scale irrigation plot owners use watering cans or hoses water plants from the water source. Farmers growing some high cash crops and living near market centres use small pumps and generators to raise water to higher points for gravity application.

Out of necessity, farmers adopt the principle of irrigation from their relatives and neighbours. Some farmers have adopted irrigation practice provided water is available.

However, furrow irrigation wastes water through seepage and evaporation by flowing a long distance. Adoption of concrete tubes or plastic hose can reduce the loss of water. Hand watering can also increase the efficiency of water management and reduce the incidence of disease spread from one plot to another.

Management of irrigation water

Irrigation management under competing use of water

In many places where irrigation water is managed under commercial plantation, many perennial trees are observed near the canal or around the homestead and villages. These trees are planted for beautification of the landscape or for cooling and shading effect. However, the negative contribution of these perennial trees is their consumption of water, which is greater than that of the major crop produced. Renault et al. (2001) reported up to 43% of water consumption by the perennial trees compared with 22% by the crop in a tropical humid environment. Under the present circumstances of unlimited watering by furrow irrigation in the Awash Valley, the high evapotranspiration observed and the high consumption by the non-intended perennial trees planners should reconsider traditional criteria for design and performance assessment.

Salinity

Salinity affects over 11 million hectares of land in Ethiopia (Tadelle 1996). These naturally salt-affected areas are normally found in the dry lowlands and in the Rift Valley. The semi-arid climate of the Awash Valley has contributed to limited leaching by favouring accumulation of soluble salts in the soil. Most of the irrigated large-scale farms in the Awash Valley have been developed without giving due consideration to the delivery of irrigation water and provision of drainage facilities for safe disposal of the excess water.

Sustainable land management

Soil erosion

The unique topography, type of soil, deforestation, intensive rainfall and low level of land management and the land use type practised have resulted in heavy runoff that induced soil erosion particularly in the northern and central highlands. Soil erosion is taking place all over the country but because of the effect of overpopulation on land that is already fragile (steep and mountainous), and mismanagement of the land itself, the northern and central highlands are the worst affected. Estimation made on the amount of soil that leaves the plot and deposited elsewhere or that leaves the country is unpredictable. This is expected because the Ethiopian topography, agro-ecology, type of soil associations, land use type etc. vary from one location to another. Measuring the source of variation in estimation of land degradation is difficult. However, the estimations made by the Ethiopian Highlands Reclamation Study (EHRS) and Soil Conservation Research Project (SCRP) are 100 t/ha with 1.8% loss of productive cropland (Constable and Belshaw 1989) and 42 t/ha with 2% loss of productive cropland per annum (Hurni 1988).

Soil conservation

The Soil Conservation Research Project (SCRP) of the Ministry of Agriculture, and the Institute of Agricultural Research (IAR, now the Ethiopian Agricultural Research Organization, EARO) have conducted major soil and water conservation research at the national level. Limited research activities carried out by the various research centres focused on quantifying the runoff and soil loss under different management and topographic conditions. Results showed that grass cover was effective in minimising both runoff and soil loss as compared with bare fallow and crop cover. If properly implemented, soil conservation practices can be effective in counteracting soil erosion and increasing productivity by reducing nutrient losses and conserving moisture. Recommended actions to combat the constraints in soil and water conservation are contouring, terracing and tree planting. However, because of immense diversity in the social, topographic, agro-ecological and watershed setups adoption rate is slow and sometimes rejected. Therefore, more emphasis has been given to soil fertility management

Adoption rate was low because of:

- poverty
- lack of participation by the end users at the planning stage
- lack of land use policy, e.g. on grazing land, community forest and,
- lack of legislation pertaining to natural resources management.

Catchment management

Except in a few cases, research in soil and water has not taken into consideration the catchment management. Hence, the effect of mismanagement of the catchment areas is already being felt in many communities with steep lands and where small-scale irrigation is practised. Sedimentation of micro-dams is becoming a serious problem in the absence of an integrated watershed management practice. The issue may become the concern of many communities as development of small-scale irrigation continues. Catchment management is an important practice to adopt in soil and water conservation activities and agricultural water management.

A catchment area may comprise different soil types or agro-ecological conditions, depending on its extent and the physiographic and climatic conditions of the area. In Ethiopia, however, field orientation of agricultural experiments is on plot or single site basis. With the present situation of land degradation and possible expansion of small-scale irrigation in the highlands, the adoption of a watershed management approach becomes imperative. The country has also been more dependent on rain-fed agriculture but this is no more reliable. Under this approach, each community will develop its own devices to conserve soil moisture *in situ*. Hence, research centres are advised to adopt the watershed management approach. Because of the advantages that watershed management approach offer, few regional states have now initiated several watershed management projects and depending on the success of these more of similar development projects will be initiated.

Infertile soil management

Causes for declining soil fertility

Farmers have a common perception regarding the cause for the decline in soil fertility. These are:

1. continuous cropping
2. decline in manure application
3. little or no agronomic management, particularly cropping systems

4. decline in inorganic fertiliser use and,
5. soil erosion.

Continuous cultivation

An example of the declining size of farms per household is indicated in Table 1. Throughout highland and midland Chiro *woreda* in eastern Ethiopia, farmers were forced to move onto the valley slopes with 50% gradient or more, despite a guideline to cultivate only lands with slopes below 35%. This is the case in many other parts of the country. Farmers are also forced to cultivate the same land year after year without fallowing. Among the cropped land, cereals occupy about 90%. Hence, there is little option left to the farmer to improve soil fertility through crop rotation although resource-rich farmers do practice some rotations and apply manure. Farmers with relatively small farmlands do not adopt soil conservation practices and this has an impact on soil fertility management and soil conservation, which will then cause land degradation because of unsustainable intensification of the land. The continuous cultivation has also aggravated soil erosion because the land where most agricultural activities take place is steep in many areas. The method of land preparation has favoured erosion where essential nutrients have been washed off together with the soil. Severely degraded land has gone out of production particularly in steep slopes.

Nutrient cycling

Nutrient balance studies

Braun et al. (1997) summarised and reported nutrient cycling between tree plantations and natural forests, a few agroforestry tree species and forage species and the use of mineral fertilisers on cultivated crops. Under a situation where almost all cow dung is used as fuel, where most of the crop residues are used as animal feed and as fuel or construction material, the nutrient imbalance would be self-evident (Table 1).

Table 1. *Total nutrient balance for land/water classes in the Ethiopian highlands.*

Land/moisture class	N kg ha^{-1}	P ka ha^{-1}	K kg ha^{-1}
Good rainfall	–52	–7	–33
Uncertain rainfall	–35	–5	–24
Problem rainfall	–41	–4	–24

Sources: Braun et al. (1997).

Water resources

It is believed that Ethiopia has a total volume of 109 billion cubic metres of surface water and about 2.6 billion cubic metres of ground water. The western half of the country receives sustainable amounts of precipitation and has many perennial rivers and streams while the precipitation is marginal in the eastern half of the country. Because of the progressive land degradation that is taking place at present, the amount of water leaving the catchments carrying away soil with it must have increased ever than before. Hence, the amount of available water *in situ* has been reduced particularly in the eastern half of the country. The Ethiopian plateau is the source of the Abay, Awash, Tekeze, Mereb, Baro-Akobo and Omo rivers that flow to the west and south-west. The Baro-Akobo basin is potentially the largest possible irrigable area (about 483 thousand hectares) though only a negligible portion of it has been developed probably because of the large investment cost required and its distance from the central market makes it less favourable for commercial agriculture. Awash River is the only river extensively used for commercial plantations of industrial and horticultural crops in the Rift Valley. Out of the total irrigated area of about 161,125 ha, over 43% is found in the Awash River basin. The remaining potential of the Awash River for irrigated agriculture is estimated at 136,220 ha.

Because of deforestation, soil erosion and over-exploitation by the population, the highlands are significantly degraded. This has resulted in increased acceleration of runoff along the slope thereby reducing water infiltration. Acceleration of runoff movement down the slope has also increased sedimentation in the downstream flat bottoms contributing to poor quality of water. Consequently, some small rivers, streams and springs have their volumes reduced or dried particularly during the dry season.

Social factors such as demographic pressure, land shortage, and social and cultural aspirations affect the quality of soil and the environment. These socially driven forces lead to several activities with major changes in soil and environmental characteristics such as deforestation, and new land development. Some may argue that trees increase evapotranspiration during the dry season thereby reducing the amount of water received by the soil, but in a steeping slope like in many parts of the Ethiopian highlands, trees can reduce the velocity and increase infiltration contributing to the more ground water recharge.

Goal and objectives of the soil and water research strategy

General objectives

The general objective of the soil and water research strategy is to improve the utilisation and minimise the degradation of natural resources for the sustained benefit of the nation at large and farmers in particular.

The goal of the strategy is therefore:

- increasing land productivity per unit area through the adoption of the integrated plant nutrient management (IPNM) approach
- improving the conservation and efficient utilisation of soil and water resources
- intensifying and diversifying land use-based knowledge and characteristics of the soil and ecological resources classification

- optimising the scientific capacity of all centres in soil and water research to attain all the above.

Agricultural Water Management Research Program

The importance of irrigation in agriculture to overcome food deficiency in the rapidly growing population of the world is rapidly increasing (EARO 2000b). Ethiopia is already suffering from food shortage because of its increasing population and chronic drought occurrence in most parts of the eastern and northern part of the country. The estimated six million hectares of land used for cereal production has become under-productive while some of it could have been producing twice a year. At the same time, Ethiopia is endowed with water resources, which could be easily tapped and used for irrigation.

This programme will handle basic soil–crop–water relationships, water balance, agro-hydrology, irrigation and drainage methods. Drainage of heavy clay soils will be an important component in the programme as a large area of the heavily populated land is covered by waterlogged soils. Reclamation of degraded soils and implementation of runoff farming for supplementary irrigation, efficient utilisation of water resources with special emphasis on the development of small-scale irrigation will be emphasised in the different agro-ecological zones (AEZs). Until now, research on irrigation has focused at the Werer Center, which is located in the midst of irrigated agricultural land. However, the centre is deficient in skilled manpower and facilities compared with the service it renders to irrigated agriculture in the country. However, the research being conducted on agricultural water management at Werer may not cover the interest of the highlands or other potentially irrigable areas in the lowlands because of differences in agro-ecology and soils.

Summary

The current government's policy for economic development and pathways to industrialisation is through the development of the agriculture sector. There are some obstacles facing the development of the water sector such as land tenure and land use issues, and water basin development vs. ethnic bound development planning. However, there are some positive sides, too, regarding agricultural development. These include:

- emphasis has been given to support the development of private smallholder agriculture despite the fragmented and small-size land holdings
- large sizes of commercial enterprises are encouraged in areas with sparse population in the lowlands with large opportunity for irrigated agriculture
- conservation based development of agriculture to combat soil degradation, deforestation and improvement and maintenance of soil fertility
- the institutionalisation of strong soil and water and forestry research programmes at directorate level equivalent to that of crops and animal science research in EARO to generate technologies to combat desertification
- agro-ecological and watershed management approach is being adopted in EARO

- the emergence of institutions like the Arbaminch Water Technology Institute and Mekelle University College of the Drylands that train students in irrigation and hydrogeology and soil and water conservation skills, respectively
- the National Extension Improvement Program which has soil improvement as part of its packages
- a number of non-governmental organisations getting involved in natural resources development and
- the emergence of market-oriented soil fertility improvement/management programmes.

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Agriculture, irrigation and drainage research in the past and the future

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Abstract

Irrigation has so far not been very important in the development of agriculture in Ethiopia. Unfortunately, the country suffers from severe food shortage due to chronic droughts when there is a potential to develop over three million hectares by irrigation. Land under irrigation accounts for only 5% of the potential and nearly half of this is under traditional irrigation scattered all over the country. Most of the modern commercially managed agriculture is found in the Awash Valley and mainly produces cotton, sugarcane and horticultural crops.

Irrigation and drainage research in Ethiopia has been undertaken at the Werer Agricultural Research Center where most of the commercial farms are found and serves mainly these farms or similar other farms in far away places.

The major outputs of research in irrigation and drainage management at Werer have been the determination of water requirement, frequency and depth of application for cotton, wheat, maize and horticultural crops. Significant investigation has also been done on drainage and fertiliser management under irrigation in the region. Continuous monitoring of the quality of Awash River water for irrigation has indicated no major problems concerning salinity except for a few sites.

The constraints and gaps observed in irrigation and drainage research, limitations observed in the scaling up of the technologies to other locations, and future strategies and approaches in research on agricultural water management are presented in the paper.

Background

Presently, irrigated area in the country accounts only for 5% of the total land suitable for irrigation and about one-third of this is located in the Awash basin. But the improperly planned irrigation projects not supported by improved irrigation and drainage management technologies, had invited further degradation causing salinity, sodicity and siltation problems. This is observed in the major state farms of the Middle and Lower Awash.

Research on irrigation management and drainage in Ethiopia was first initiated in 1964 at Werer Agricultural Research Center. The main focus of the research was on the agronomic aspects of irrigation on cotton production. More work has been done on the crop water-requirement of different crops, namely fibres (cotton and kenaf), horticultural and lowland oil crops. Investigations on alternative irrigation systems and an assessment of indigenous knowledge were conceived only recently. At present, research on irrigation, drainage and water conservation has been initiated in other centres of the Ethiopian Agricultural Research Organization (EARO) located in the sub-moist and moist agro-ecological zones of higher altitudes such as Debre Zeit and Melkassa. The justification for this is that the research on agricultural water management at Werer may not cover the interest of the highlands or other potential areas for irrigation development. However, the centre still lacks skilled manpower and facilities.

Ethiopia needs to raise the national capability in agricultural water management activities (irrigation, drainage, water harvesting), and water resource development through research and development.

In Ethiopia, most of the research activities have been mainly concentrated on agronomic components giving less attention to the engineering aspects. It is also observed that the research has focused on plot-based studies than looking into integrated water management for agriculture.

Adoption of research findings in water management and assessing and upgrading the indigenous knowledge of irrigation by farmers should be the major outputs of the research activities.

Objectives

The objectives of this paper are briefly to assess:

1. the irrigation and drainage research by the former Institute of Agricultural Research (IAR, now the Ethiopian Agricultural Research Organization, EARO)
2. the gaps and constraints encountered in the process and,
3. the strategy to strengthen irrigation and drainage research in the future.

Research achievements

Water requirement studies

Irrigation research at Werer has been going on for over 35 years assisted by the Food and Agriculture Organization of the United Nations (FAO) in the first 10 years. The main activities during this time were determining frequency of irrigation and water closure dates, experiments to determine optimum combination of irrigation frequency and depth of application, and experiments to evaluate sensitive stages of growth for moisture stress, moisture depletion patterns and the effect of water logging on yield.

It was reported that the water requirement of cotton planted in mid-May was 1009 mm while that planted in mid-July was 915 mm. The drop in July is due to the reduced evapotranspiration and the small rain received at the time. The amount reported was within the range and values given by other researchers (e.g. Kandia 1982). It was also found that cotton in the Middle Awash can be irrigated by one of two irrigation regimes, i.e. once in two weeks with 75 mm of water per application, or once in three weeks with 120.5 mm of water per application. Water budget method was also studied and it was found that with 70% irrigation efficiency, gross irrigation requirement for cotton in mid-Awash region is found to be 120 mm (Kandia 1982).

Studies on cotton–water yield relation confirmed that irrigation of 150 mm water at squaring; flowering and boll formation stages are best for optimum production. Irrigation intervals for cotton grown on salt-affected soils revealed that one to two pre-planting irrigation perform well on cotton yield.

Other practical recommendations were made on optimum irrigation regimes (frequency and amount) of maize, kenaf, groundnut, sesame, bean, wheat, onion, pepper, banana, tomato and citrus.

Monitoring the water quality of Awash River

The quality of Awash River water for irrigation has been monitored for many years. In 1973 the quality of the water sampled at Amibara Irrigation Project site was reported to be satisfactory for sustained irrigation with adequate leaching and drainage. The quality reported from 1987 to 1989 for Middle Awash was also considered safe except when water was not available in June and July between Werer and Meteka farms (Endale et al. 1992).

Drainage

Studies on sub-surface drainage systems under a pilot drainage scheme revealed that a 40 to 60 metres drainage spacing with red-ash filter material is best to reduce soil salinity and control groundwater table in the Middle Awash Valley. Leaching as a reclamation method for salt affected soils revealed that intermittent leaching practice with 150 mm of irrigation water is effective in removing soluble salts from the root zone of cotton crop in the Middle Awash.

Cumber-beds of different width have been recommended for draining excess moisture and application of N and P fertilisers highly increased the yield of crops grown on vertisols.

Constraints and gaps

a Manpower status

Manpower is one of the limiting factors in agricultural water management research. The balance of manpower in soil and water research compared with that in the crop science research is discouraging. It also indicates the low weight that had been given to the management of the natural resources in the past. The balance within the programme is not also encouraging. Of the total manpower engaged in the programme, the ratio for agricultural water management, soil and water conservation and soil fertility and plant nutrient management is 15:18:57. Laboratory technicians (diploma graduates) are also the most limiting resource.

The technical capacity of the available staff is also limited due to lack of in-service training, scholarships and support from more advanced research and academic institutions.

b Financial allocation

By nature, agricultural water management research activities need relatively higher amount of financial resources. Unlike the other sectors of agricultural research the funding for irrigation, drainage and water harvesting research from EARO has been extremely restricted inhibiting involvement of the research staff into the solutions of agricultural water management problems.

Therefore, it is important that this area of research must get financial assistance from other sources. International institutions need to have a better involvement in this respect.

c Facilities

Most of the soil and water management divisions in the research centres have a small unit of soil laboratory. However, the constraints faced are lack of hydraulic laboratory, maintenance of instruments, shortage of chemicals and glassware in the existing laboratories.

d Scope of research area

The scope of the research has been confined to irrigation agronomy trials to recommend irrigation application and to develop the methods of drainage of heavy clay soils. Priority areas for irrigation and drainage research, based on studies of the country's problems, have yet to be identified.

Research in water resource development could enable the development of low-cost structures and irrigation systems for handling water. Where research information is lacking, there is a danger of over-design, which results in high cost or under-design, which results in failure. Specific research have not yet been conducted to address problems related with flow structures (canals, ditches, flumes etc.); water storage facilities (farm ponds, irrigation reservoirs) and sediment traps.

Agricultural water management research should, therefore, be accompanied with the water resource development and research activities to have a significant impact on the future development of irrigated agriculture.

e Poverty

Not only the research work, but also the implementation of developed agricultural water management technologies has high initial cost. Most of the grass-root communities who are supposed to use these technologies are poor. Due to this fact, it is difficult to implement these technologies unless they get financial support.

f Dissemination of research results

Even though there are some technologies already developed in agricultural water management programmes, little has been done in disseminating these technologies. This is because of loose linkage between the research and extension on the one hand, and lack of awareness by the extension services about the importance of these technologies on the other hand.

Much attention by extension people has been given to the dissemination of high yielding crop varieties and fertiliser, rather than agricultural water management technologies.

Lessons learned

Need for participatory approach

Under the former Institute of Agricultural Research (IAR) (now EARO), most of the research activities were developed through the initiatives of the researchers themselves without the participation of the stakeholders and the end users. This has not speeded up the transfer of the developed technologies to locations away from the centre.

According to Andargachew (2002), the participation of the stakeholders in the research has the following importance:

- a recognition that farmers' input in the research leads to more adoption and sustainability
- contacts between researchers and farmers lead to recognition of the value of local knowledge especially in complex, diverse and risk prone conditions
- provides technologies relevant to the needs of resource-poor farmers
- allows the generation and/or dissemination of technologies under local conditions
- provides opportunity for accepting or rejecting technologies at an early stage and at the same time allows the easy adoption of promising technologies and
- gives information on the characteristics of a technology that farmers consider important.

Participatory approach is, therefore, the best solution for the dissemination, adoption and sustainability of any research activities.

Need for strong research–extension linkage

Like in crops research, aggressive dissemination work is required in the transfer of available technologies of agricultural water management to the farming communities, to bring real change in the agriculture sector. For example, considerable efforts have been put to build soil and water conservation structures using available technologies, unlike agricultural water management. Efforts should be made by the researchers in water management to make strong and closer linkage with the research–extension group to disseminate the improved technologies to the end users.

Need for integrated water management research

In the past research projects were developed independent of the involvement of other disciplines and this has incurred more time and cost to the research activity. Future approach should consider involving the different stakeholders from planning to implementation of the research projects to shorten the time frame between technology generation and transfer.

The research should also focus on the investigation of national, zonal, regional and other problems in particular to the needs of the people related to water resources development in line with the agricultural water management. This could provide practical and sustainable solutions to the existing problems. Moreover, applied research should be given priority than the theoretical one. Therefore, integrated research approach is the key for bringing effective, efficient and complete research technologies to the end users.

Need for research networking

Based on their importance, some research activities will be undertaken at a larger scale involving many users. To ensure complementarity of efforts and avoid duplication, it is suggested that some of these activities be grouped under the umbrella of networks where appropriate centres would play the lead co-ordination role.

Ongoing and planned activities

Ongoing activities

- establishing soil, crop and water relationships and developing efficient water uses for sustainable production particularly by determining the crop water-requirement and irrigation scheduling for different crops under different agro-ecological zones (AEZs)
- evaluating different surface irrigation systems aimed at increasing the water use efficiency and crop yield of different AEZs
- monitoring the water quality of the Rift Valley lakes and Awash River to facilitate the existing and new irrigation works by avoiding risk and uncertainty
- assessing and evaluating farmers' indigenous knowledge of agricultural water management practices to upgrade and improve the traditional knowledge on irrigation water management
- developing of different drainage technologies to manage poorly drained soils and
- water harvesting and conservation using contour bund in arid areas to mitigate the risk of chronic drought (EARO 2002).

Planned activities

Short term

- Identifying and prioritising agricultural water management research
- Inventoring, characterising and evaluating farmers' knowledge of agricultural water management practices of watershed areas and water logging soils
- Evaluating the existing research outputs on agricultural water management and making them available to the users
- Studying the tolerance of different crop, grass and tree species on salt affected soils and developing crop production management systems.

Medium term

- establishing soil, crop and water relationships and developing efficient water use for sustainable production. Developing appropriate irrigation and drainage technologies
- developing engineering parameters for irrigation and drainage design
- undertaking water balance studies in different AEZs
- identifying suitable and appropriate irrigation methods under different AEZs (EARO 2000).

Summary

Research on irrigation has been going on at Werer Agricultural Research Center, for more than 30 years. It has served the interests of the large commercial plantations of cotton and horticultural crops in the valley. It will continue serving the purpose of these large-scale commercial farms as many more are expected to come into existence in the next few years. However, from now on, irrigation development is not only focusing on the production of industrial crops but also food crops and high value cash crops in the highlands where most of the population live. The Ministry of Water Resources has nearly completed comprehensive master plan studies of the major river basins and is embarking on the implementation phase. The master plan studies not only focus on the potential lowland irrigation but also on the development of potential areas in the highlands with emphasis on food crop production.

The Ethiopian Agricultural Research Organization (EARO) is mandated to generate technologies on irrigation and drainage in all agro-ecologies of the country and to this end it has developed strategies for short, medium and long-term periods. To implement the strategy EARO has started to recruit junior researchers in agricultural and water engineering. Agricultural water management, watershed management and water conservation are given high priorities in the short- and medium-term plans of the organisation. EARO is working with all stakeholders and partners to achieve its objectives.

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Advances in integrated water resources management research in agriculture

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Abstract

This paper presents an overview of integrated water resources management (IWRM) with particular reference to agricultural water use in sub-Saharan Africa (SSA). The importance of adopting an integrated, river basin based approach to analyse water availability and to assess the possibilities for water resources development, water productivity improvements, and water savings is highlighted. The role of storage, the merits and demerits of different techniques for improving water productivity, the need for sustainable management of groundwater, and the potential for recycling wastewater for agricultural production 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.

What does integrated water resources management mean?

The concept of integrated water resources management (IWRM) was born of the realisation 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 utilisation of the resource and resource protection?

Population growth and greater demand for water exert increasing pressure on available water resources and lead to water scarcity in many countries and regions, especially during dry seasons and droughts. In addition, rising demand intensifies competition among water uses and water users and may trigger disputes and conflicts.

IWRM is a comprehensive approach to water management that takes into account different types of water (e.g. surface water and groundwater, brackish and fresh water), combining both quantitative (e.g. floods, droughts, consumption) and qualitative aspects (e.g. pollution, water temperature changes, ecological functions). 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 founded on an understanding of the interactions and interfaces between those different uses and users, particularly the impacts of water use by a particular sub-sector, or at a particular location, on other sub-sectors or locations.

Scope of the paper

This paper reviews concepts and issues related to IWRM in relation to the challenge of meeting the expanding food and fibre requirements of growing populations in SSA. The many facets of agricultural water use, with particular reference to tools and approaches for increasing water availability and realising water productivity improvements in light of the multiple uses and users of water in river basins are discussed. The need for an enabling environment, including policies, institutions and support services, in seeking strategies to improve and sustain agricultural water use, is highlighted.

Water and food security challenges in sub-Saharan Africa

Achieving the goal of food security in SSA has to contend with the fact that some of the world's most water-scarce countries are located in the region. Research carried out by the International Water Management Institute (IWMI) (Seckler et al. 1998; Seckler et al. 1999) shows that almost all countries in Africa would face either absolute or economic water scarcity in 2025. In the first case, countries will simply not have sufficient water resources to meet their projected agricultural, domestic, industrial and environmental needs, even if water is used with the highest feasible efficiency and productivity. The second set of countries, although having sufficient water resources, will be limited by their capacity to develop the additional storage, conveyance and distribution facilities needed to harness those resources for agricultural development and food production. 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 many countries in the semi-arid regions of SSA, rainfed agriculture is practised 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. It overcomes the need for shifting cultivation and reduces the pressure on fragile environments. The risk of crop failure is minimised and farmers can hope for higher and more reliable agricultural production and better levels of income. However, large-scale irrigation expansion is slowing down as the best sites are progressively exploited, the cost of developing the less favourable sites rises, and the availability of investment capital diminishes. The generally disappointing performance of large irrigation systems and the social costs associated with large-scale developments act as further disincentives.

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 sectors considered to be more lucrative, prospects for increasing food production, which even now is hard-pressed to keep pace with population growth, may be further undermined.

Appropriate decision-support tools and techniques can play a significant role in water allocation. The Water Evaluation and Planning System (WEAP) is one such example (SEI 2001). IWMI has begun using it as a research tool to simulate and analyse water allocation scenarios in river basins in response to various sources of supply (e.g. rivers, groundwater, and reservoirs) and variations in abstractions, demands, and ecosystem requirements etc. The scenarios address a broad range of 'what if' questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented? Preliminary results of an application of WEAP to the Steelpoort basin in South Africa are reported in Lévite et al. (2002).

So, the challenge before us is how to make the most productive use of the available land, water, financial and other resources, including the adoption of policies and institutional arrangements, to promote economically and ecologically sustainable soil, water and crop management practices, and agricultural production.

Agricultural water use and IWRM in the basin context

Agriculture is the world's biggest user of land and water resources; it accounts for over 85% of water withdrawals in Africa (Rosegrant and Perez 1995). But at the same time, not all of the water withdrawn for irrigated agriculture reaches the crops—it either evaporates, seeps through canals, or leaks through pipes. Sally et al. (2000) pointed out that the imprecise nature of many canal water delivery systems and surface irrigation methods leads to more water being applied than crop transpiration needs because of the difficulty in (a) ensuring that all crops in the field receive a uniform and adequate water supply and (b) knowing when enough water has been applied. Water applied in excess of crop transpiration evaporates from soil surfaces, or percolates past the root zone to groundwater, or ends as surface runoff and return flows to the drainage and supply systems. Some of this 'lost' water is thus available for reuse especially if pollutants such as agro-chemicals, salt residues, or domestic and industrial waste have not adversely affected its quality (Seckler et al. 1998). In terms of a basin, irrigation return flows are therefore externalities that are sometimes positive, as for instance when groundwater is recharged, and sometimes negative, for example when salinity build-up is exacerbated; hence the need to take a basin perspective to ascertain if such excess water is desirable or not.

Water savings: Some misconceptions

It is recognised that the river basin is the appropriate unit for planning, developing and managing water resources, and for analysing water availability and water use, and thereby, the scope for water savings. Sakthivadivel et al. (2001) pointed out that water saving means different things to different people. If a farmer uses less water in his fields, he may well consider that he has also saved water. But increases in efficiency (which typically relates the quantity of water beneficially used to the amount of water diverted) at a local level do not necessarily lead to water savings at a basin scale, especially if return flows are being reused or contribute to groundwater recharge. In such situations, any reduction in the amount of water diverted for irrigation will have an adverse impact on water-related activities downstream, especially if the basin is 'closed'.[1] But in cases where there are drainage flows out of the basin or to sinks, then using less water in the field will also translate into water savings at the basin level.

Agriculture and irrigation projects on the one hand, and technological and management interventions on the other, are often justified on the basis of water savings. But, as shown above, this may sometimes be misleading. The adoption of these techniques may result in less water use per hectare and an increase in water productivity on some fields. But to determine whether water was really saved or not, we have to find out what happens to the water that is not used. If water is not affected by pollutant loading and can be used productively at another location, then there is no net change in water use (i.e. water productivity increases, but there is no overall water saving).

Some tools and techniques

When contemplating water resources development, we therefore see the importance of properly accounting for water flows in a river basin, including return flows from seepage, percolation and surface runoff traditionally counted as 'losses' at farm and system level. Molden and Sakthivadivel (1999) showed how this could be done using a water accounting framework that integrates water balance information with the various water uses within a basin. The different ways in which water flows into and out of basins can be assessed and potential areas of water scarcity and those where further development of water resources can occur identified.

1. In a closed basin, all of the water in the basin is fully committed and depleted by various uses within it and there is no outflow of utilisable water. Any further depletive use in one part of the basin will thus affect users in other parts. In such cases additional water needs can only be met through gains in water productivity (e.g. by reducing non-beneficial evaporation, by reallocation or by augmentation from an outside source). In an open basin, on the other hand, there are outflows of utilisable, uncommitted outflows all year round and more water could be developed even in a low flow season without diminishing existing uses.

While there are many proven hydrologic models that can estimate likely runoff given particular combinations of rainfall, land cover, topography etc. rather less is known about water abstractions for irrigation and other uses. Many water abstractions are private and small scale, and do not enter directly into the official records of water use in a basin. But they can have a significant cumulative impact that ultimately will affect natural hydrologic regimes. Approaches combining analysis of past records, field surveys, interviews of key informants, and the use of remote-sensing images and data contained in global databases such as the IWMI World Water and Climate Atlas (IWMI 2000) may be useful in this regard. Droogers (2002) provided an overview of the available global datasets on irrigated areas and an evaluation of their strengths and weaknesses and shows that remotely sensed data can usefully complement existing field-based approaches and land-use classification information to map irrigated areas and to assess actual evapotranspiration from both irrigated and non-irrigated areas.

The foregoing discussion shows that, in reality, water used for agricultural purposes may have a variety of other uses; the full potential of agricultural water use cannot be realised without an overall knowledge and understanding of basin-level water use and availability.

Meeting increased demands for agricultural water use

There are two ways of meeting this increased demand: developing additional water supplies (e.g. reservoir construction, trans-basin diversions), or making effective use of existing facilities. The role of storage will be discussed as an example of the first approach; in the case of the second, attention will be focused on improving water productivity. Discussions of the potentially important contributions of (a) groundwater and (b) the recycling of wastewater towards enhancing agricultural production will conclude this chapter.

Role of storage

Different rainfall regimes result in different levels of availability of fresh water resources. In permanent humid climatic zones, rainfall distribution is regular and runoff is quite stable. In many seasonally humid and semi-arid climates, river runoff is irregularly distributed within the year—heavy rain alternates with dry spells resulting in alternating flood and drought periods. Such areas stand to benefit from suitable measures to capture and store excess water for irrigation, industry and domestic use.

The essential function of storage, whether in reservoirs, tanks, farm ponds, or groundwater aquifers, is to help meet water demand in the face of spatial and temporal variations in natural water supply. Keller et al. (2000) discussed different ways of storing water: in the soil profile, in underground aquifers, and in reservoirs. They point out that storage of water in the soil profile, though important for crop production, is very short-term, lasting only a few days. Small reservoirs can store water for some months whereas in the case of large reservoirs or aquifers, the storage horizon can extend to years.

While recognising that each storage technology would have strong comparative advantages under specific conditions of time and place, they show that substantial gains can be achieved in water resources development projects by integrating aquifers and reservoirs, wherever possible.

Enhancing the productivity of water

When managing water for agriculture, especially in areas where water rather than land is the limiting resource, the focus should shift to increasing the productivity of water. That is, to identify and adopt agricultural and water management practices that achieve more output per unit of water consumed, thereby easing the strains of water scarcity and reducing the need for additional storage.

Techniques such as deficit, supplemental or precision irrigation that allow better control, timing and reliability of water supplies will enable farmers to apply limited amounts of water to their crops in the time and amount that help realise optimum crop response to water. One can select crops or crop varieties that are less water consuming or which yield higher physical or economic productivity per unit of water, or adopt improved land preparation and fertilisation practices. Any water thereby freed up can, in turn, be reallocated to other uses with potentially dramatic increases in overall economic productivity of water.

Sally et al. (2000) discussed issues related to the adoption of precision irrigation techniques in a basin perspective: what they are, where in the basin they could be promoted, and how they could benefit poor people. It is emphasised that such techniques are not always high-technology options but include a broad range of innovative and affordable technologies and water management practices such as simple bucket and drum kits for drip irrigation, small sprinkler systems, level basins, and conventional drip and sprinkler systems. They enable farmers with limited access to water to make effective use of that water; in addition, non-beneficial evaporation can be minimised and water diversion requirements from the source reduced. Overall, small, resource-poor farmers in water scarce areas thus have an opportunity to improve agricultural production, household food security and income. This is especially important for farmers in marginal areas of SSA given that the 'costs' of water scarcity invariably tend to fall more heavily on the poor, particularly women who constitute nearly half the agricultural labour force (van Koppen 1999).

In light of the spatial and temporal interactions between different water users in a basin, it is important that water conservation interventions be properly located within the basin. The concept of 'hydronomic zones' (*hydro*: water, *nomus*: management) introduced by Molden et al. (2001) provides a simple framework for interpreting water use, evaluating water-balance based performance measures, and formulating strategies for the development and management of basin-wide water resources. It provides guidance on whether the geographic location and quality of outflows would allow reuse or not, thus helping to target and prioritise efforts and investments for more productive use of water.

Sustainable management of groundwater[2]

Groundwater development offers major opportunities for promoting food production and improving livelihoods in many countries with high levels of rural poverty. Groundwater is also an increasingly important source of water for urban and industrial uses. Affordable water-lifting devices such as small diesel or electric pumps, or muscle-powered treadle pumps have dramatically improved poor people's access to groundwater in Bangladesh, eastern India and Nepal (Shah et al. 2000). At this scale, the capital requirements to develop groundwater irrigation are generally low and its productivity is higher compared with surface irrigation. It offers farmers irrigation water 'on-demand' and reacts slower to drought.

Benefits of groundwater development have to be balanced against the risks of over-exploitation and contamination. Groundwater is being heavily depleted in many areas—the 1 to 3 metres annual decline in water tables occurring in pump intensive areas of India and China illustrate the gravity and magnitude of the problem. This is compounded by problems of inequitable access to water and health problems arising from contaminants such as arsenic, fluoride or other contaminants.

Management of groundwater resources is a typical example of how to reconcile resource use against resource conservation. The lack of reliable data on water availability, quality and yield and aquifer characteristics in many semi-arid areas of SSA is a serious constraint to establishing the limits to groundwater use. Measures to regulate groundwater overdraft should be combined with approaches to promote groundwater recharge and increase water productivity. The associated challenges are formidable. But they have to be faced if we hope to make use of the available reserves of groundwater in a rational and sustainable way.

Recycling of wastewater in peri-urban agriculture

Although the rural population remains in the majority, the rate of urbanisation in SSA is higher than in any other continent (Merrey et al. 2002). Driving this phenomenon are demographic growth and migration to cities. A common feature of growing cities is that they generate large volumes of wastewater but possess little or no sanitation infrastructure. Poor sanitation results in wastewater entering waterways used for agriculture in urban and peri-urban areas and hence *de facto* recycling of wastewater.

Urban and peri-urban agriculture is increasingly becoming an important source of livelihoods, income and nutrition. It fills a niche for perishable products such as fruits and vegetables, produced and marketed directly with very little processing. It contributes to household food security of the urban poor and marketable surpluses provide a regular source of income to peri-urban farmers, particularly women. But very often, the source of water and nutrients in peri-urban agriculture is city 'waste', far more reliable than rainfall, but with attendant health implications.

The global extent of peri-urban agriculture is not known but available estimates indicate that about 900 thousand hectares of cropland worldwide are irrigated using treated or

2. Adapted from Sakthivadivel and Sally (in press).

untreated municipal wastewater, with Mexico alone accounting for over 600 thousand hectares (Raschid and Abayawardena 2002). It is suspected that this is just the tip of the iceberg and comprehensive assessment at a global level is needed to understand its significance. Countries in Africa (such as Botswana, Ghana, Kenya, Mozambique, Namibia, South Africa, Zambia and Zimbabwe) are examples where wastewater (with varying degrees of treatment) is used for agriculture. In fact, the National Agricultural Master Plan in Botswana makes provision for treatment facilities to ensure the reuse of wastewater for agriculture. In Ruai, Kenya, the effluent has been treated to a degree compatible with World Health Organization (WHO) micro-biological quality guidelines for irrigation of crops without risk to workers and the public (Hide et al. 2001; Inocencio et al. 2002).

On-going research is focused on developing and promoting technical, management and policy options to support wastewater use in peri-urban agriculture that adequately address concerns such as the possible health hazards to workers and the consumer, the effect of repeated application of wastewater to the soil, and the possible accumulation of contaminants in the soil and groundwater. They include crop restriction, low cost treatment at the point of use (such as short-term retention of water in pools before applying to the crop), additional pre-treatment, alternative irrigation methods (furrow, drip and trickle irrigation are supposed to reduce risks to farm workers) and controlled use of effluent.

Further details and discussion on the subject of reuse of waste for irrigation can be found in Drechsel and Kunze (2001) and Hussain et al. (2002).

Institutions, policies and support services

Sound institutions and policies, together with the development of the requisite organisational 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:

a. demarcation of the roles, rights and responsibilities of the various actors in the water sector
b. promotion of new forms of partnerships for investment, operation and maintenance of facilities
c. participation of stakeholders at all levels and scales and
d. emergence of financially self-reliant service delivery organisations that are responsive and accountable to water users.

But there are huge challenges ahead. 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. 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.

When agricultural water stakeholders are provided with reliable and responsive support services, they are more likely to invest in improved technologies and practices, usually resulting in improved performance, increased production, and higher incomes. The support services on offer should therefore be commensurate with the (often scarce) skills and resources available in rural environments. Reliable service delivery requires the establishment of:

a. clear rules and agreements between providers and users giving details of the nature of the service, including the compensation arrangements for providing and receiving such services
b. mechanisms for monitoring and control of obligations
c. modalities for resolution of conflicts and disputes and
d. procedures for modifying and updating agreements.

These factors take on added significance in light of the progressive disengagement of public agencies from many aspects of agricultural water management accompanied by the transfer of responsibilities to the beneficiaries.

Concluding remarks

Feeding the world's population means contending with growing demands for food and nutrition, more pressure on arable land, increasing competition for water resources, and dealing with major concerns about deteriorating ecosystems. The challenge therefore is to manage land, water and other natural resources to achieve food and environmental security, alleviate poverty and raise living standards in an equitable and sustainable manner.

Water rather than land is generally the limiting resource in SSA—whereas some countries just do not have sufficient water resources, others do not have the means to develop the additional supplies to meet their needs. In this paper, emphasis has been placed on improving the productivity of agricultural water use, as part of an integrated and holistic approach to water resources management.

The use of models and indicators at field, system and basin levels to understand water use, water availability, water productivity and water allocation has been discussed. Identifying and promoting affordable but effective technologies to capture, collect and distribute water that are commensurate with local conditions, organisational skills and expertise, have significant scope for improving household food security and the livelihoods of the poor. The importance of effective policy and institutional mechanisms that reflect the aspirations of all stakeholders to derive the full benefits of technological innovations and approaches has also been underlined.

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Improving the water productivity of livestock: An opportunity for poverty reduction

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Abstract

In Ethiopia, intensification of agricultural production is the primary focus of the government's poverty reduction strategy. Livestock constitute an invaluable resource providing essential goods and services to small-scale poor farmers and their families and communities. Production of high valued livestock products provides a route out of poverty especially where growing urban demand fuels the markets. Water security is a requisite input for livestock production and its resultant contribution to poverty reduction. Typically, one tropical livestock unit (TLU = 250 kg live weight) requires less than 50 litres/day derived from drinking water and moisture in animal feeds. Assuming annual rainfall of 500 to 1000 mm and a stocking rate of one TLU/ha, the drinking water required by livestock is less than 0.2% of the intercepted precipitation. While sufficient high quality water is essential to sustaining livestock production, direct water intake is only of minor significance in terms of livestock water budgets in farming systems and watersheds where the water required for feed production can be up to 5000 litres/TLU per day or 100 times the amount directly consumed.

Water productivity of livestock may be high or low depending on the context within which livestock production is evaluated. Livestock produced solely with irrigated forage and grain crops may be very inefficient in terms of water consumed for food produced. However, 'cut-and-carry' and grazing production relying on consumption of crop residues and tree fodder can be very efficient since the water used for plant production would have been used with or without livestock feeding on it. The stover or feed is simply a by-product of growing crops and does not require additional water for its production. Livestock also provide rural farmers with additional value in terms of consumable and marketable outputs without incurring significant demand for water. Understanding and managing water productivity of livestock presents opportunities to contribute to poverty reduction.

Water productivity varies according to the geographic scale being considered and depends largely on the degree to which water is depleted or available to other users or ecosystem services. Livestock have a profound impact on downstream water resources. In urban and peri-urban areas, livestock production may be an ideal agricultural practice in terms of water productivity if downstream contamination can be avoided. Increasing demand for livestock products implies increased future demand for water that can be expected to rival the water requirements for production of all other food products consumed by the urban population. In many cases, livestock management practices jeopardise water quality, human health and aggravate water mediated land degradation. Research is needed to develop practical strategies to enable poor people in rural, peri-urban and urban areas to better manage livestock so that they can realise poverty reducing benefits and minimise harmful effects on themselves and others. An utmost need exists for community based natural resources management, a critical issue of interest to water and livestock managers. Given the paucity of literature on livestock–water interactions, key areas for future research are highlighted.

Introduction

Poverty is the pronounced deprivation in human well-being encompassing not only material deprivation but also poor health, literacy and nutrition, vulnerability to shocks and changes, and having little or no control over key decisions (ILRI 2002).

About 1.3 billion people or one-fifth of the world's population live on less than US$ 1 per day. Women constitute 70% of the poorest of the poor. They provide more than half the labour force required to produce food in the developing world. In Africa, close to 70% of the staple foods are produced by women. Women typically spend a higher proportion of their income on food and health care for children (Ashby 1999).

Ethiopia ranks near the bottom of the global poverty scale. About 45% of the people live on less than US$ 1/day, and life expectancy is about 47 years and falling. Diseases of poverty such as malaria, tuberculosis (TB), Human immunodeficiency virus/Acquired immuno-deficiency syndrome (HIV/AIDS), parasites, blindness, respiratory infections and diarrhoea are widespread (WHO 2002). Safe drinking water and sanitation are woefully inadequate particularly in rural areas. Chronic food insecurity evidenced by high prevalence of stunting and wasting in children trap future generations into continued poverty. Efforts by the poor to sustain themselves contribute directly to land and water degradation. For example, collection of wood and manure for fuel renders land vulnerable to erosion resulting in flooding, soil loss and sedimentation of water bodies.

Poverty reduction is the driving goal of Ethiopian development strategies. The International Livestock Research Institute (ILRI) and its partners are committed to reducing poverty and making sustainable development possible for poor livestock keepers, their families and the communities in which they live. In Ethiopia, the Ethiopian Agricultural Research Organization (EARO) is ILRI's traditional and primary partner in promoting effective use of animal agriculture for poverty reduction. Through new partnerships, this workshop affords the opportunity to integrate animal agriculture into the wider poverty reduction strategy including the integration of diverse livelihood strategies within watershed and river basin systems. Indeed, the moral imperative of today is to sustainably reduce poverty with particular emphasis on improving the lives of women and children.

The purpose of this paper is to highlight a few key principles related to the role of livestock keeping as an important pathway out of poverty taking into account both beneficial and harmful livestock management practices associated with integrated watershed and river basin management. Global issues and principles are discussed with reference to the Ethiopian context for development, integrated natural resource management (INRM) and the improvement of water productivity through effective water management.

Livestock and poverty reduction

The potential of livestock to reduce poverty is enormous. Livestock contribute to the livelihoods of more than two-thirds of the world's rural poor and to a significant minority of the peri-urban poor. The poorest of the poor often do not have livestock, but if they can acquire animals, their livestock can help start them along a pathway out of poverty. Livestock also play many other important roles in people's lives. They contribute to food and nutritional security; they generate income and are an important, mobile means of storing wealth; they provide transport and on-farm power; their manure helps maintain soil fertility; and they fulfil a wide range of socio-cultural roles (ILRI 2002).

A predicted increase in demand for animal food products in developing countries offers the poor, including the landless, a rare opportunity to benefit from a rapidly growing market (Delgado et al. 1999). In brief, the global process of urbanisation creates expanding market opportunities for food products. Increasing disposable income enables people to increase the proportion of their diet comprised of meat, eggs and milk products including milk, butter and cheese. Consequently, urbanisation leads to a consumer driven increase in the demand for animal products relative to the demand for plant based components. Satisfying this demand provides a great opportunity for poor farming families to rise out of poverty. Mismanaging the production of animal products places unnecessary demands on water resources and can result in enhanced degradation of water and land resources.

Water requirements of livestock

Water contributes up to 80% of an animal's body weight. Deprivation of water more than any other nutrient quickly leads to reduced feed intake, production, reproduction, poor health, and death. Water intake depends upon the size of animal, feed and salt ingested, lactation, and ambient temperature and an animal's genetic adaptation to its environment. For example, indicative water intake by dairy cows could be estimated by the following equation (after Pallas 1986):

$$y = 16.0 + 0.71i + 0.41m + 0.05s + 1.2t$$

where, y is the daily water intake (litres per day assuming l litre, and weights = 1 kg), where i is the daily dry matter feed intake (kg/day), m is the daily milk production (kg/day), s is the sodium intake (g/day) and t is the mean weekly mean minimum temperature (°C).

Indicative water intake levels of livestock range from about 5 litre/TLU in cool wet weather to about 50 litre/TLU in hot dry conditions (Table 1). Although much effort has been devoted to the important task of providing drinking water for animals, the actual water required to produce daily feed for livestock is about 100 times the actual daily requirements for drinking water. Livestock typically require daily feed intake of dry matter amounting to about 3% of their weight, but about 1 m^3 or 500 litres of water is required to produce 1 kg dry matter. One TLU of small livestock such as sheep and goats would require up to 5000 litres of water a day to produce the feed required, and larger animals such as camels will require at least half of this amount.

Table 1. *Indicative water requirements for drinking and feed production necessary to sustain animal production.*

Species	Mean live weight (kg)[1]	Tropical livestock units (TLU/head)	Daily dry matter intake		Water needed to produce daily dry matter intake[2]		Voluntary daily water intake by season and average temperature (litre/TLU)[3]		
			Kg	Kg/TLU	Litre	Litre/TLU	Wet (27°C)	Dry (15–21°C)	Dry hot (27°C)
Camels	410	1.6	9	5.6	4500	2813	9.4	21.9	31.3
Cattle	180	0.7	5	7.1	2500	3571	14.3	27.1	38.6
Sheep	25	0.1	1	10.0	500	5000	20.0	40.0	50.0
Goats	25	0.1	1	10.0	500	5000	20.0	40.0	50.0
Donkeys	105	0.4	3	7.5	1500	3750	5.0	27.4	40.0

1. One TLU = 250 kg.
2. Assuming 2 kg/m^3 (Kijne et al. 2002).
3. Pallas (1986).

Water productivity—General principles

Popular literature often criticises the use of livestock in agricultural production because of their apparently high water requirements (e.g. Goodland and Pimental 2000; Postel 2001). Water requirements of various agricultural commodities varies (Table 2) with beef production reportedly requiring 200 times more water than potatoes. Many details are missing from such summaries. For example, the food items listed have highly variable water contents. The figures do not take into account market values of the commodities. The requirements do not clearly explain how the water was used in the production process and how much could have been re-used for other purposes. The example in Table 2 for example could have come from a North American feed lot where the feed is irrigated maize and where large quantities of water are used during the slaughter, processing, and packaging of animal products. It probably does not represent livestock keeping and production in the sub-Saharan African context. Despite these, the reported differences cannot be ignored.

Understanding their implication and managing them for integrated natural resource management requires analysis of innovative new research on water productivity of livestock.

Table 2. *Estimates of water required to produce diverse food products.*

Food product	Litres of water required to produce 1 kg of food item
Potatoes	500
Wheat	900
Alfalfa	900
Sorghum	1110
Maize	1400
Rice	1910
Soybeans	2000
Chicken	3500
Beef	100,000

Source: Goodland and Pimental (2000).

Water productivity of livestock is a measure of the ratio of outputs such as meat, milk, eggs, or traction to water depleted (i.e. used as an input and subsequently not available for other uses). When multiple outputs such as milk (litres), meat (kg), and traction (ox-days) are involved, productivity must be expressed using a common measure such as US dollars or Ethiopian Birr per unit of water depleted. Degraded water can be viewed as water depleted for high value purposes. Water productivity can be estimated by the following equation:

$$\textit{Water productivity of livestock} = \sum \left[\frac{\textit{livestock outputs and services}}{\textit{Depleted water}} \right]$$

Water productivity measures are scale dependent (Table 3), and water considered depleted at one scale may not be considered as such at a different scale if it has been or can be used for additional purposes. At the level of the individual animal, water lost through evaporation and respiration are no longer available to the animal or to any other users. This is depleted water. Losses such as those in urine and milk have no further value to the individual, but may be of use to other users. Degraded water is partially depleted water that can have lower value uses. A clear research challenge is to develop livestock management practices that increase water productivity and reduce depletion and degradation. Applicability of interventions will be scale-specific as suggested in Table 3. For example, urine provides nutrients to the forage crops on which animals feed and contributes to soil moisture. This is depleted water from the perspective of the individual animal but not to larger systems (e.g. a pasture).

Estimating water productivity of livestock can be tricky. For example, Goodland and Pimental (2000) suggested that 100 thousand litres of water are needed to produce 1 kg of beef. In contrast, let us assume that one head of cattle consumes 25 litre/day over a two-year period to produce 125 kg (the approximate dress weight of one TLU). This implies that it will drink up to 18,250 litres over a two-year period. Let us also assume that all of the feed comes from crop residues for which no additional water input was required. Then productivity of beef production would be about (18,250 litres)/(125 kg) or 146 litres/kg, an amount far more efficient than the figure given for potatoes (Table 2). In addition, much of the water consumed by livestock is released into the soil as urine providing soil nutrients and soil moisture. From this example, it is clear that livestock production could be viewed as either one of the most efficient or inefficient means of producing food for people depending on the system in which the livestock are raised. The difference between the two water productivity scenarios of 100 thousand and 148 litres/kg of beef, that we must assume that we know very little about the true water productivity of livestock keeping. Understanding water productivity of livestock is lacking, especially at a watershed or river basin level, and must be given priority in future research and development.

Table 3. *Examples of depleted and degraded water with mitigation approaches for different scales of livestock production.*

Scale or type of livestock system	Forms of depleted and degraded water linked to livestock management at lowest scale of importance	Examples of livestock related methods to reduce depletion and degradation linked to system scale where applied
Biosphere	None	Implies that water is never lost and is always recycled so that interventions operate at regional or local scales
River basin	River discharge Contaminated ground and open water	Replenish ground water Manage upper catchment Manage manure, and animal by-products International financing mechanisms
Watershed that includes many farming systems	Runoff Contaminated ground water Downstream flow beyond watershed boundary	Reduce contamination by urine and manure Increase ground cover and infiltration Create incentives for downstream users to assist upstream water and soil conservation Improve common property and community based natural resources management (NRM)
Household including livestock and crop production	Transpiration, evaporation and runoff Export of agricultural products containing water Infiltration below roots	Increase ground cover and infiltration Increase soil water holding capacity Construct contour erosion barriers
Livestock grazing and feeding of crop residues (pasture or crop land)	Transpiration, evaporation and runoff Infiltration below root layers Removal of agricultural products containing water	Maintain ground cover and increase soil water holding capacity Plant deep-rooted fodder species (e.g. tree fodder) Use drought tolerant plants (e.g. C4 forages) Increase water holding capacity of soil (e.g. adding manure)
Individual animals	Respiratory loss Lactation, urination and defecation Evaporation (thermoregulation)	Use of drought and heat tolerant animals Provide shade Provide non-saline drinking water

Because animal products have high value compared with most staple plant based foods, livestock production will likely be increasingly valued as an effective strategy to alleviate poverty in situations where market opportunities exist. Following on the argument that water productivity of animal products derived from consumption of crop residues is competitive with crop production, it follows that in terms of water productivity, livestock can make an important contribution to poverty alleviation.

The case of urban and peri-urban livestock production

Globally, urban demand for livestock products is growing rapidly because of the combined effects of migration and increased income (Delgado et al. 1999; ILRI 2002). Assume that animal products will make up 10% of the future urban diet, and that feed conversion efficiency of animal feed is about 10%, and that water requirements for production of animal and plant food are about the same. Then the water required to meet the future urban demand of animal products would be about the same as that required to produce all other food for the urban population. Urbanisation often leads to the re-allocation of water from agriculture to urban demands for domestic water and industry (Molden 2002). This suggests that future competition for water between livestock and other water users will intensify. However, urban and peri-urban livestock production systems can give high value products for relatively little use of urban water if water requirements for feed production are not drawn from the urban and peri-urban areas where water demand is high. By importing feed from outside of the source area for urban water supplies, urban livestock producers can avoid having to compete with urban demand for this essential input. This is a form of 'virtual water' (Meissner 2002) that provides a mechanism to improve water productivity within urban and peri-urban agriculture. It also reduces the land area required for production.

Non-consumptive interactions of livestock and water resources

As Steinfield et al. (1997) observed, livestock do not degrade the environment—humans do. The decisions and actions of people who manage livestock rather than the livestock themselves are primarily responsible for the mix of positive and negative impacts that they have on environmental and human health. In Ethiopia, many farmers would fail to harvest crops without access to oxen to plow and drain waterlogged vertisols (e.g. Astatke and Saleem 1997). The water required by the oxen must be factored into the productivity of these crops. When poorly managed, livestock keeping can contribute to degradation and depletion of water resources. Yet, studies in Ethiopia demonstrate that conversion of cropland to grassland reduces annual soil loss from 42 to 5 t/ha presumably with an accompanying decrease in runoff because well-maintained grass cover is perhaps the best natural method of erosion and runoff control. Establishing watering points for livestock creates foci for high human and animal populations and unleashes unsustainable pressure on natural vegetation (Steinfield et al. 1997). In some savannah systems, scarcities of vegetation are caused by drought and not grazing pressure (Ellis and Swift 1988; Cavendish

1995) where livestock numbers are determined by rainfall levels, and attempting to revive grassland through manipulating livestock numbers is thus misguided. Livestock management has a major impact on river basin hydrology and on the sustainability of livelihoods of the inhabitants. Integrated watershed management will need to integrate effective livestock management to attain sustainable poverty reduction. Finding optimal livestock keeping practices and feeding systems for different species and conditions is a primary need for future research and for development of watersheds and river basins.

Human health is a fundamental aspect of poverty (ILRI 2002) and significant health issues are linked to both livestock and water management. For example, clean water is essential to ensure hygiene in processing dairy and meat products. Without quality water, food safety is jeopardised and market opportunities are lost.

Malaria, the number one cause of mortality in Ethiopia (WHO 2002), exists where water provides suitable habitat for larval *Anopheles* mosquitoes. Some vector species prefer blood meals taken from livestock raising the prospect that livestock treated with insecticides such as deltamethrine could attract mosquitoes and control malaria (Habtewold et al. 2001; Rowland 2001). However, watering practices for livestock may generate breeding sites for the vector and contribute to increased prevalence of malaria. Land use changes such as converting papyrus swamps to pasture and crop appear to increase temperatures and enable survival of anopheline populations in African highlands (Lindblade et al. 2000).

Waterborne human illnesses often arise from contamination of domestic water by poorly managed livestock. For example, Cryptosporidium, a parasite whose oocysts are common in livestock, has been associated with various outbreaks of human illness in recent years and is thought to aggravate the impact of HIV/AIDS (FAO 1977).

To ensure that productivity gains to reduce poverty are not offset by an associated poor human health, there is a need to integrate human health into R&D related to water and livestock management.

Conclusion: Emerging research priorities

Livestock are valued assets for the rural poor and marketing of livestock products is a practical and effective pathway out of poverty. Opportunities exist to increase the water productivity of livestock at scales ranging from households to river basins. However, surprisingly little integrated research has been done on this subject, and little of the existing knowledge has been translated into policy and technology to improve the livelihoods of the poor. Livestock interact both positively and negatively with the management of water and other natural resources. A number of critical human health issues are linked to water and livestock management. Research is needed to better understand the role of livestock in integrated water management, and strong evidence exists to suggest that this must be addressed in the implementation of Ethiopia's poverty reduction strategy.

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Water resources for livestock in Ethiopia: Implications for research and development

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Abstract

Ethiopia is home to about 35 million tropical livestock unit (TLU), and on average, one TLU requires about 25 litres of water per day. Based on this calculation, the total daily water requirement for livestock is estimated at 875 million litres. This amounts to about 320 billion litres per year. Ethiopia has about 173 thousand km^2 of water bodies that include lakes, rivers, reservoirs, small water bodies, swamps and flood plains. The total lake area in Ethiopia is estimated at 750 thousand hectares. There are nine major rivers, totalling 6400 km with an annual discharge of 63 billion cubic metres, of which the Blue Nile accounts for 80%. Contrary to this however, 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.

Research and development work on water as a limiting nutrient to animal production and management practices to increase efficiency is rare in Ethiopia. This paper assesses water resources in Ethiopia, examines water requirements for different species of animals and attempts to identify some research and development issues related to development of the livestock sector in Ethiopia. The climatic and environmental conditions in the country are variable. Temporal and spatial distributions of rainfall with consequent large fluctuations in the quantity and quality of feed and variations in ambient temperatures and water availability result in variations in body composition and have a profound influence on the productivity of animals in their environment. It is therefore necessary to undertake studies on water metabolism and requirements for livestock under the relevant environmental conditions and physiological states. Water quality both with respect to drinking water for animals and animal management practices that affect the water resources are other areas of concern that deserve attention. Research has to focus on environmental pollution specifically in waste management in densely populated areas of livestock such as in the highlands and urban and peri-urban areas. Moreover, research should provide information on improving the environment and management techniques to increase water use efficiency and raise animal productivity.

Introduction

Ethiopia is one of the African countries endowed with huge water resources, which include rivers, lakes, reservoirs, small water bodies, swamps and flood plains. These resources are important for fisheries and aquatic resources development, livestock resources, irrigation, power generation etc. The rains in the highlands of Ethiopia, which supply these waters, have significant influence in the livelihoods of downstream countries such as The Sudan and Egypt. As a result, the highlands of Ethiopia are considered as the water towers of Africa. Contrary to this however, water is a very scarce commodity for many of the smallholder farmers.

Livestock are major components of the livelihoods of both pastoralists in the arid and semi-arid lowlands of the country, and the crop–livestock farmers in the highlands. Access to water during the major part of the year is variable and both human and livestock suffer from its shortage. In many parts of the country, animals are trekked to distant watering points once in two or three days. Watering animals is a major occupation for pastoralists and shortage of water often leads to social conflict. In most instances, the quality of available water is poor and is a major source of parasitic infestation to animals. Where both human and animals consume water from the same source—as it happens in most cases—this poses a major risk for public health. Water requirement for animals in urban and peri-urban centres has never been considered in urban planning; and as a result, animals are often forced to consume wastewater with high health risks. This will have significant implications on product quality and public health.

Water resource is pertinent and vital for the existence and development of the livestock sector. It should be recognised that the multiple use of land and water resources lead to various conflicts that arise from the shared use of these limited resources. It is noted that, of a whole variety of purposes of water resources development, which include *inter alia*, rain water harvest, irrigation, hydropower generation and water storage often relegate the fisheries and its ecosystem. It should be stressed that planners and policy makers should be continuously made aware of the importance of livestock in the overall rural development schemes. This paper highlights water requirements for livestock and specifically focuses on opportunities and constraints related to water resources research and development.

Water resources for livestock use

There are three sources of water for the animal: (1) drinking water (2) water contained in feeds and (3) metabolic water. Water contained in feeds consumed (preformed water) is highly variable from feed to feed according to the moisture content, which can range from as low as 5% in dry feeds to as high as 90% or more in succulent feeds (Sirohi et al. 1997). Water derived from dry feeds may be insignificant compared with the total water intake, while that obtained from succulent feeds can supply all the water needs. Sheep would drink little or no water when the water content of the feed is over 70% (Degen 1977; Sirohi et al. 1997). When water content of the feed ingested is low, drinking water is the major source of water intake, and its provision for livestock becomes the main concern. Most of the water that is utilised by the animal's body is ingested either as drinking water or as a component of the feed (Woodford et al. 1984).

The oxidation of organic nutrients during metabolic processes in the body leads to the formation of water (metabolic water) from the hydrogen present. On the average fats, carbohydrates and proteins respectively yield 1.07, 0.56 and 0.40 ml water per gram oxidised, or an equivalent of 0.12, 0.14 and 0.10 ml water per kcal metabolisable energy derived from oxidation (Maynard et al. 1981). For most domestic animals, metabolic water comprises only 5 to 10% of the water intake. Metabolic water may account for up to 15% of the total water intake in sheep (Aganga et al. 1989; Abdelatif and Ahmed 1992; Sirohi et al. 1997) and remains constant provided metabolic rate is constant (Maynard et al. 1981). In certain cases, and in animals consuming less food than required, the production of metabolic water becomes more important, since depot fat and tissue protein are catabolised to supply energy.

Water losses from the animal

Faecal water constituted the least avenue of water loss (18%), but in normally hydrated sheep feacal water accounts for up to one-fourth of the total water loss (Degen and Young 1981; More et al. 1983; Aganga et al. 1989; Abdelatif and Ahmed 1992; Sirohi et al. 1997). Urine water loss is the second avenue of water loss and studies show that it accounts for up to one-third of the total water loss in sheep (Degen and Young 1981; More et al. 1983; Aganga et al. 1989; Abdelatif and Ahmed 1992; Sirohi et al. 1997). It was also observed that there is an increase in urinary water loss with supplementation, which could be related to the higher dry matter intake (DMI) and nitrogen and ash intakes. The increased demand in water turnover/requirement with supplementation was a reflection of the rise in water loss through evaporation and urine, as observed from the decrease in the relative contribution of faecal water loss, but an increase in relative contribution of urine and evaporative water losses with supplementation.

Evaporative water loss represents the remainder of the water loss not collected in faeces and urine, and includes water presumably lost through respiration, perspiration and evaporation from the respiratory tract and the skin. Insensible perspiration and non-panting respiratory water losses are obligatory, whereas losses by panting and sweating come into picture in response to relatively higher thermal stimuli for thermoregulation. Evaporation becomes the major avenue of water loss from the body, particularly under tropical conditions, where evaporative cooling may account for up to three-fourth of the total water loss in sheep (More et al. 1983; Aganga et al. 1989; Abdelatif and Ahmed 1992; Sirohi et al. 1997). Study has shown that even at relatively moderate environmental conditions, evaporative water loss still constituted the major avenue of water loss (55%), and increases with supplementation. The increase in metabolic water loss with supplementation could be due to high metabolic rate caused by high feed and/or water intakes/turnover accompanying supplementation. It has been indicated that water requirement, respiratory rate and evaporative water output are directly proportional to feed intake because of increment in metabolic activities (Aganga et al. 1989). It, therefore, seems that the amount of water used at low levels of feed intake during supplementation is less than at high levels of intake when metabolic rates and cooling requirements become greater. Generally, evaporative water loss followed by urine water loss is considered as important sources of body water loss during supplementary feeding of ruminants.

Functions of water

Accounting for about 99% of all molecules and 73% of the fat free empty body mass (King 1983), water is by far the largest single chemical component of the animal body. From a functional point of view, no other chemical compound has so many distinct and vital roles as water; by far the greatest number of life processes in the body takes place with water as a key substance. Accordingly, water stands second only to oxygen of all environmental constituents immediately necessary for life. While an animal may survive a loss of practically all of its body fat and over half of its protein, a loss of one-tenth of its body water is fatal (Maynard et al. 1981). Since relatively small changes in body water cause profound changes in function, the body water content must remain reasonably constant.

Many of the biological functions of water are dependent upon the property of water acting as solvent for numerous compounds. Water takes part in digestion (hydrolysis of proteins, fat and carbohydrates), in absorption of digested nutrients, in transport of metabolites in the body and in excretion of waste products. Many catabolic and anabolic processes taking place inside the tissues involve the addition or release of water. Water also plays an important role in the animal's thermoregulatory mechanisms. The body temperature is dependent partly on the high conductive property of water to distribute heat evenly within the body and temperature is prevented by high specific heat of water.

Water requirements of livestock

Water requirement by livestock appears to be a very individual and specific characteristic. Such differences are reflected in their respective abilities to withstand dehydration and in their demand for free water. As the demand of the individual animal for water is variable, only average estimates of water requirements in a specific climatic environment are generally indicated (Tables 1 and 2).

Table 1. *Some general guides to water intake of different class of animals.*

Class of livestock	Daily water requirement (gallons/day)
Beef cows	7–12
Dairy cows	10–16
Horses	8–12
Swine	3–5
Sheep and goats	1–4
Chickens	8–10/100 birds
Turkeys	10–15/100 birds

Note: Extremely hot heat-stress weather could increase the high values another 20 to 30%.

Table 2. *Estimated water requirement and voluntary intake of livestock under Sahelian conditions.*[1]

Species	TLU[2]	Mean live weight	DM intake	Wet season air temperature (27°C)		Dry cold season air temperature (15–21°C)		Dry hot season air temperature (27°C)	
				Total water requirement	Voluntary water intake	Total water requirement	Voluntary water intake	Total water requirement	Voluntary water intake
				Litres/day					
Camels	1.6	410	9	50	15	37	35	50	50
Cattle	0.7	180	5	27	10	20	19	27	27
Sheep	0.1	25	1	5	2	4	4	5	5
Goats	0.1	25	1	5	2	4	4	5	5
Donkeys	0.4	105	3	16	5	12	11	16	16

1. Volutary water intake has been calculated from the water requirements by assuming a water supply from the plants corresponding to:
   70 to 75% of moisture content of the plants during the wet season
   20% of moisture content of the plants during the dry and cold season
   10% of moisture content of the plants during the dry and hot season.
2. TLU = Tropical livestock unit is equivalent to an animal of 250 kg live weight on maintenance.

Source: Pallas (1986).

Ethiopia has an estimated livestock population of about 35 million TLU. Assuming an average consumption of 25 litres of water/day per TLU, the estimated daily water consumption is about 875 million litres. This adds up to about 320 billion litres per annum. This requirement is expected to increase due to the increase in livestock population and envisaged improvement in productivity (milk, meat, eggs). Improvements in the dairy sector, for example, will require additional water for milk production and sanitary management.

The water requirement of domestic animals varies between species, between breeds or varieties within species and between individuals within breeds. For example, heavy western breed cows have a higher water intake (60 to 90 litres/day) than zebu cows (25 litres/day with 350 kg live weight (King 1983). The water demands of sheep, goats and camels are not as high as those of cattle. Water requirement increases with growth, and with increases in productive processes such as lactation and egg laying. Lactating cows consume more water to cope with the water excreted with milk than cows of similar weight fed on maintenance level.

Water requirements also largely vary according to other factors such as food intake, quality of the food and air and water temperature. Water consumption increases with increasing dry matter intake and increasing temperature. *Bos taurus* cattle weighing 450 kg and eating 10 kg dry feed per day drank 28, 41 and 66 litres of water per day when the temperature is 4, 21 and 32°C, respectively (Maynard et al. 1981). Not only high ambient temperature, but cold weather also influences water intake. Cold weather may reduce water intake. This reduces water flow through the bladder and kidneys and reduced water flow allows kidney stones to precipitate. When desirable weather returns, water intake increases. The effect of ambient temperature on water intake varies between types of livestock; breeds within the same type and acclimatised animals require less water than un-acclimatised when managed at high ambient temperature. The direct effect of climate on the water intake of livestock is, however, very complex and the relationship between increased water intake of livestock with increasing ambient temperature is not simple (Winchester 1964).

The type of feed plays a decisive role on water intake. Inclusion of legumes into tropical diets was found to cause an increased water requirement (Zewdu 1991). This is because water consumption increases with the level of roughage intake and its nitrogen content and with the intake of other feeds that have laxative properties. Sheep reportedly require more water on high- than on a low-protein diet, since the nitrogenous end products require a larger urine volume for excretion (Wilson 1970; Bass 1982; Banda and Ayaode 1986; Nuwanyakpa et al. 1986; Abdelatif and Ahmed 1992; Sirohi et al. 1997). Similarly, higher proportions of salt or other minerals in the diet of sheep can result in more urine excretion and, accordingly, more water requirement (Wilson 1970; Abdelatif and Ahmed 1992; Sirohi et al. 1997). Studies with poultry have shown an increase in water consumption due to increases in the fat, protein, salt or potassium contents in the diet.

It is generally agreed that water requirements are correlated with feed intake; as feed intake decreases or increases, there is a concomitant change in faecal, urinary and evaporative water losses and, accordingly, in water requirement (Wilson 1970; Degen and Young 1981; Abdelatif and Ahmed 1992; Sirohi et al. 1997). Because of the close, direct relationship between dry matter and water intake, it has been customary to express water requirements as a ratio of dry matter intake. Such observation was a reflection of the composition of the ingested dry matter, ash and in particular nitrogen. Given the strong relationship between feed and water intakes, any feed improvement/supplementation strategy should also consider the availability of water, or supplementation would rather exacerbate dehydration and physiological stress at times of water scarcity. However, the potential benefits of water economy should be realised in relation to productive parameters, because there would be a trade-off between water saving strategies and production.

Existing published knowledge on factors of water requirement and turnover in the tropics often relates to small ruminants and lacks information on the relationship among water, dry matter intake, milk yield and other metabolic effects in large ruminants. Ayantunde et al. (2001) derived the following equation in estimating water intake (WI) for tropical cattle fed with fibrous diets in dry regions of West Africa:

$$WI = \left[\frac{492(\pm 32) \times DMI + 397(\pm 28) \times LW^{0.75}}{1000(r = 0.98)} \right]$$

In Ethiopia, there are only few studies carried out on water turnover for instance in the highlands, involving Boran cattle at Abernossa Ranch (Nicholson 1987) and Blackhead Ogaden sheep at Jijiga (Zewdu 1991). Feed resources available in the highlands are mostly crop residues that are bulky and of poor digestibility (Said et al. 1993). A study on water turnover in Boran and Boran × Friesian cows at the ILRI Debre Zeit Research Station (Janet et al. unpublished data) showed that the total water intake in early and late lactation was 49.2 and 54.0 kg/cow per day, respectively. The major part of the difference comes from a difference in drinking water intake although the higher feed intake of the late lactating cows was accompanied by a significantly higher extra water intake (+0.1 kg/cow per day). The mean amount of metabolically generated water accounted for 3.1 kg/cow per day. Water turnover, including water intake and metabolically generated water was also lower in early (52.3 kg) than in late lactation (57.1 kg; Standard Error Mean (SEM, 1.53)). The percentages of total water excreted through faeces, urine and milk were 38.0, 17.0 and 13.8%, and 45.0, 19.3 and 8.2% in early and late lactating cows, respectively.

Low milk yield in late lactation resulted in high water excretion via faeces (and urine). The ratio of water excreted to water intake showed no change between stages of lactation. The overall relation of water turnover to DM intake was 5.67 (±0.187). The quantity of water consumed was with the range of 3.5 to 5.5 kg of water per kg of dry diet given for ambient temperatures between –17°C and 27°C. The overall water turnover rate of cows was 408.3 g/live weight per day, which was also in agreement with values calculated for purebred zebu and western breed cattle (Roubicek 1969). Although occasionally extremely deviating water intake and turnover rates are observed in tropical cows, variation between animals remained astonishingly low, illustrating that estimates should be valid for a great part of the population under the conditions of the study.

Water stress

Limitations on water intake depress animal performance quicker and more drastically than any other nutrient deficiency. Water deprivation affects feed intake (Steiger et al. 2001), metabolism and productivity. Domestic animals can live about sixty days without food but only seven days without water. The provision of adequate quantities of clean drinking water is a major prerequisite for satisfactory milk production, growth and animal health (Little and Shaw 1978), but the minimum amount required is affected by various factors and therefore seldom known exactly. There is no consensus on the frequency of drinking to livestock. Usually, it is suggested under hot climate, cattle should be watered every day and sheep and goats may be watered every second day. In the eastern lowlands of Ethiopia at Jijiga, Zewdu (1991) found that Blackhead Ogaden sheep, watered once every three days, could save 34% more water without any adverse effect on performance when compared with daily *ad libitum* watering regime. Nuwanykapa et al. (1986) also concluded that watering highland sheep once every three days instead of *ad libitum* is an economical and labour-saving 'drought response' watering frequency. Pallas (1986) quoting the study made in Niger indicated that water intake every second day may be profitable for cattle when the distance from the grazing areas located 10 km away from the water supply. However, in pastoral areas the distance between grazing and water is so big and animals often have to walk long distances. Camel has an outstanding capacity to withstand infrequent watering interval. Camel can withstand the loss of up to 27% of its body weight and is able to drink exceptional quantities of water at a time. There are some indications that goats will survive better when food is in short supply provided sufficient water is available and sheep suffer comparatively severe hyperthermia relative to goats.

In moisture stressed areas, the major problems are seasonality of the pasture, the possibility of low nutrient intake and water deprivation during the dry season. In dry season, the nutrient content of available feed may decrease and this may lead to further decrease in voluntary DM intake and physiological problem in maintaining body temperature. The cumulative effects are the nutrient intake of the animals would be inadequate and thus has a pronounced effect on production and productivity of the animals in this environment. In extreme cases, signs of dehydration can occur which can be seen as tightening of the skin (skin folds), loss of weight and drying of mucous membranes and the eyes.

Importance of water quality for livestock production

There is a significant amount of knowledge regarding chemicals found in water supplies and their effect on livestock. The total salt content of water is regarded as one of the major important characteristics that may reduce suitability and palatability of water. The expression Total Dissolved Solids (TDS) is often used to denote the level of water salinity. Commonly present salts include: carbonate, bicarbonates, sulphates, nitrates, chlorides, phosphates and fluorides. High levels of specific ions in water can cause animal health problems and death. Substances that are toxic without much effect on palatability include nitrates, fluorine and salts of various heavy metals. Excess fluoride causes degeneration of the teeth. One gram of sulphate per litre may result in scours. Salts such as sodium chloride change the electrolyte balance and intracellular pressure in the body, producing a form of dehydration. Salts also place a strain on the kidneys. The National Academy of Sciences offers upper limits for toxic substances in water (Table 3) and levels of total solids and effect on livestock and poultry are given in Table 4.

Table 3. *Recommendations for levels of toxic substances in drinking water for livestock.*

Constituent	Upper limit	Constituent	Upper limit
Aluminium (Al)	5.0 mg/L	Lead (Pb)	0.1 mg/L[1]
Arsenic (As)	0.2 mg/L	Manganese (Mn)	No data
Beryllium (Be)	No data	Mercury (Hg)	0.01 mg/L
Boron (B)	5.0 mg/L	Molybdenum (Mo)	No data
Cadmium (Cd)	0.05 mg/L	Nitrate + nitrite (NO_3–N + NO_2–N)	100 mg/L
Chromium (Cr)	1.0 mg/L	Nitrite (NO_2-N)	10 mg/L
Cobalt (Co)	1.0 mg/L	Selenium (Se)	0.05 mg/L
Copper (Cu)	0.5 mg/L	Vanadium (V)	0.10 mg/L
Fluorine (F)	2.0 mg/L	Zinc (Zn)	24 mg/L
Iron (Fe)	No data	Total dissolved solids (TDS)	10,000 mg/L[2]

1. Lead is accumulative and problems may begin at threshold value = 0.05 mg/L.
Sources: NAS (1972), Ayers and Wescot (1976).

Highly mineralised waters (high solids) do not have much effect on health as long as there is no objectionable continuing laxative effects and as long as normal amounts of water are consumed. High salt concentrations that are less than toxic may actually cause an increase in water consumption. Animals may refuse to drink high saline water for many days, followed by a period where they drink a large amount. They may then become sick or die. The tolerance of animals to salts in water depends on factors such as water requirements, species, age, and physiological condition, season of the year and salt content of the total diet and the water. Animals, however, have the ability to adapt to saline water quite well, but abrupt changes from water with low salt concentration to high concentration may cause harm.

Table 4. *The use of saline waters for livestock and poultry.*

Total dissolved solids in water (mg/l)	Comments
<1000	These waters have a relatively low level of salinity and should present no serious burden to any class of livestock or poultry
1000 to 3000	These waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhoea in livestock not accustomed to them or watery droppings in poultry (especially at the higher levels), but should not affect their health or performance
3000 to 5000	These waters should be satisfactory for livestock, although they might very possibly cause temporary diarrhoea or be refused at first by animals not accustomed to them. They are poor waters for poultry, often causing watery faeces and (at the higher levels of salinity) increased mortality and decreased growth, especially in turkeys
5000 to 7000	Avoid the use of these waters for pregnant or lactating animals even if non-lactating dairy and beef cattle, sheep, swine and horses may tolerate these salinity levels. These waters are not acceptable for poultry, almost always causing some type of problem, especially near the upper limit, where reduced growth and production or increased mortality will probably occur
7000 to 10,000	These waters are unfit for poultry and probably for swine. Considerable risk may exist in using them for pregnant or lactating cows, horses, sheep, the young of these species, or for any animals subjected to heavy heat stress or water loss. In general, their use should be avoided although older ruminants, horses, and even poultry may subsist on them for long periods of time under conditions of low stress
> 10,000	The risks with these highly saline waters are so great that they cannot be recommended for use under any conditions

Source: Peterson (1999).

The microbial quality in drinking water can also be important. There are many micro-organisms in water supply; most of them are quite harmless. There are, however, certain organisms where caution should be used. Green scum that builds up in livestock drinking troughs and tanks is algae. Some blue-green algae are toxic. Most blooms of blue-green algae contain either brain toxins (neurotoxins) or liver toxins (hepatotoxins). Just over 1 litre of water can be fatal to a 100 kg calf, depending on the toxin present in the blue-green algae bloom. No good method exists to predict whether the algae will produce the toxins. The only practical way is to monitor livestock behaviour when algae bloom heavily. Occasionally putting baking soda in water troughs will help prevent algae growth. Copper sulphate or other commercial copper containing products will also kill the algae for a period of several months. In troughs or small tanks, a safe dosage is one level teaspoon of copper sulphate per 1500 gallons of water. Generally, treatment is done only when algae growth is heavy or if a toxicity problem occurs. Livestock should be allowed to drink the treated water source at least after 24 hours. One of the most effective ways to avoid problems with blue-green algal toxins is to water cattle out of troughs rather than direct watering.

Knowledge of the effects of disease-causing micro-organisms on livestock is limited. However, to achieve benefits in terms of herd health and performance, one must avoid contamination of watering supplies for livestock and possibly treating water supplies to ensure that the water is clean or contains only low concentrations of disease-causing micro-organisms.

Impact of livestock production practices on water quality and forage availability

Water quality parameters related to livestock management include nutrients (nitrogen and phosphorus), micro-organisms (e.g. bacteria, faecal coliforms, *Cryptosporidium*, *Giardia* and organic materials such as livestock waste. Water quality concerns include impacts on receiving streams and aquatic life, and reuse of the water downstream for agricultural, recreational and drinking water (Cooke 1997).

Watering practices that can impact water quality include destruction of riparian ecosystems through over-grazing and direct cattle access to waterways. Belsky et al. (1999) in their review have shown the impacts of grazing on water quality and quantity. Water contamination from grazing includes increased sediment and bacterial counts in runoff. High runoff is due to the compaction of the soil from cattle's hooves and grazing practices.

Direct access to water sources for cattle allows for direct deposition of wastes and increased erosion. Waste management and disposal can also impact water quality. Localised concentration of animal waste is considered a point source of pollution for surface or ground water. Mismanagement or improper storage of animal waste can contaminate water sources. Ground water contamination can result from infiltrated livestock wastewater. A study in North Carolina investigated nutrient runoff from animal waste as the source of surface water contamination that resulted in large blue-green algal blooms, fish kills and declining commercial and sport fisheries. Flushed manure into ponds caused high ammonia concentration and high biochemical oxygen that resulted in a fish kill. Higher stream temperatures reduce the survival of some aquatic organisms. Livestock use can also increase in stream temperatures (Cooke 1997).

In Ethiopia, the potential causes of environmental degradation and pollution and their effect on extent aquatic resources is not documented. The potential source of major pollutants affecting Ethiopian lakes and rivers are factories, agriculture and sewage. Recent survey work on 16 industries with respect to their practices of discharging of effluents indicates that only two of them are not discharging effluents of various contents to water bodies (Table 5).

Table 5. *Industries using and discharging effluents of unknown content to water bodies.*

Factories visited	No. of factories	%
Discharge treated effluents to surface waters	6	37.5
Discharge untreated effluents to surface waters	8	50.0
Discharge not released to water bodies	2	12.5
Total	16	100

Source: EARO (2001/02).

Water is a major determinant of livestock distribution in rangelands. Animals graze from a water point to a distance they can afford depending on the availability of forage and their dependency on water. Many authors have reported changes in rangeland conditions around water points. The impact of over-grazing and trampling shows a pattern of decreasing effects with distance from the water. It is reported that heavy grazing pressure and trampling in the vicinity of the water point killed sensitive perennial grass species resulting in a zone dominated by annual plants. Problems of the impact on rangeland condition near water points are likely to cause soil erosion because of the reduced protection of soil surface during the dry seasons and enhanced bush encroachment. If livestock are allowed to overuse watering points, an impact on the vegetation is expected, or cannot be avoided.

Increasing water access to livestock

Improvement of water resources has a significant impact on the livelihood of farmers and improving the productivity of the animals. Water availability for livestock is critical in the lowlands. Most of the year, animals have to walk long distances in search of water, and are usually watered once in two to three days. The effect of water stress can be simply stated in the energy loss in long distance walking in search of water and low nutrient intake. Water stress is also pronounced in highland areas of the country especially in areas that receive low rainfall (both in amount and distribution).

Animals that are economical in water consumption and efficient for meat and meat production are highly desirable in drought prone areas. Increase in total body water content in animals under hot climatic condition is considered an adaptive reaction to ameliorate heat stress. Heat-tolerant animals are those that manifest the least changes in most of the physiological functions including body water content when subjected to a hot climate. Thus selections of animal that have such characteristics are desirable for breeding in hot desert areas. Pastoralists in Ethiopia select breeding camels based on their ability to withstand drought (shortage of feed and water) and resist diseases (EARO 2001/02).

There are a number of ways of increasing water availability, including construction of wells, pumps, canals, boreholes, tanks, cisterns, reservoirs, water yards, dams and water-harvesting systems. Selection of the method in increasing the water availability should be based on the production system and socio-economic situation of the farmers. The rehabilitation and up keep of water sources are usually a challenge in most of the areas. The process for developing water points for farm communities need to incorporate equitable arrangements for sharing the water and facilities, and account for the legal framework of use as the potential for conflict is high. The role of institutions such as community-controlled co-operatives or herders' associations and mode of operations for efficient utilisation of water resources need attention.

It should be stressed that water economy has significant implications for ruminant animal production where and when water supply is limited in total amount and/or frequency of distribution. The limited availability water, especially during the dry seasons, compels herders to economise water use in livestock production. One possibility would be to control factors that aggravate water requirement of animals, so as to save water and serve more animals on a daily basis. During adverse conditions, such as drought, when water is required for survival than production, such water saving option will help more animals survive and transit dry/drought periods to normal and rainy seasons.

Research areas

The following research issues warrant future action:

- water in the physiological ecology of ruminants: There is a need to develop water requirement for the different class of animals under their own environment. This will assist in designing management practices based on demand of the livestock farming and available resources. Water resource utilisation programme should take into account the current and future demands of livestock and fish production and productivity
- appropriate water source selection, management and protection of these sources are all critical issues to ensure that a safe water supply is used for livestock. It is necessary to define the standards of quality required for each particular use to determine the degree of pollution control necessary and to forecast the probable effect of augmented or new discharges of effluents. Establishment of water quality criteria for freshwater fish need to be undertaken
- aquatic resource laws should be developed to incorporate a system of user rights and to control access to productive waters. Legal arrangement should address all the different uses of aquatic ecosystems including fisheries, aquaculture, waste disposal and recreation. They should address the ownership of the resources and the surrogates (for example, sites, stocks, waste emissions levels) that can be used in each production system to support quantitative use right. They should define the mechanisms (economic, administrative, collective) and the structure required for allocating use rights to optimise use and ensure conservation of resources
- improve water sources such as utilisation of water harvesting techniques, developing water holes etc. and management practices to improve the utilisation
- define number and spatial distribution of water points in the rangeland; expanding and improving the network of water points
- selection and breeding animals for drought tolerance and
- community empowerment for effective range and water resources.

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Managing water for livestock and fisheries development

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Introduction

Ethiopia has an agrarian dominated economy, with 85% of the total employment, 98% of the total calorie supply, 70% of industrial raw material supplies, over 45% of GDP and 90% of the foreign currency earning. Despite its important roles, however, it fails to meet the minimum food requirements of the population.

Ethiopia hosts the largest livestock population in Africa and can produce over 51,500 t of fish per annum. However, their exploitation and consequently their contributions to food security and growth in the country is minimal despite the technologies capable of resolving the problems of livestock and fisheries production.

Livestock production in the past had been almost stagnant and thus failed to keep pace with the rapid population growth and in effect leaves the demand for meat and milk considerably unsatisfied. Current per caput meat and milk productions are 8 and 17 kg per year, which were 14 and 25 kg in the early 1970s. Even under the present low level of resource use, livestock account for about 30% of the agricultural gross domestic product (GDP), and 16% of the national foreign currency earning (second to coffee). Its contribution to the entire traction power to over nine million hectares of cropped land, to rural transport, soil fertility and household energy are substantial though these benefits are not valued properly.

Fisheries production is also under-exploited whilst current demand exceeds supply by about four-fold. One of the big and immediate challenges of our country is addressing the problems of food security and poverty. Currently, about 45% of the total population are living under poverty and the level of impoverishment is worse in rural areas, where 85% of the total inhabitants dwell.

It must be noted that under-development of the country's water resources towards increasing and sustaining agricultural production, which has a two-track interaction in the whole economy, contributes to the low level of socio-economic development in the country. This paper is therefore devoted to make critical assessment of the current water resources use status, prospects, constraints and improvement measures in relation to livestock and fisheries development in the country.

General role of water in socio-economic development

Cox (1987) viewed socio-economic development as general advancement of a given society to a higher level of welfare or well-being. The role of water resources to achieve this level of development is fundamental because of the wide-range and two-track interaction between water and socio-economic activities. First and foremost, water is a basic component of welfare for people, animals and fish. From a development perspective, water supply is a socio-economic infrastructure essential to the various productive processes, such as irrigation, fisheries, industries, tourism, hydropower, navigation and waste disposal. In turn, these development activities involve modifications of the quality and flow characteristics of water. One must understand from this that the total absence or shortage of water supply is a great menace for growth and development. Water resource must therefore be viewed as a dynamic element along all the development process.

Apart from its beneficial aspects, water has adverse effect on socio-economic development when it causes flood, soil erosion, crop failure, suffering and death of people and animals. So, there must be a water management policy and administration mechanism capable of maximising the beneficial uses and minimising the non-beneficial aspects of water (World Bank 1984).

Influence of water on the livestock production system

Based on the physical and socio-economic environments, two broad production systems are distinguished: mixed and pastoral. Livestock is integrated with crop in the highlands of the country. Expansion of croplands at the cost of pastureland (reduced by 1% every year) and recurrent drought result in increasing deterioration of grazing lands. The highland areas have generally good access to alternative sources of water and receive adequate rainfall though some localities are still in short of water, and affects livestock productivity.

The situation is much different and complex in the lowland areas of the country, which broadly comprise all lands that lie below 1500 metres above sea level (masl), with some exception that goes up to 2000 masl. The pastoral farming systems are generally located in drier and fragile lowland areas, where rainfall is relatively low, poorly distributed and highly erratic thus impeding cultivation and sustainable livestock development. Despite the harsh environment and holding a lower abundance of animals than the highlands the contribution of the pastoral farming system to the national livestock economy is significant; beyond serving as basic source of livelihood for the people, it supplies 90% of the legal export of live animals and 20% of the draft animals to highlands (MOA 1996).

Shortage of water and feed, particularly during the dry season, constantly force nomadic pastorals to migrate together with their livestock long distances to maintain their sources of subsistence. The situation put the people increasingly impoverished and vulnerable to droughts and famine.

Out of the total rangeland available (781 thousand km^2), 88% lies on the lowland. But this extensive pastureland remains under-utilised due to shortage of drinking water. Where permanent or temporary water sources are available for the dry season the pastureland near and around the supply sources are subjected to over-grazing and environmental degradation. Just contrary to this, in areas where water supplies are short, an extensive area of pastureland is left under-utilised. There is also a health factor that affects the efficient use of the available water and rangeland as many parts of the lowland areas are infested by a wide range of animal diseases, including tsetse and Rift Valley fever, which reduce the traction power of animals and restrict exports, respectively. The main problem for over- or under-exploitation of the ecology is lack of harmony among the different actors.

Drinking water for livestock also plays key role during transport and marketing of live animals from points of surplus to markets. In effect, individual animal lose 25 to 30% of its liveweight during the journey.

Drinking water requirement increases at a higher temperature and low humidity. Depending on season, cattle must be watered at least every second day at a rate of 10 to 40 litres/head, and camel must consume 100 to 150 litres/head at a time every 5–6 or even 8 days. Against the requirements, however, animals in the lowland drink every four days, and perhaps insufficiently. So, the impact of under-watering is very clear—poor animal health and under-productivity. When seen from the large livestock population of the country the demand for drinking water is substantial and its provision is expensive.

The practice of using water bodies for fisheries

One of the primary tangible benefits which water can offer is the living asset—fish stocks. Fishing activities contribute directly to human welfare, for example, by providing source food (animal protein), which is urgently needed particularly by the poor rural population.

Almost 120 thousand km^2 of the total land constitutes water and water courses, which may be exploited for fisheries directly or through enhancement. However, knowledge on their stock sizes and the means to exploit them are still to be known for each fishery waters. Despite this limitation, as indicated before, empirical estimates put the country's total fish potential to 51,500 t per year, with a current exploitation of 30%. This leaves considerable potential for expansion.

Under-exploitation of existing fisheries potential contained in the natural water bodies of the country is a great concern. Even if the available stocks of these fishery waters will be fully exploited in the near future, both current and future demand for fish by the population cannot be met. For instance, current total demand for fish is about 67 thousand tonnes, which is envisaged to grow nearly to 95 thousand tonnes in 2015, and 118 thousand tonnes in 2025. To fill this gap, therefore, new alternative fish supply sources must be found.

In the country, small to large size man-made water bodies have been and will continue to be built for drinking water supply, hydropower generation, irrigation and fisheries. In practice, however, almost all those multi-purpose water development programmes and projects overlook fisheries as a component whilst it would be possible to bring additional fish supply for local consumption and is capable of improving the overall efficiency of the programme at large.

Integration of fisheries with other components may only require minor engineering modifications to meet biological requirements of the important fish stocks, in return to provide a wide range of socio-economic benefits, which include food, income and employment.

Almost entirely, all pertinent institutions which are active in water resource or watershed area development and management unintentionally neglect the roles and conservation requirements of the fisheries because they are either little aware of the significance or lack the necessary knowledge in the field of aquatic living resources, in general, and in fisheries, in particular.

Despite the technical limitations, efforts have been made in the past to stock or enhance known creator lakes, reservoirs and other small water bodies in different parts of the country, and are shown success, for instance at Lugo, Koka, Fincha and Ashengie. Yet there are several water bodies of similar kind, which need stocking or enhancement with good performing fish species, but data on the geographic distribution, physico-chemical characteristics and socio-economic features of these water bodies are lacking. The Ministry of Agriculture, due to lack of capacity, has not undertaken a baseline survey, nor do the developers of these water bodies communicate the information to the Ministry.

If current practices are allowed to continue, the country's water bodies, which exist now and those to be developed in the future will remain under-exploited for fisheries. Integration of water development schemes with fishery requires developing capacity for stocking, enhancement and monitoring. Parallel to this, emphasis must be given to further increase the awareness and fish consumption levels of the public at large. Unless this is done, fish production, which will come from new water bodies, will lack adequate and effective demand, and thus the envisaged benefits will not be fully realised.

In addition to extensive fish culture system on reservoirs and ponds, there are greater possibilities to introduce and expand rural and commercial aquaculture within controlled environment. Technically, the diverse ecological zones, availability of by-products as feed, and the genetic resource (the three top cultured fish species in the tropics are found in Ethiopia) provide the opportunity for aquaculture development in Ethiopia. The present and future socio-economic conditions in the country equally support fish development. However, aquaculture practice is almost new to the country and hence this remains to be addressed to allow fish culture in the country to take off. Aquaculture requires sufficient water supply of the required quality.

Recreational fishing is an additional opportunity that water resources can provide and to be integrated with tourism. This however requires introduction of fish species into natural or artificial water bodies, which are deemed to be suitable for sporting purposes.

Water related and water management constraints

Water management—dealing with scarcity or abundance of water with some objectives in view—faces problems ranging from inadequacy to supply water for drinking and agricultural use to inadequate control over water related problems which cause suffering and death of people and animals, and ecological degradation from abuse of watershed areas.

Severe water supply shortage in the lowlands and some pockets of the highland areas call for water management activities, of course, along side other complementary activities. However, the activities and capabilities of water management system are generally constrained by technical inadequacy, fund limitation and institutional weakness.

In livestock and fisheries production the following constraints are identified:

1. Drinking water and pasturelands are not available harmoniously, which results in under-utilisation of the extensively available pastureland, on the one hand, and over-grazing and environmental degradation, on the other.
2. The unpredictable, infrequent and low rainfall patterns on most of the semi-arid areas limit agro-pastoral farming systems. Even certain pockets of land along the river basins, which have the potential for mixed farming, remain unused, and prevent the possibility for sedentarisation. The situation leaves most of the lowland population relatively dispossessed of socio-economic infrastructures or disadvantaged from public investment programmes.
3. The capital outlay required to improve the condition of water supply and rangelands management is substantial. In addition, available water-harvesting technologies and knowledge are limited.
4. Past and present polices and programmes in livestock system lack effective co-ordination and integration inter- and intra-institutions. So, returns from investment on rangeland and water supply management were not only low but also not sustained.
5. Socio-cultural factors in water resources development or even improvement of the livestock system are not sufficiently considered due to lack of understanding.
6. A large number of, small- to large-size, man-made water bodies of good potential for fisheries have been built but knowledge about them is scanty. Besides, they seldom consider the needs and requirements of fisheries in their design and construction. Low awareness and lack of technical capacity in the field are identified as major drawback.
7. Lake and river fisheries as part of the watershed system are not sufficiently considered by watershed area developers and managers, and therefore the aquatic system, in general, and the fisheries, in particular, absorbs various unintended adverse effects from other water or watershed area users. These are related dam construction, diversion, irrigation, deforestation and release of toxic effluents. As said before, the root cause of the problems are weak institutions with absence of the required technical capacities in the field of living aquatic resources.

Recommended pathways for integrated water resource management

The objective of managing multi-purpose water resources is beyond reduction of hunger and poverty through its effects on increasing agricultural production, including livestock and fisheries. Its role as socio-economic infrastructure helps achieve establishment of agricultural settlements, industrialisation and economic growth. The return from multi-purpose water development programmes is commutative and much higher than from single purpose scheme. This can best be achieved through effective co-ordination and integration between the various activities using common resources—water and the watershed area. This approach can only provide the possibility to achieve resource use efficiency and environmental sustainability.

Under this general framework, the following specific recommendations are drawn to make better use of water resources to the needs and requirements of livestock and fishery development.

1. Research. Sufficient and accurate data is seldom available to base sound planning and informed decision on natural resources and their uses. We know for sure that we lose our natural resources but the degree of the loss, the root causes and mitigating measures are rather less clear. This implies that existing researches and studies poorly meet the needs of resources management, water, agricultural land, rangeland, livestock and fisheries. In addition to limited expertise and fund, research management either lacks focus, continuity, coherence, participation, or the research outputs themselves are not effectively disseminated to ultimate users.

   Therefore, strengthening research management capabilities that recognises the interdependence between water supply and water use activities, and the interaction between these activities should deserve priority. More specifically, assessment of both the ecological, technical, economic and socio-cultural environments within which the country's livestock system can realise its potential needs to be researched. The problems, needs and potentials of water supply to meet current and future requirements by the livestock system should be critically evaluated.

   Baseline survey. Identification and characterisation of the present and future man-made water bodies for further stocking or enhancement is essential. Based on the knowledge from the study, fish seed supply and propagation centres must be created at strategic areas of the country.

2. Policy and planning. Policies and plans that address the underlying cause than the symptom of environmental degradation are effective. So to meet food requirements and preserve the future resources base urgent action is required to the livestock development, and the actions should combine education and motivation, local level institutional building and empowerment, zoning and property right regime.

   In addition, clear objectives, target groups and priorities must be set for livestock and fisheries within the broad multi-purpose water management policies and programmes. Because resource is scarce, the choice and decision between competing water use activities must be based on good technical and economic justifications and stakeholders participation. To achieve this, horizontal linkages between pertinent sectors and departments having interest in water and watershed area must be established or strengthened and implemented with the aim to exchange information and discuss matters of common interest.

3. Beyond the convention. Socio-cultural environment within which the development processes take place determines success. Initially, the development effort will be influenced by culture, which will, at a later stage, affect the culture in return. However, such a two-track interaction remains the missing element in most development activities, including efforts to supply water for agricultural use, animal drinking or for integrated activities. This must be corrected through increasing understanding and capacities on how to integrate this sensitive and powerful factor.
4. Water harvesting. Drinking water from natural pools will dry out in a short period. So, temporary water courses must be exploited by creating and improving water-retaining structures, and must be complemented with artificial pools to allow herds to graze the dry pasture within a walking distance. In areas where the rains are rare but heavy, it is advantageous to harvest the runoff water at a lower point, the surface of which is established by a bed of concrete and then the water will be pulled to water trough by pump or gravity for the herd. Where drinking water from permanent and temporary surface water sources are difficult or insufficient then ground water should be exploited by establishing wells and bore holes.
5. Integration. There must be harmony among water supply, feed, and herd size, and an equitable distribution of the opportunities among the target communities. These avoid encroachments, promote peace and settlement among the pastoralists.
6. Transformation. Pocket lands suitable for irrigation development along the rivers should be developed, and the productivity of dry land farming can be improved using water-harvesting techniques. However, the backbone of the economies of the lowland area will remain extensive livestock system till the available rangeland is exhaustively utilised and calls for a change towards mixed or intensive farming. Developing a system for a gradual transformation of the nomadic pastoralists towards sedentarisation helps build assets for relatively rapid and sustained development for the well-being of the population and rejuvenation and balance of the ecology.
7. Early warning. Establish an early warning mechanism for combating possible events of natural catastrophe.
8. Assistance. The hope to realise the potentials of the country's livestock and fishery productions demands external assistance in addition to government support. The assistance may be extended to meet the need for integrated water supply infrastructure, improved rangeland management, effective veterinary service, research and extension, and credit and marketing services.

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Livestock grazing impact on vegetation, soil and hydrology in a tropical highland watershed

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Abstract

The aim of this research was to establish vegetation, soil and hydrologic responses to grazing pressure; and determine thresholds for optimum herbage utilisation of pastures and grazing land resources conservation. The treatments were no grazing (NOG, control), where animal grazing was excluded using 10 m by 10 m fenced enclosure, moderate grazing (MDG) and heavy grazing (HVG). During free grazing period (January–May) stocking rate on medium and heavily grazed plots depends much on the preference of grazing animals, and in some cases the stocking rate in controlled or medium grazing pressure exceeds that of the heavily grazed plots. The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha. Grazing pressure increased the percentage cover of annual plant species and composition as compared with no grazing pressure. Particularly, in medium-grazing pressure annual plant species coverage has improved significantly. The soil loss at 4–8% slope was high in heavily grazed plots. Besides, the soil loss in grazed plots was below the soil tolerance limit for natural pasture. The infiltration rate was lower in heavily grazed plots.

Introduction

In livestock production systems at smallholder levels, the overriding considerations are to increase the efficiency of using local natural resources that are not directly beneficial to human unless converted to useful products (Daniel 1988). A successful livestock development strategy, therefore, needs to fit into the overall resource management plans and complement the wider economic, ecological and sociological objectives. The combination of moderate temperature, adequate rainfall and freedom from many tropical diseases has encouraged the growth of large human populations and diverse farming systems (Jahnke and Assamenew 1983). Grazing of pasture and rangelands is an integral component of livestock production systems in many countries (Johanston et al. 1996). Livestock grazing stimulates nutrient mobilisation and uptake through consumption of vegetation, in that mobilisation of nutrients to the growing points per root biomass is enhanced by frequent defoliation (Mohamed Saleem 1998). It is clear that the degradation of the highlands relates to the combination of human exploitation exceeding the natural carrying capacity of the land resources systems, and inherent ecological fragility of the systems (Mohamed Saleem and Abyie 1998). Investigations into how grazing can induce different bio-physical process including vegetation and hydrological changes that are related to bio-diversity, nutrient uptake and cycling in the grassland ecosystems are required for developing models to predict levels of primary productivity to meet grazing requirements of livestock and also predict vegetative cover required to protect soil from degradation. The general objectives of this research are, therefore, to establish vegetation, soil, and hydrologic responses to grazing pressure; and determine thresholds for optimum herbage utilisation of pastures and grazing land resources conservation.

Materials and methods

Study description

The study was conducted for four years starting from 1996 at Tero Jemjem watershed in Ginchi, 80 km west of Addis Ababa, Ethiopia (38°13′9″E and 9°1′5″N) in Yubdo Legebatu Peasant Association where farmers graze their livestock within and around Tero Jemjem watershed. The annual rainfall is 1150 mm and the rainy season starts in June, peaks in August and tails off in September (Figure 1). The mean annual temperature is about 17°C with insignificant seasonal variation; however, the period from October to March is slightly warmer and June to September is cooler. The elevation of the Tero Jemjem watershed ranges from 2190 to 2770 metres above sea level (masl), and the study area is approximately 350 ha.

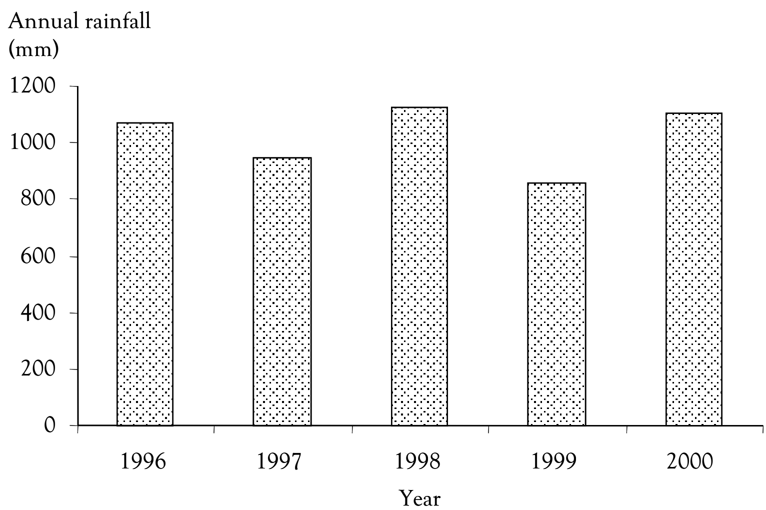

Figure 1. *Mean annual rainfall of the study area.*

The area has clay soils of the Vertic Cambisol Association (55–78%) on <10% slopes (Kamara and Haque 1988). Due to high smecite clay content, these soils have marked swelling and shrinking properties. Clay soils of the Chromic Cambisols Association (55–72% clay) occur on the upper slopes (>10% slope).

The vegetation was largely dominated by *Andropogon abyssinicus*, *Bothrichloa inscuplta*, *Eleusine floccifolia*, and *Eragrostis tenuifolia* grass species and by *Acacia abyssinica*. The balance of the vegetation is composed of a very diverse assemblage of grass and forbs species most of which are readily accepted by grazing livestock.

The treatments were no grazing (NOG, control), where animal grazing was excluded using a 10 × 10 m fenced enclosure, moderate grazing (MDG) and heavy grazing (HVG). The grazing pressure at MDG was regulated by opening flexible fencing around the plots for three days a week to allow free access for farmers' animals. There was no fencing around plots subjected to HVG. The NOG plots were fenced and kept closed to livestock grazing throughout the experiment. The number and type of animals and duration of grazing in the MDG and HVG treatments were recorded daily to determine the stocking rate and grazing intensity. Similar cultural practices as used by surrounding farmers were imposed; manure was collected from grazed plots by the herders and used as source of fuel.

Stocking density was expressed as animal units per hectare (AU/ha) and calculated as proposed by Scarnecchia (1985). An animal unit (AU) is defined as a 450 kg steer at 30 months of age (Edwards 1981; Le Hou'erou 1989). Animals kept were local zebu cattle, donkeys and horses, sheep and goats that belonged to the farmers in the watershed.

Vegetation assessment

Metal quadrants (0.5 × 0.5 m) were used for vegetation sampling. Two samples were taken on monthly basis by clipping the herbage in the quadrants to the ground level from each plot within and outside of the movable cages to measure regrowth, residual and biomass consumed by the animals. After clipping the herbage the cages were moved at random each month to a new spot along transect, but outside a 3 × 6 m area demarcated to study the soil erosion (Figure 2). The clipped samples were oven-dried at 70°C for 24 hours, weighed and biomass was converted to t/ha. Within each plot every year in September, October and December a total of 100 points (10 × 10 m), using a 1 m long metal frame species richness and botanical composition were determined. Every year botanical composition and species richness were measured in August, October and December.

Hydrological studies

In mid-October the effect of livestock trampling on water infiltration was measured in three replicates on each plot using a double-ring infiltrometer (Bower 1986).

Surface runoff measurement

To measure runoff and soil loss, each plot had an installation consisting of a metal gutter at the lower end of the plot, a sedimentation box, and a drum connected to a collection drum.

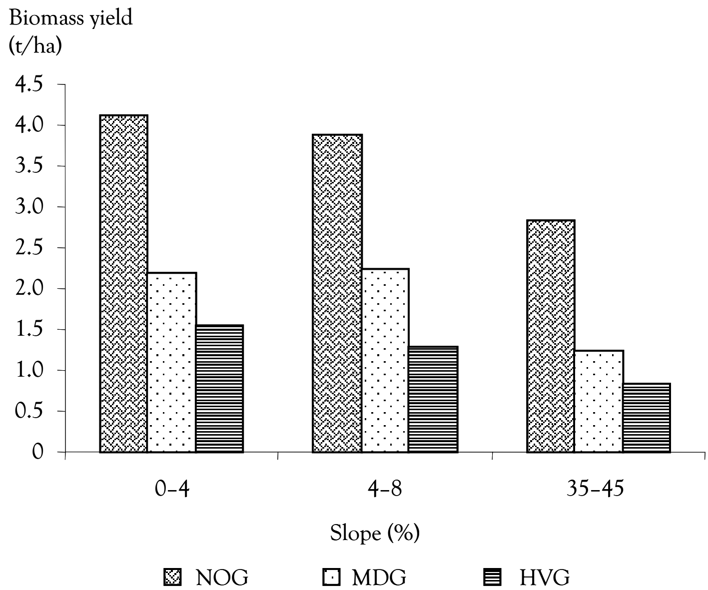

Figure 2. *Effect of grazing on mean biomass yield (t/ha) at different slopes (1996–2000).*

The metal gutters intercepted runoff and directed it to the collection tank. The sedimentation box also acted as a multi-pipe divisor with seven pipes. Only the middle pipe was connected to the runoff-collecting tank through a 12.5-mm diameter plastic hose, thus allowing only (in theory) 1/7 of the runoff to be collected during each rainfall event. The actual amount going into the drum was determined using a calibration curve. The box and tank were shielded from direct rainfall and animal trampling by an iron sheet cover. Each plot was also provided with up-slope runoff by run-on barrier and an interceptor drain at the upper end on the plot.

Sediment and water samples were collected after each rainfall event that produced runoff in the treatment. Samples were collected from the sedimentation box and the overflow drum after stirring the mixture vigorously. Concentration of suspended material was determined using the fixed-volume method (Barnett and Holladay 1965). Runoff was measured in the field as soon as possible after each rainfall event that produced runoff. The total amount of runoff consisted of the amount collected in the sedimentation box, the amount collected in the drum and the amount drained through the six pipes. In theory, the total volume overflowing from the sedimentation box (*OVcal*) is equal to seven times the amount collected in the drum. The actual total amount overflowing from the sedimentation box (*OVactual*) was determined using the calibration curve shown in equation (1).

$$OVactual = OVcal \times F \qquad (1)$$

where, *OVactual* is the actual volume of runoff overflowing from the sedimentation box; *OVcal* is 7 times the amount collected in the drum and *F* is the multiplication factor, which varied from plot to plot.

Soil loss measurement

The total weight of a fixed volume of soil and water is equal to the weight of water with soil plus the weight of soil, minus the weight of water dispersed by the soil:

$$W_{s+w} = W_w + W_s - W_s/S_g \qquad (2)$$

where W_{s+w} is the total weight of water and soils; W_w is the weight of water in fixed volume without soil; W_s is weight of soil; and S_g is specific gravity of soil assumed to be 2.65. After making an allowance for the water displaced by soil, the weight of the soil in the sample was calculated. Then the weight of the soil was converted to sediment yield in tonnes per hectare (Heron 1990; Hudson 1993).

Data analyses

General Linear Model/multivariate and simple linear correlations were used for data analysis (SPSS 1999).

Results and discussion

Grazing pressure

Grazing pressure on natural pasture in the Ethiopian highlands follows four distinct patterns (Table 1). During free grazing period (January–May) stocking rate on medium and heavily grazed plots depends much on the preference of grazing animals, and in some cases the stocking rate in controlled or medium grazing pressure exceeds that of the heavily grazed plots. As a result, the stocking rate in medium grazing pressure was higher even than the heavily grazed plots. Except draft animals, most of the livestock species are moved from bottomland of the communal grazing lands to upper slopes (Jahnke and Assamenew 1983; Daniel 1988). October to December is the period when sown crops get maturity and gradual cessation of natural pasture begins, and the stocking rate on the natural pasture rises again. After crop harvest predominantly free grazing on agricultural field is resumed, and burden on natural pasture is reduced. During this time cattle are needed for threshing the harvested crops, and donkeys are needed for transporting harvested crops from agricultural field to nearby settlement areas, and the available crop stalks can be kept for winter as supplementary feed (Mwendera et al. 1997; Mohamed Saleem 1998; Mohamed Saleem and Abyie 1998).

Influence of grazing pressure on biomass production

As grazing pressure increases biomass production decreases. The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha

(Figure 2). Biomass yield decreased as the slope increases. Biomass production over time varies and therefore causes seasonal variation in forage availability (Holechek et al. 1998). Likewise, grazing pressure varies across time because of differences in forage production among spatially separated plant communities (Zerihun 1986). Under heavy grazing pressure, plants may not compensate sufficiently for the biomass removed by grazing animals (Wood and Blackburn 1984; Zerihun 1986). Hence, net primary production (NPP), which is the difference between non-grazed and grazed biomass production, is a useful tool to establish the defoliation level of plant vegetation (Dawson 1974; Mills and Lee 1990).

Table 1. *Grazing pressure as expressed per animal unit (AU/t).*

	0–4% slope		4–8% slope	
Year	MDG	HVG	MDG	HVG
1996	20.69	41.28	118.01	336.73
1997	22.99	60.38	124.08	351.8
1998	60.75	160.31	108.66	455.6
1999	88.29	161.83	97.82	389.95
2000	95.1	170.31	115.75	367.5

Plant species and species richness

Botanical composition of plant species and productivity of the pasture are highly influenced by animal species, intensity of grazing and edaphic factors. Under very high stocking rate plant species such as *Pennisetum sphacelantum-Commelina africana* type may develop to *Andropogon abyssinicus-Hyparrhenia arrhenobasis* type when grazing is relaxed (Zerihun 1986). Grazing pressure increased the percentage cover of annual plant species and composition as compared with no grazing pressure (Table 2). Particularly, in medium-grazing pressure annual plant species coverage over the grazed area has improved significantly. At 4–8% slope, the vegetative cover of annual species in no grazing plots was almost nil. Predominantly perennial plant species were observed in no grazing treatment at both slopes compared with the grazed plots. Grazing has demonstrated positive effect on species composition and diversity (Janzen 1982a, b). The species richness was high in medium grazed plots compared with the rest of the treatments (Figure 3). The species richness in the lightly to moderately grazed plots remained relatively high as this was encouraged by selective grazing in the growth of the vegetation species.

Runoff, soil loss, bare-ground and infiltration rate

The overall mean annual soil loss in non-grazed and heavily grazed plots varied from 0.65–1.1 t/ha per year, and from 3.1–5.52 t/ha per year, respectively. The soil loss at 4–8% slope was high in heavily grazed plots (Figure 4). Besides, the soil loss in grazed plots was below the soil tolerance limit for natural pasture (Belay 1992; Mwendera et al. 1997). This was due to low formation of bare-ground patches. Moreover, no bare-ground patches were observed on non-grazed plots (Figure 5). The infiltration rate was lower in heavily grazed plots (Figure 6). The type and amount of vegetative cover alter surface runoff and water intake rate (Figure 7). Livestock grazing effects on infiltration, runoff, erosion, on-site water use, and consequent downstream impact are of great concern particularly in highland agriculture (Mwendera and Mohamed Saleem 1996). When vegetation cover declines, soil bulk density increases, rate of water infiltration decreases and sediment production increases.

Table 2. Effect of grazing pressure on dominant plant species cover* (%) at different slopes (1997–2000).

Area	Life form of dominant species	0–4% slope				4–8% slope			
		1997	1998	1999	2000	1997	1998	1999	2000
NOG	Annual	0	5	8	11	0	0	10	14
	Perennial	70	82	71	80	45	31	73	81
MDG	Annual	45	33	10	11	32	22	14	20
	Perennial	23	27	70	75	31	35	61	69
HVG	Annual	18	2	10	12	18	8	15	17
	Perennial	27	18	65	70	27	25	64	67

* Plant species with 5% cover are included in the data.

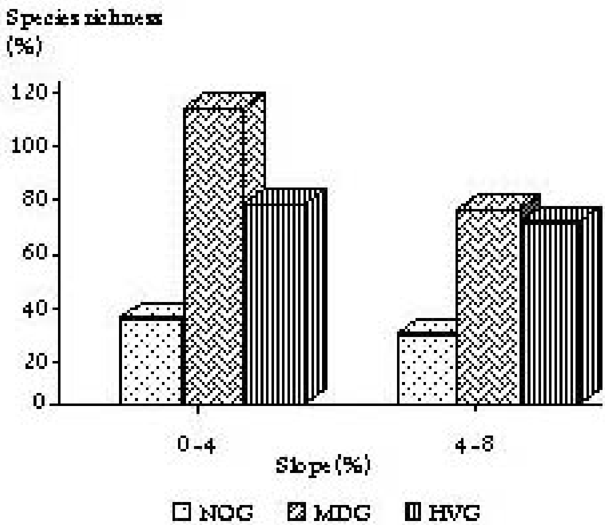

Figure 3. Effect of grazing pressure on mean species richness (%) at different slopes (1996–2000).

The nutrient balance

The nutrient balance under natural pasture in the absence of fertiliser or manure was negative for each nutrient. As the soil nutrient pool has to offset the negative balance, it implies that the grazing system is mining soil nutrients and not sustainable (Girma et al. 2001). The farmers removed the cow dung for fuel. This had negative impact on nutrient recycling and biomass improvement (Table 3).

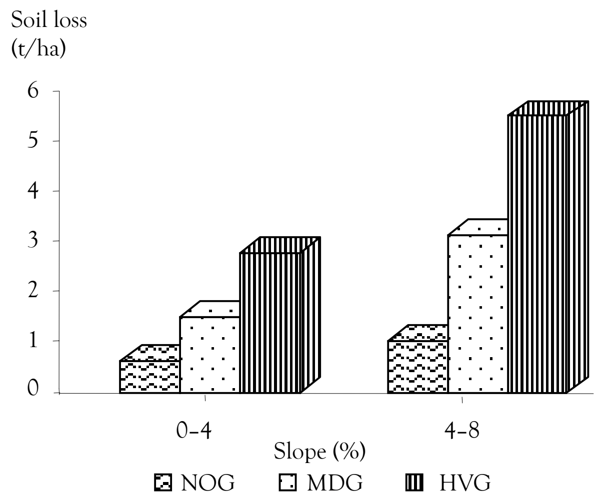

Figure 4. *Effect of grazing pressure on mean soil loss (t/ha) at different slopes (1996–2000).*

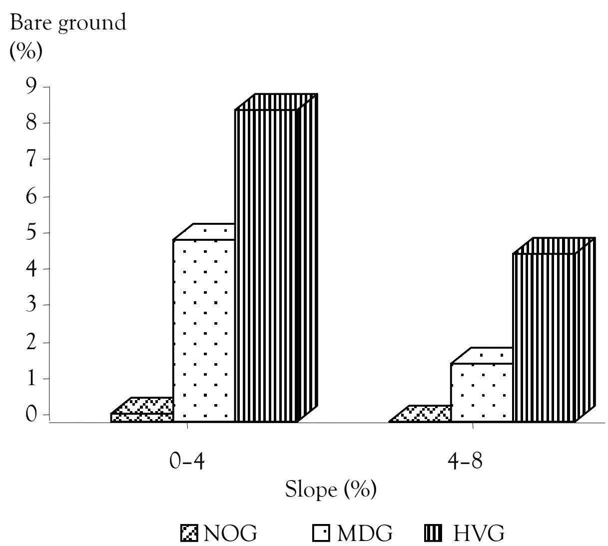

Figure 5. *Effect of grazing pressure on bare ground formation (%) at different slopes (1996–2000).*

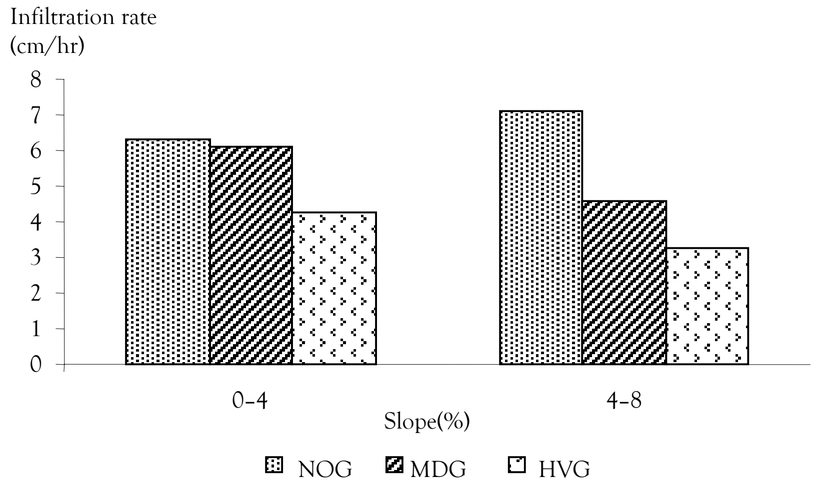

Figure 6. *Effect of grazing pressure on mean inflitration rate (1998–2000).*

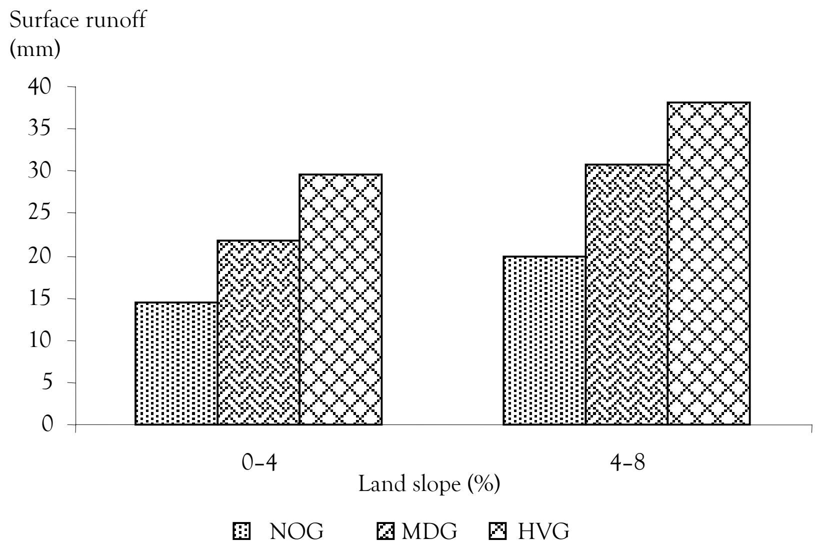

Figure 7. *Effect of grazing pressure on runfall (300 mm rainfall) at different land slopes.*

Table 3. Mean nutrient balance of the natural grazed pasture at smallholder farmer's level (kg/ha per year), 1996–99.

	0–4% slope			4–8% slope		
	In–Out			In–Out		
Treatment	N	P	K	N	P	K
NOG	52.2	8.7	62.66	–104.06	–13.69	–93.71
MDG	–361.07	–43.37	–234.52	–804.57	–116.26	–514.43
HVG	–587.87	–82.01	–383.73	–1043.36	–115.92	–671.71

Source: Adapted from Girma et al. (2001).

Conclusions

The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha. Particularly, in medium-grazing pressure annual plant species coverage has improved significantly. The soil loss at 4–8% slope was high in heavily grazed plots. The infiltration rate was lower in heavily grazed plots.

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Community health, water supply and sanitation

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Abstract

Ethiopia is a developing country with a predominantly rural population. The health status of the people is very low compared with other low-income countries (largely attributable to potentially preventable infectious diseases and nutritional deficiencies) and a high rate of population growth. Widespread poverty along with general low income level of the vast majority of the population, low education levels, inadequate access to clean water and sanitation facilities and poor access to health services have also contributed to the burden of ill-health.The level of water supply and sanitation development coverage in rural and urban areas of the country continues to be low. According to official estimates, only 32% of the people have access to safe water supply. The sanitary situation is considered even worse, with only 17% having access to adequate latrines. The figure for waste disposal is still worse.

Community health

Any social service rendered in a given country is a direct reflection of the socio-economic system of that country. The health service that the Ethiopian people received has proved this truth.Ethiopia is a country sadly affected by frequent outbreaks of disease, drought, famines and conflicts and continues to suffer from its age-old challenges of infectious diseases, malnutrition and illiteracy.The health status of the people is very low accompanied with the high rate of population growth. An estimated 60 to 80% of the health problems are due to infectious and communicable diseases and nutritional problems. The health system is under-developed and able to provide health care to only about half of the population. Much of the rural population has no access to health care, leading to inability of the health care delivery system to effectively respond to the needs of the people.

The country remains one of the poorest nations in the world. As a result, life expectancy at birth is the lowest (54 years), and infant and under-five mortality rates are among the highest in the world (97/1000 live births and 140/1000 live births, respectively). The total fertility rate stands at 5.9 children per woman while the crude birth rate is 40%.

Acute respiratory infection, malaria, nutritional deficiency, diarrhoea and Human immuno-deficiency virus/Acquired immuno-deficiency syndrome (HIV/AIDS) account for the large share of the disease. HIV/AIDS has emerged as a major problem of public health posing a serious threat to the nation.

The health service coverage compounded by poor quality of services is very low (51.24%). Antenatal care coverage is estimated at 20.7%, while institutional delivery is about 10%. The number of health care facilities and the ratio of health personnel to population is very low. One hospital serves a population of 594,036 while a health centre covers an estimated population of 171,057. Similarly one medical doctor serves 47,976, one nurse serves 8460, and one health assistant serves 8847 people.

The uneven geographical distribution of health personnel and health facilities at all levels has exacerbated these conditions. Most facilities and health personnel are concentrated in urban centres at the expense of the health needs of most of the population that lives in the rural area.

Environmental health profile

Environmental health services have a long history in Ethiopia. But data on environmental health conditions and the magnitude of environmental health problems are scanty.

However, some studies, reports from various health units and experiences of health professionals indicated the seriousness of the problems. They attribute the problems to the occurrence of 60–80% of the communicable diseases that are prevailing in the country thereby resulting in high mortality and morbidity, especially among infants and children. In other words, about 80% of the diseases in Ethiopia are communicable in nature, which can be easily prevented or controlled by applying simple sanitary measures such as provision of safe and adequate food and water supplies, safe and adequate waste disposal system, vector control and the promotion of personal, family, neighbourhood and community hygiene and sanitation.

Other environmental health problems that Ethiopia faces are those emanating from both under-development and adverse consequences of developments. It is moving to situations of advanced pollution problems before control over the traditional pollution sources is achieved. Complex problems evolving from modern development schemes such as population growth, urbanisation, industrialisation, modernisation of commerce and trade, mechanisation of agriculture, uncontrolled uses of agro-chemicals, mining etc. are emerging. Another case in point is the pollution of water bodies by discharges of wastewater from industries, cesspools, septic tanks and solid wastes etc. Thus, the environmental and ecological problems continue to threaten the health, productivity and quality of life requiring an urgent need for devising comprehensive control measures against environmental pollution.

Water supply and sanitation

The water supply and sanitation situation in Ethiopia is very poor, as most of the population does not have access to safe and adequate water supplies and sanitation facilities. As a result, three-fourth of the health problems in Ethiopia are due to communicable diseases attributable to unsafe/inadequate water supply, and unhygienic/unsanitary waste management, particularly excreta. Diarrhoeal diseases caused by improper management of water and sanitation is among the major causes of infant and child morbidity and mortality.

Water and sanitation programmes have a direct bearing on the prevalence of diarrhoeal diseases in the population. Projects, which are properly designed and implemented, have the potential of attenuating diarrhoea morbidity by approximately 25% and reducing diarrhoea-caused deaths by 55%. The combination of safe water supply, sanitation facilities and hygienic practices demonstrated a potential in contributing to a remarkable decrease in the prevalence of a child and maternal morbidity and mortality.

Despite the significant water resources available in the country, the status of water supply in the country is poor particularly in the rural areas. It was estimated that only 28.3% of the total population, 75.7% of urban population and approximately 19.9% of the rural population had reasonable access to adequate water supply. Adequate water supply is defined as 20 litres per capita per day made available within a range of one to two kms from the dwelling. Average per capita water consumption varies between 10 and 20 litres per day in some areas. However, in most rural areas of Ethiopia, depending upon seasonality and location of source and availability of water, daily consumption is as low as 3–4 litres per capita per day. Women and children particularly girls have to fetch water, often walking for 3–8 kms from their dwellings.

Lack of sufficient quantities of clean water critically impairs the ability of most rural populations to engage in appropriate personal, food and environmental hygienic practices which would greatly assist in stemming the tide of infectious diseases. The inaccessibility of protected and improved water supplies to about 80% of the rural population and about 24% of the urban dwellers clearly indicates that the health and well-being of the population, in general, and that of women and children, in particular, is at risk from a multitude of water-borne or water-related diseases. Although it is difficult to quantify morbidity and mortality related to unsafe and inadequate water supply because of lack of an effective monitoring and surveillance system and country-wide baseline survey, limited information on disease prevalence reported indicates that water-borne or water-related diseases are among the major causes of sickness and death. Women and children particularly girls as the main water carriers are in frequent contact with contaminated water. They are, therefore, the segment of the population most vulnerable to water-related diseases which, according to the World Health Organization (WHO) estimates, are accountable for 80% of all morbidity in the developing world. Among the major water related diseases is diarrhoea, which alone is accountable for 46% of under -five-child mortality. Therefore, the strongly held opinion of public health experts is that the provision of safe water is a prime importance to public health.

Sanitation, both urban and rural, has been accorded little importance in the promotion of environmental health programme in the country. The sanitation conditions of both urban and rural areas are very poor; the situation in the latter is one of the worst in the world. In the rural areas, the sanitation service is virtually non-existent in most parts of the country. Use of open field for defecation/urination is a common practice for almost all the rural population. National sanitation coverage is estimated to be 10.4%. The urban and rural sanitation coverage is estimated to be 46 and 3.9%, respectively. Even in the capital city, Addis Ababa, 30% of the populations have no sanitary facilities of any form, while 70%

have varying types of sanitation facilities. Only a portion of the city has an underground sewerage system with stabilisation pond treatment device serving only the smallest portion of the population in part of the city centre and some planned housing areas. Nonetheless, the current coverage is less than 1%. In the past, efforts had been made through external support from non-governmental organisations (NGOs) to provide pit latrines of various designs, such as traditional dry pit latrines and VIP latrines to the rural communities in particular in the form of demonstration and/or pilot projects. These efforts ended in failure in most parts of the rural areas once assistance has been withdrawn. Other major reasons include unaffordability of most of the community to replicate the technology; the insufficient provision of pre- and ongoing hygiene education to the beneficiary communities to enable them develop a latrine culture.

Many diarrhoeal diseases such as cholera, typhoid and hepatitis caused by poor sanitation conditions are serious threats to life, particularly childhood diarrhoea, which is a leading cause of morbidity and mortality in children under five years. The high prevalence of intestinal parasites among the population, especially worm burden in children is the direct results of faecal contamination of food and water.

Countrywide, solid waste management facilities coverage is estimated at 2%. Refuse disposal sites in urban areas are often insufficient and unorganised. As a result, in the urban centres including the capital city, solid wastes are not properly stored, collected, transported and disposed of, but accumulated in drains, on open lands thus providing breeding areas for disease vectors. In rural areas, solid waste disposal system of any form is almost non-existent. Indiscriminate disposal of waste-water (liquid waste) in both urban and rural settings is a common practice.

In summary, sanitation, both urban and rural, has never received the emphasis it deserves. It has not been seen as a priority area of concern. Policies on community participation, ownership, management etc. taking into account the special needs of women and children, have not been a focus for sanitation projects and this sustainability of interventions such as sanitary facilities has not been achieved.

In general, the sanitation sector has met with many setbacks in the past due to many varied reasons. A few of these reasons are:

- lack of or low awareness of the communities particularly the rural ones about health implication of sanitation practices; insufficient government commitment to the sector; lack of or insufficient government funding to the sanitation programme
- lack of or inadequate or not clearly defined sector policies, legislation, regulation strategies, guidelines, and standards to promote the sector services, programme and projects
- lack of integration and networking among key sectors such as health, water, education and NGOs
- inadequate or lack of support for research and experimentation on low-cost, affordable and sustainable sanitation technology options
- inadequate technology choice. No appropriate sanitation technologies, which take into account cost, weather, ground water level, availability of water, construction materials, culture/religion and special needs of women and children.

The level of hygiene education and general awareness of the communities concerning safe water and environmental hygiene is very low. Lack of awareness of the health implications of water and sanitation and hygiene practices particularly by the rural population have resulted in high water, sanitation and personal hygiene-induced morbidity and mortality affecting all ages. The low level of consciousness of communities is also responsible for the unsustainability of most of water supply and sanitation schemes developed in the past.

Safe water and adequate sanitation not only are the bases of life and health, but they also are essential contributors to human dignity. Improved sanitation and water supply must be an important goal if improved health and sustainable development in Ethiopia is to be ensured.

Managing sustainable rural water supply in Ethiopia

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Introduction

General

Ethiopia is a country with a current population of 63.5 million and with a 3% population growth rate. In rural Ethiopia, which comprises 85% of the total population, water supply and sanitation coverage are limited to 23 and 7%, respectively (MoWR 2002). In a country where rural settlement is dominantly rural, a lot of effort is required to change the low profile as indicated in Table 1 below.

Table 1. *Comparison of selected indicators.*

Selected indicators	Ethiopia	Low income countries
GNP per capita	US$ 91.5	US$ 360
Life expectancy (LE)	49 years	56 years
Adult illiteracy	65%	46%

Source: World Bank (1996).

Figure 1 shows the trend of water supply coverage of selected African countries as compared with Ethiopia. The gross national product (GNP) increase to more than US$ 300 to cross the 50% coverage line set to be the global target for the poor.

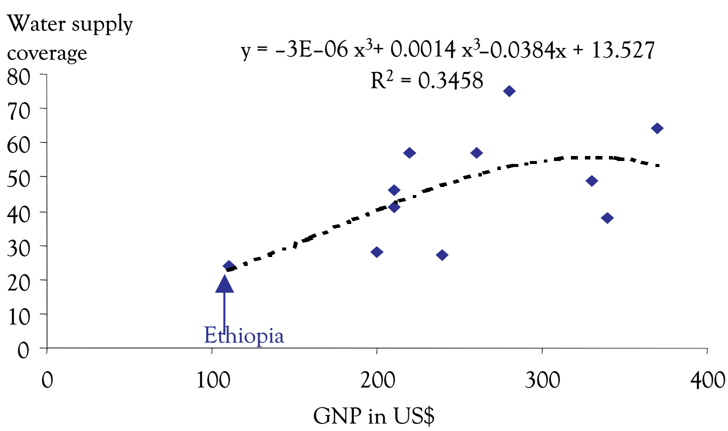


Figure 1. *Trend of water supply coverage for selected African countries.*

Background

CSA (1998) reported that in rural areas, less than 15% of the people had access to safe water. The difficulty in finding appropriate water sources coupled with scattered settlement patterns and nomadic lifestyles significantly influence the opportunity to increase and sustain access to water for the rural population.

This study is aimed at finding solutions to the anticipated problems that were hindering sustainability in four pilot regions, i.e. Amhara, Benshangul, Oromiya and Southern regions where access to water supply has declined as per the Central Statistical Authority's (CSA) 1998 data.

Physical resources base

Water resources potential

The annual runoff from 12 river basins is estimated at 123 billion m^3 whereas the ground water potential is about 2.6 billion m^3. Ethiopia contributes >85% of the Nile River water (MoWR 2000).

Water quality

Turbidity, fluoride and nitrate are the major problems.

Issues

The major issues in the Ethiopian rural water supply intervention are the following:
- sustainability (more than 30% of the schemes are not functional)
- ability to pay
- stakeholder participation
- capacity building
- technology choice
- livestock watering.

Problems

The study based on the actual conditions of the 40 typical schemes surveyed in the four sample regions has proved that the problems of rural water supply reliability fall under:
- lack of finance
- lack of skilled manpower
- inadequate stakeholders participation
- lack of co-ordination amongst stakeholders

- lack of well institutionalised set up and appropriate regulatory framework and
- poor infrastructure.

The study further indicates that the software and hardware aspects of rural water supply are not treated in a balanced manner. This has an adverse effect as population is increasing at 3% while sanitation is at a virtually non-existent level. The study also highlights that social work incorporating sanitation awareness, birth control, gender, community ownership and management that addresses these problems to the grassroot level shall soon be launched thereby ensuring the reliability of access to safe water sources. Neglecting software aspects is putting a snare that thwart the relentless effort of some regions that have partially succeeded in constructing a relatively larger number of schemes (Getachew 2002).

Objectives of the study

The initial objective of this study is the building of community management models that could contribute to the strengthening of management at scheme level thereby ensuring improved reliability of water supply service in the four selected regions.

The ultimate objective is the replication of findings to other regions to improve access to water supply through community management at a national level.

Accordingly, three-fold partnership amongst the community, as owners of the schemes, the government as the creator of enabling environment, Environmental Site Assessments (ESAs) and non-governmental organisations (NGOs) and donors as support organisations is presupposed to achieve sustainability.

Methodology

The methodology of the study included the following:

- problem identification using the problem tree
- setting of objective using the objective tree
- survey on performances in relation to sustainability and coverage
- literature review on reliable community managed schemes, stakeholder participation and appropriate technology
- sustainability assessment in the four pilot regions using spread sheet and SWOT analysis
- spread sheet and Multivariate analysis of the collected data for confirming correlation. Use of SPSS version 8
- building scheme level management models and determination of resource requirement.

Analysis of sustainability performance

The analysis has shown that emphasis on:

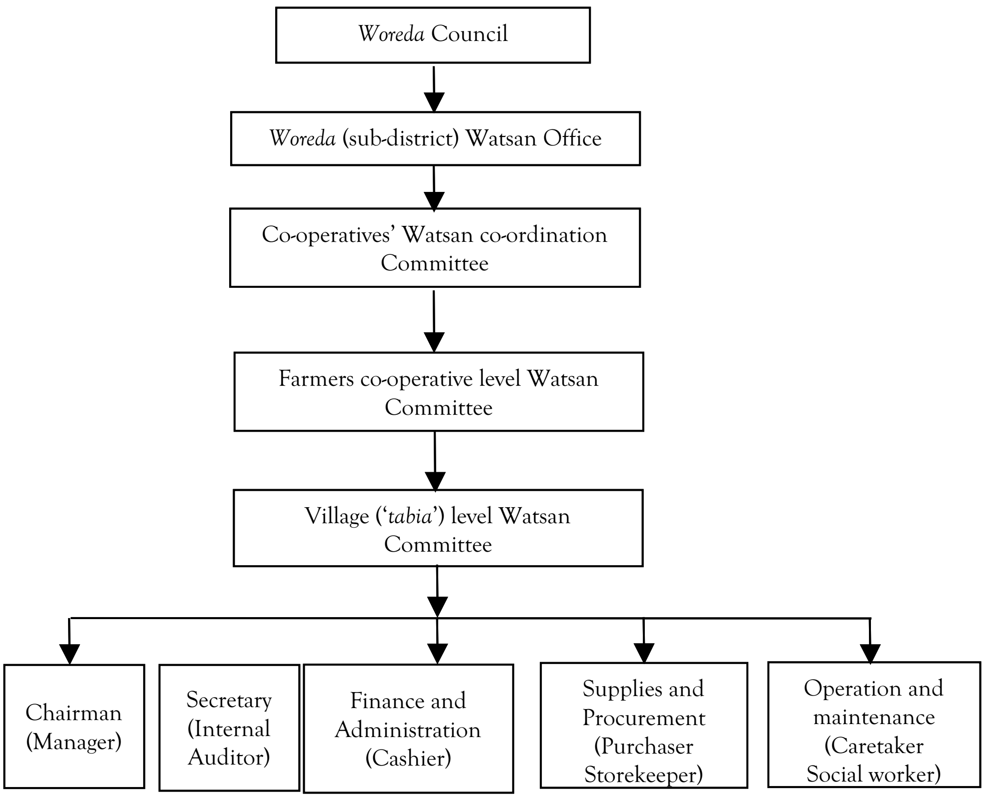
- community management supported by three-fold partnership

- cost recovery
- software (social) aspects
- technology choice and
- research and development is required.

Sustainability performances of the typical schemes in Amhara, Oromiya, Benshangul and Southern regions have displayed a correlation of high order. Therefore, more or less similar scheme level management models can be prepared for the four sample regions.

Management models

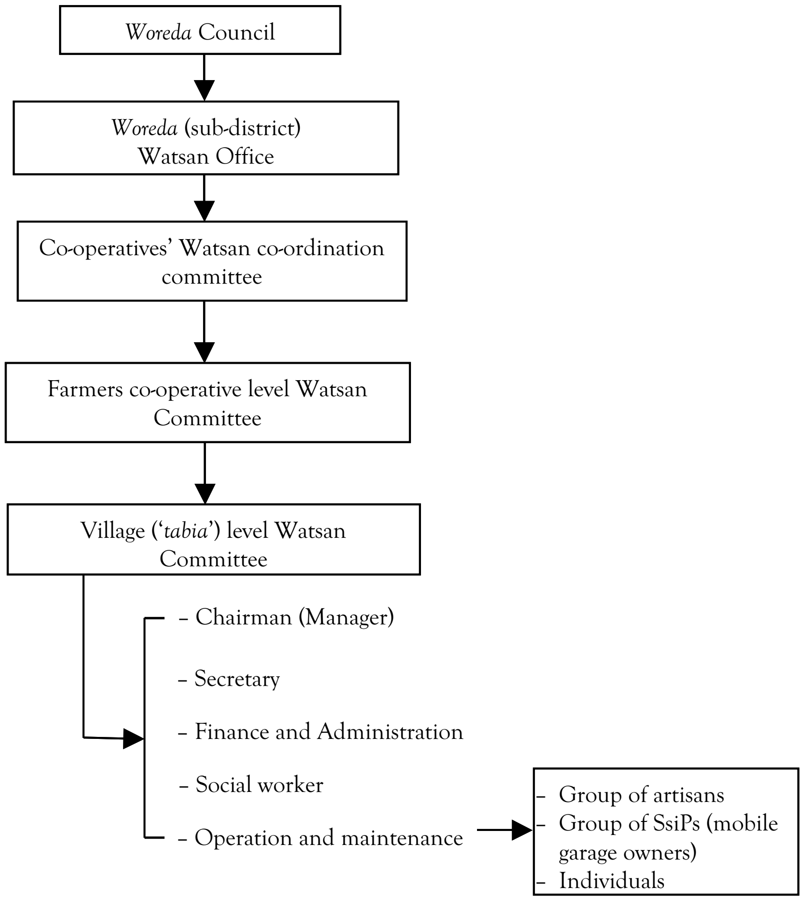
In harmony to the findings, community management models that can address the software and hardware aspects in a balanced manner are developed as shown in the two options below. Option 1 (Figure 2) makes use of *woreda* council, co-operative Watsan committee and village water committees among others.



Source: Getachew (2002).

Figure 2. *Watsan committee structure (Option 1).*

Option 2 (Figure 3) encourages public–private partnership by involving artisans, small-scale independent providers (SsiPs), individuals, garage owners etc.



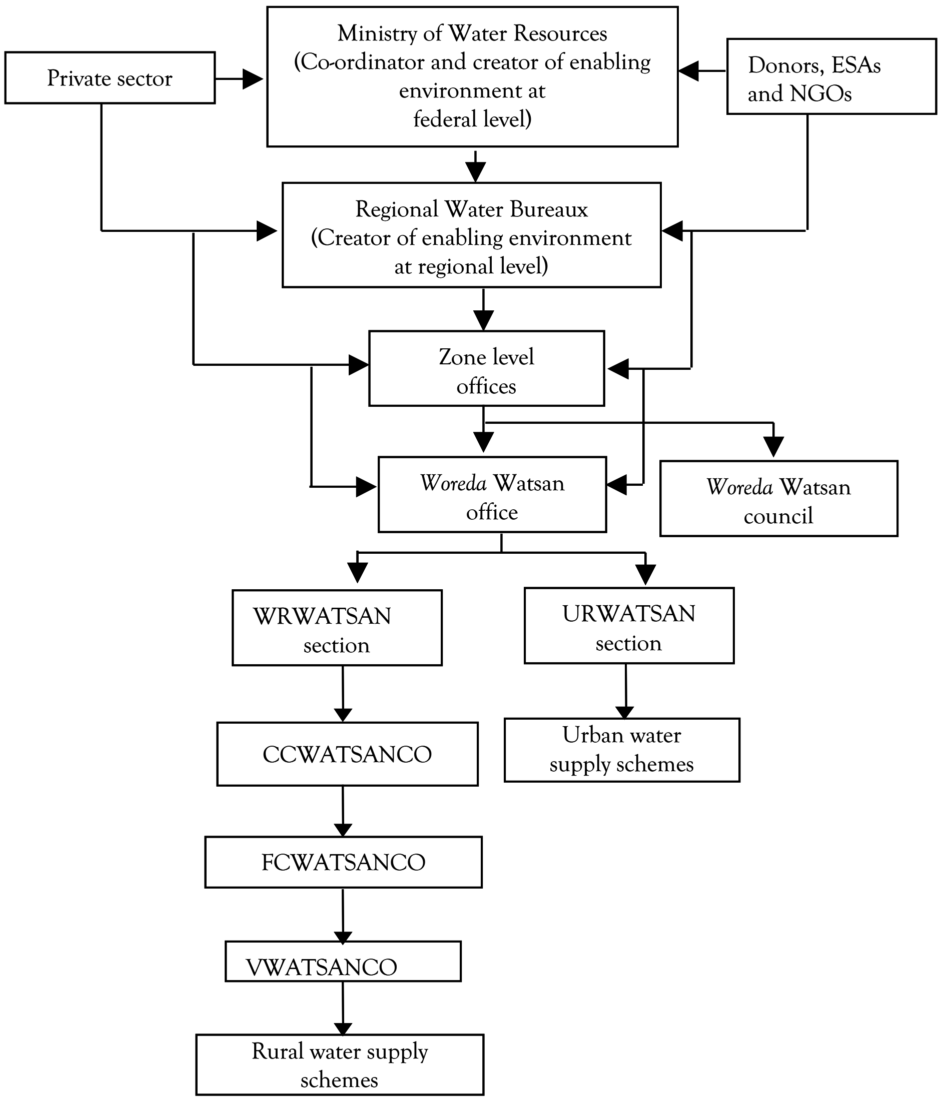
Source: Getachew (2002).
Figure 3. *Watsan committee structure (Option 2).*

Moreover, it would be worthwhile to introduce an organisational structure that looks as the one shown in Figure 4 below to have good co-ordination at all levels.

Resource requirements

As a supporting exercise, manpower that are required to provide safe water to 71% of the rural population by the year 2015 were estimated and shown in Figure 5.

The financial requirement as per the Water Sector Development Program is more than US$ 2 billion ascertaining the need for cost sharing mechanisms as shown in Figure 6.



Source: Getachew (2002).

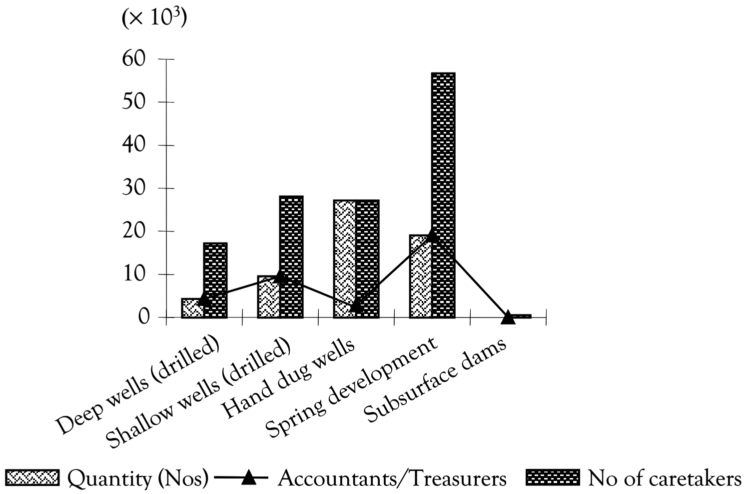
Figure 4. *Proposed organisational chart.*

Appropriate technology and use of renewable energy

The huge resource requirement to develop sustainable water supply calls for the use of appropriate technology and renewable energy that focuses on shallow wells, springs, Village Level Operation and Maintenance (VLOM) hand pumps, windmills, solar pumps etc.

Rural water supply (RWS) fund model

In early 2002, the water resources fund designed for urban water supply and irrigation was established in Ethiopia. Rural water supply that is put aside for government investment would require a fund model as shown in Figure 7 if a considerable improvement is required (Getachew 2002).



Source: HoWR (2002).

Figure 5. *Scheme and manpower requirement to increase coverage from 23–71% by the year 2015.*

Source: MoWR (2002).

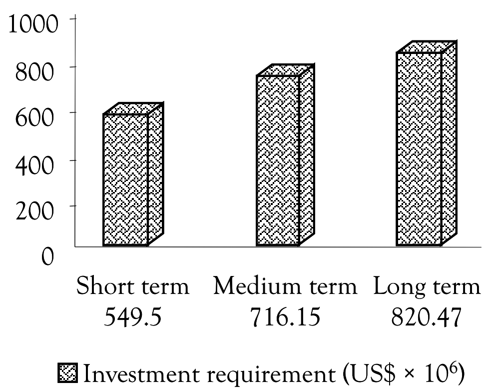


Figure 6. *Investment requirement in (US$ 10^6) up to the year 2015 to increase coverage from 23–71%.*

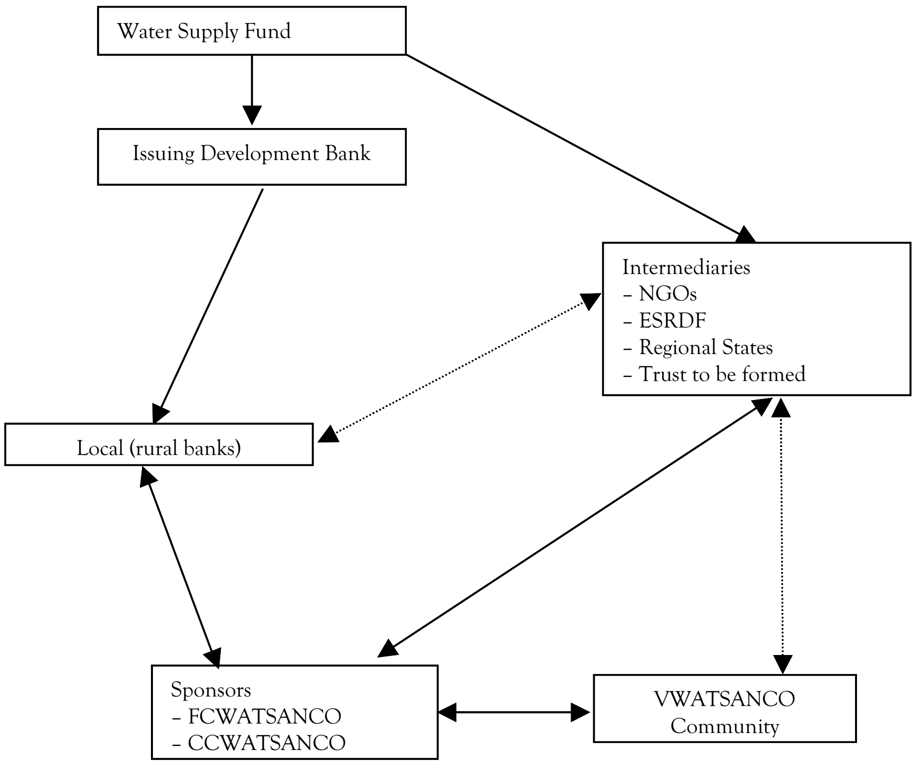


Figure 7. *Rural water supply (RWS) fund model.*

Sustainability process

Figure 8 summarises how sustainability could be achieved in Ethiopia. The figure considers sustainability as a continuous cyclical process. The more the cyclical process the better the sustainable and reliable water supply services would become (Getachew 2002).

Conclusion

Building financial capacity requires a three-fold partnership amongst the regional states as the creators of enabling environment, the community as owners of the schemes and ESAs and NGOs as support organisations as highlighted by the National Water Sector Development Program once the models are introduced. A well-organised and equipped *woreda* office that can play a leading and productive role in tackling the problems shall replace remote follow-up from the regional and zonal offices. A water supply and sanitation fund that will have its branches at least at regional level shall be established to build its own financial capacity. International donors are also expected to support the effort by providing soft loans and grants possibly through the Nile Initiative Programme, donor conferences and poverty alleviation programmes. Technically, the launching of adaptive research and

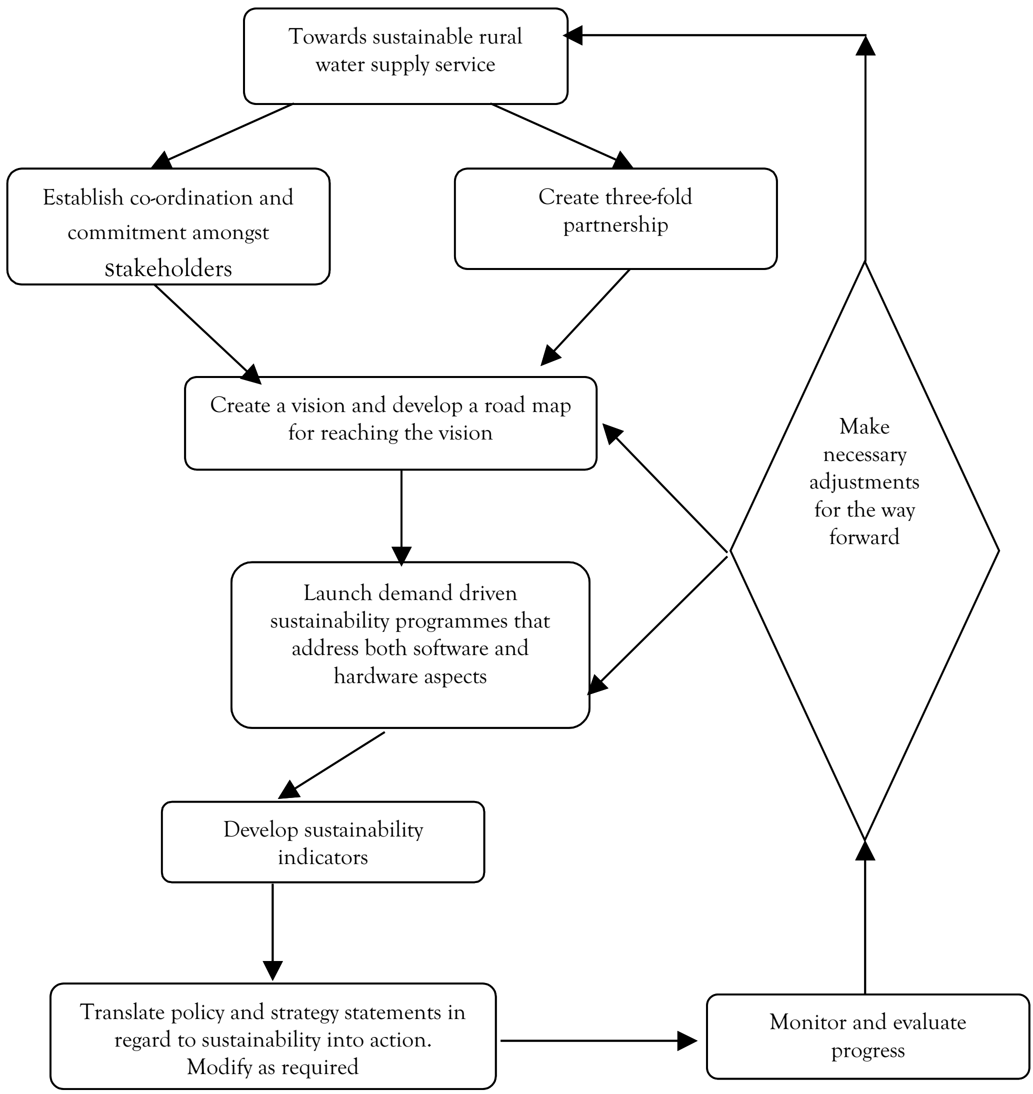


Figure 8. *Sustainability process.*

development in the water sector that enables the use and provision of appropriate technology, VLOM pumps and spare parts at an affordable rate is required.

In conclusion, a dedicated effort that involves community empowerment, full-scale community participation and the mobilisation of all stakeholders in integrated development with water as a focal point is required to improve access to reliable rural water supply services in Ethiopia.

The way forward

For success in the improvement of sustainable water supply coverage, the country needs to give attention to the following major actions:

- accelerated and integrated development of sustainable and reliable rural water supply services
- formation of co-operatives or water user's association
- balanced action on software and hardware aspects
- replacement of supply driven approach with demand responsive approach that could start with affordable cost sharing initiative
- implementation of the models and the above-mentioned prerequisite activities for achieving reliable service
- replication of the findings to other regions based on consultative process
- integrated development to boost up the economy
- promote public–private partnership that will eventually lead to privatisation
- establish three-fold partnership amongst the community, government and support organisations and
- special consideration for the drought affected and nomadic community.

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Water and the environment in Ethiopia

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Abstract

It is generally recognised that fresh water is regarded as one of the most important natural resources for all socio-economic development and a basic input for environmental management. Failure to successfully develop and appropriately utilise this resource leads to a progressively declining economy and degraded environment.

In Ethiopia, despite the huge potential of fresh water resources, recurrent droughts and rapidly progressing desertification have disrupted food and fibre production systems. Food shortage and starvation is ever increasing. The national economy is either stagnant or declining while population size is rapidly increasing. Domestic water supply is at its infancy. Potentials in irrigation and hydropower are also hardly exploited. The cumulative effect of these has reflected on overall poverty and associated environmental degradation.

In view of the above-mentioned issues, the need to develop and utilise the available water resource in the country is discussed in this paper. The discussion is focused on the relationship between water resources, the environment and poverty.

Introduction and background

Water is a precious natural resource, vital for life, development and the environment. It can be a matter of life and death, depending on how it occurs and when it occurs and how it is managed.

Irrespective of how it occurs, if properly managed, water can be an instrument for survival and development. It can be an instrument for poverty reduction. Access to safe water and sanitation to meet human and livestock needs is a prerequisite for sustainable development.

However, when inadequate in quantity and quality, it can rather serve as a limiting factor in poverty reduction and overall national development, resulting in poor health and low productivity, food insecurity and constrained economic development. It is therefore imperative that the linkages between water development initiatives in the agriculture, food, energy, health, education and decentralised governance sectors be clearly understood and carefully managed to benefit from the inherent synergies and to minimise or avoid negative cross-sectoral impacts.

It is on this basis that water is one of the most essential substances for the sustenance of life. It is generally recognised that fresh water is the most important natural resource in all socio-economic development endeavours and indispensable input for environmental management. It is an important component of every type of environment where life is found. Successful management of the environment, therefore, can never be achieved in isolation from appropriate management of water resources. Water is a product of the environment, and vice versa, as it comes as rain from the environment and goes through land, which is the major component of the human environment and ends up in the sea or in the land. Managing water is thus intimately linked with managing the environment—all terrestrial, aquatic and atmospheric resources including human welfare.

Based on the bond between water resources and the environment, integrated water resources management is gaining paramount importance worldwide. In pursuit of integrated solutions, it is observed that decision-makers and planners tend to be oriented towards the management of water while preserving the environment through appropriate legal tools and sustainable actions of development.

Integrated management of water resources entails co-ordinated development of water, land and related resources to maximise socio-economic benefits and preserve the sustainability of the ecosystems. Being viewed as comprising an ecological system of interdependent components, the water system interacts with land, environment and other related political and economic systems. The whole process should be directed towards the assessment of water needs, sources, the causes of water related problems, and means to optimise the utility and equitability among stakeholders throughout the water system management.

Although implementing water resources in an integrated manner is important, its management is complex. The complexity also differs across place and time because the integration entails needs and equitable distribution of water for all domestic utilisation and agricultural and industrial use together with the need for ecosystem management. These require co-ordination, harmonisation and reducing temporal availability constraints and situational pressure. Effective co-ordination and integration between the water system and other systems require efficient decision and controlling mechanisms that are based on knowledge of water acquisitions, development and efficient allocation to different socio-economic and ecosystems management activities. The need for such connection in the water system is due to the fact that water has economic, ecological, social, cultural and religious value.

The state of water resources in Ethiopia

Ethiopia has 12 major river basins/valleys, 11 lakes, 9 saline lakes, 4 crater lakes and over 12 major swamps. The total mean annual flow from all the 12 river basins is estimated to be 123.25 billion m^3. Based on this information, it is always stated and often quoted that 'Ethiopia is the water tower of East Africa'. The country can only be a water tower in terms of receiving ample water and donating it to neighbouring countries but not in terms of ample water resources that is readily available for use. This is because, most of the major rivers have created deep gorge in the country and the water they contain passes to neighbouring countries, thus constraining development and utilisation of the water resources in the country. In addition, uneven spatial and temporal distribution of the available water resources either demand huge investment to develop and extend to the water scarce areas or constrained the utility at required time and place. This is again due to the fact that most perennial springs and streams exist only in the highlands comprising just over 40% of the country's geographic area, whereas there is hardly any surface runoff and perennial springs and streams in areas below 1500 metres above sea level (masl) that comprise over 55% of the country. Even the country's estimated 2.6 billion m^3 ground water which, fairly distributed in the lowlands, could not be appropriately developed and utilised because of financial and capacity problems. Such failures in developing and utilising the country's water resources and mismanagement to the sparsely available water have already been reflected as a root cause for overall environmental degradation.

Problems associated with water management and the environment

Environmental risks and/or benefits are often related to the way natural resources are managed. Environment is defined as related to a range of natural resources it contained, the interactions between the different resources and the state of resources in space and time. All living organisms and their habitats are dependent on the availability and quality of water resources. Therefore, there is no such thing as managing environment without managing water resources and vice versa. We therefore could conclude that environmental risks and benefits are often related to the way in which natural resources, in general, and water resources, in particular, are managed.

The important interacting variables in environmental management is the water management system we choose; the use we make of the water; the quality and quantity of the water; and the nature and quality of the environment. The interactions between these variables often emanate problems in water resources management and utilisation because the process of water resources management and utilisation would modify the natural water systems. The process may also affect the quality and quantity of the water at the envisaged users level.

The water resources management, therefore, has to consider the heterogeneous nature of the environment, i.e. the nature of changing from place to place, that is spatial and temporal, or fragility of resources' associations and their environment. Different environmental issues would demonstrate this idea. For example, irrigation often causes severe salinity in arid lowlands while its environmental and socio-economic benefit in the humid areas is far greater than its adverse impact on the environment, with the assumption that the design and management of the irrigation in both areas are similar. However, good designs and pre-informed management actions avoid the adverse impact at any place. Similarly, mass deforestation of an area creates adverse impacts on water resources quality and quantity and the environment. It leads to soil system impediment and adversely affects the process of infiltration creating temporal floods, soil erosion and general environmental degradation. Reforestation and increased organic contents in soil acts inversely. They increase water infiltration rates; create clear and sufficient water; improve general environmental conditions in which diversity of terrestrial and aquatic organisms flourish.

The water management and utilisation problems as related to the environment in Ethiopia are not limited to uneven distribution of water resources and human actions. Natural calamities have also posed severe problems. Ethiopia and its eastern neighbouring countries were severely stricken by recurrent droughts from 153 to 242 BC, during which water flow in the river Nile was tremendously reduced. These droughts, however, affected small portion of the country and imposed less famine in Ethiopia. The extent and frequency of the famine has gradually grown until 1975, when thousands of people lost their lives. This called not only for national attention but also for global attention that after then some actions on the idea of conserving and managing environment and water resources has emerged. By the time, however, the water systems and the environment in most parts of the country had lost or severely reduced their resilience that the resources were susceptible for slight touches. The emerged actions have not been able either to reverse or stop the resource degradation and climate problems such that currently aridity has widened its scope in the country. Now it is estimated that 65 to 70% of the country's total geographic area fall under the United Nations' definition of desertification.

Although desertification is degradation of land in arid, semi-arid and dry sub-humid areas, the main element of desertification is unavailability of water resources. This renders the ecosystems in the affected areas fragile. Desertification does not refer only to the expansion of already existing desert but also over-exploitation and inappropriate use of resources in dry ecosystems. Deforestation, overgrazing, misdesigned and mismanaged irrigation practices, poverty, political instability and inappropriate macro policy directions can all adversely affect natural resources and land productivity leading to desertified environment. The results are often loss in biological productivity, disturbed and deteriorated water cycling, and loss in economic productivity, famine, starvation and general poverty ranging from household to national level. Thus poverty goes back to further over-utilisation of resources including water, and to environmental deterioration creating vicious circle to the process.

The above stated environmental problems have already taken place in Ethiopia. Clearing of forests, over-grazing and other reductions in the vegetation of the country has increased considerably during recent years. Increased silt and nutrient load of the watercourses due to increasing populations and the above-stated negative environmental products have posed serious socio-economic and environmental problems. The episodes that encourage soil erosion (depleted forest, inadequate plant cover, poor soils, improper farming methods etc.), and inappropriate management systems of water resources (at micro-level) have alarmingly taken place and most of the water systems and the environment have suffered from the consequences of the linked processes (Zinabu 1998).

The overall product of the problems is poverty. Of a total population of about 67 million people, it is estimated that close to 30 million live in absolute poverty. A report prepared for the 'World Summit on Sustainable Development' reveals that the household income, consumption and expenditure survey conducted in 1995/96 and published in 1999, estimated that:

i. forty-six percent of the population subsists below the poverty line

ii. although poverty is widespread in the country, it is more prevalent in the rural areas where 47% of the population is poor compared with 33% in the urban areas
iii. average per capita income (US$ 167) obtained from the survey is very close to the national poverty line (US$ 165) indicating that the whole nation is on the verge of poverty.

Several indicators raise the alarm that poverty is further deepening. For example, per capita food production has been declining since the 1960s indicating that the ability of the rural population to feed itself has been deteriorating. The average annual yield of cereals in the years from 1980 to 1995 showed no improvement showing that agricultural performance was stagnant throughout the 1980s and most of the 1990s while population growth is increased by 3% annually. Furthermore, the number of relief recipients is increasing tremendously both in the urban and rural areas. Poverty also hampered the provision of social services. The level of satisfaction in the basic needs such as water supply and sanitation, health, education and even shelter is low. For instance, only less than a quarter of the rural population has access to drinking water supplied from protected sources. Electricity is used as a source of energy for cooking by only 0.38% of the households. The rest depend on woody biomass, crop residues and cow dung. These had multiple adverse impacts both on water resources management and the environment.

Actions taken to reverse the trend

Policies and strategies

Although the severe poverty at micro-level creates problems on wise management and use of natural resources, the Government of Ethiopia is well aware of the problems. Accordingly, the constitution and many sectoral and cross-sectoral policies have given due attention to sustainable development, in which the management of natural resources and the environment are focus areas. A couple of policies and strategies are raised as example.

The constitution of the Federal Democratic Republic of Ethiopia (FDRE) set clear economic development policy in general and gave due consideration to environmental and socio-economic issues in particular. All sectoral and cross-sectoral policies developed and legislation enacted have been based on the general statements in the constitution.

The economic policy emphasises sustainable development that shall be based on integrated approach to rural development. It clearly states that all development actions should consider the wise management of natural resources and the environment. It pays due attention to water resource development and management with statement 'without water agriculture is unthinkable'. It further states that if the supply of water is higher or less than the required amount or if it is not available at the right time, production would significantly decrease or even be zero.

Environment policy and conservation strategies of Ethiopia on their part provoke people-centred and environmentally sustainable development. The policy affirms the need to ensure sustainable use and management of environmental resources and the wise use of non-renewable resources. It cautions stakeholders to the extent possible when managing the trade-off between short-term economic growth and long-term environmental protection. Additionally, it underscores the need to correct for market failures, and ensure social equity in the use of environmental resources. It further advises that regular and accurate assessment and monitoring of environmental conditions be conducted and the public be duly informed on the outcome. On the investment side, the environmental rights are safeguarded by a legal requirement that deploys the Investment Authority to ensure that the intended investment activity complies with conditions in the environment protection laws.

As regards to water resources management, comprehensive and considerate of all sector and cross-sector development water policy or strategy and 15 years development and management programme have been prepared that are now ready for action. The water resources management policy reinforces the prosperity, harmony and environmental health elements of the unstated vision through the policy's fundamental principles, which recognise that water is a commonly owned economic and social good that should, as much as possible, be accessible to all in sufficient quantity and quality to meet basic human needs. The principles further emphasise, among others, the need for a rural-centred, decentralised, integrated and participatory water management system. They also emphasise the attainment of social equity, economic efficiency, empowerment of water users, sustainability of water management, promoting self-financing and cost recovery. In using water resources, ensuring environmental soundness of all water resources development activities, and ensuring sound water governance regimes at all levels of governance are further required.

Conservation and development

Many different environmental management actions including forest resources management and development, soil and water conservation, dry lands water and pasture resources development and management etc. received attention since the 1970s. The actions were conducted in isolation from each other that integrated management systems were not designed and developed. The failure to design and implement actions in an integrated manner has contributed to less than effective actions.

Currently, however, an integrated approach to resource development and environmental management has been designed into the River Basin Master Plans. Resource inventories have been conducted for most of the river basins and compiled at individual river basin levels. The compilations indicate the state of all resources including land, water, floristic and faunistic resources and existing management options and constraints. Based on the knowledge of resources, management constraints and options, long-term (30–50 years) priority areas of intervention have been proposed in each master plan from which priority actions have already been adopted in the so far prepared water sector development programme. Again, the water sector development programme considers integrated socio-economic development with water resources playing a major role in development.

Furthermore, the Sustainable Development and Poverty Reduction Programme Ethiopia calls for the water supply coverage of urban, rural and country level at 82.5, 31.4

and 39.4%, respectively, from 2002–05. The programme has planned to annually increase urban sewerage coverage by 3.5% from its current level of 7%. It has further planned to develop irrigation schemes that cover 29,043 ha and small-scale irrigation that cover 23,823 ha with expected total beneficiaries of 207,900 households.

Conclusions

Different natural resources in Ethiopia complement one another. Any successful management of the environment depends on the management and utilisation of other resources, especially water resources. Again, water resources cannot be successfully managed in isolation from other resources. Integrated approach to the resources management is indispensable for sustainable management of all individual resources including water resource in particular and the environment in general. The approach in the River Basin Master Plans is encouraging and it should be strengthened.

The country has enacted a number of legal tools that are very important for the successful management of water resources and the environment. The major drawback is failure in implementation of the prepared programmes, policies and strategies, which are based on dependable information and deep consultative processes.

Furthermore, poverty affects not only socio-economic performance and human welfare but also the natural environment at large. Combating poverty has already received attention from the Government of Ethiopia and a poverty reduction strategy and programme has already been prepared. One among many issues of the strategy and the programme is water resources development for irrigation and other uses. This is basic for countries like Ethiopia that are frequently stricken by droughts.

However, although all scales of irrigation are important for Ethiopia's agricultural productivity and production, planning for the irrigation development should consider short- and long-term irrigation components. In the short-term, small-scale irrigation, especially those, which complement local knowledge and affordability, should receive greater attention for many different reasons including the system efficiency and environment friendliness.

One, therefore, strongly argues that the water resources management process should be started and strengthened at the grassroot/community level because local people understand that water is a precious natural resource, vital for life. Attention should, therefore, be given to small-scale irrigation, which is already known and practised by the local communities. The only need is to encourage and strengthen the practice and avoid possible conflicts during irrigation water use. Furthermore, small-scale irrigation is efficient in water resource utilisation (less evaporation and percolation wastage, less salinity to soil and ground water, less conflict arising with down-stream users, environmentally friendly in general etc.). The short-term food production programme and water resources management programme thus should consider small-scale irrigation in all possible vicinities.

In addition, there should be a greater effort to expand capacity and satisfy energy needs, at least in urban areas, so as to reduce fuel wood pressure from woody biomass, crop residues and cow dung that should be returned to the soil and enhance land productivity and production. Water resources, as far as financial resources allow, should primarily play this role.

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Water and health in irrigated agriculture

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Abstract

Irrigation impacts on human health in many different ways. Often yields in irrigated agriculture are higher than in rainfed agriculture, thus making more food or income available to farmers. This may lead to better nutrition, making people more resistant to diseases. Increased welfare may also be spent on better health care and protective measures such as vaccines and bed nets. However, irrigation canals, drains and hydraulic structures can also become breeding sites for agents of disease, such as malaria mosquitoes and snail hosts of schistosomiasis. Other diseases, such as skin and eye infections, may be reduced by the introduction of irrigation, simply because more water is available for hygiene and sanitation. In fact, water destined for irrigation of crops is often used for all kinds of domestic activities, including consumption. Though the quality of irrigation water usually does not meet the standards for drinking, it may be the only water available in remote arid regions. In some cases, seepage from irrigation canals recharges the groundwater and provides fresh water pockets in an otherwise saline aquifer or dilutes chemical pollution from geological origin, such as fluoride. Consequently, investments in water resources development could be more cost-efficient if multi-purpose systems were conceived, catering for agricultural and domestic water needs.

Health benefits

Higher and more diverse food production in irrigated agriculture brings health benefits to farmer families in the newly irrigated areas. People may gain access to more varied and higher quality nutrition through increased income from cash crops, though this effect is not always very clear (Benjelloun et al. 2002; Parent et al. 2002a). The construction or rehabilitation of irrigation systems has other positive impacts on the human environment through increased employment possibilities, which would raise income and subsequently increase access to health services and education. However, an increased income is not always spent on health care. Access to health services, water supply and sanitation can be facilitated if with the planning of a new irrigation system these additional services are included. Irrigation can also influence the wider physical environment in a positive way and thus increase human well-being. For instance, seepage from earthen irrigation canals may improve the quality of the water as it filters into nearby wells.

Water-related diseases

Most of the reported impacts of irrigation development on health consist of water-related diseases. Generally, four groups of diseases are distinguished based on their way of transmission (Cairncross and Feachem 1993):

1. water-borne or faecal—orally transmitted diseases, such as cholera, typhoid and diarrhoea
2. water-washed diseases, such as louse-borne infections and infectious eye and skin diseases
3. water-based diseases with an intermediate host living in water, such as guinea worm and schistosomiasis and
4. water-related insect-borne parasitic diseases such as river blindness, filariasis and malaria.

Water-washed diseases may be reduced dramatically with the development of water resources. The availability of water, regardless of quality, enhances personal hygiene practices. This effect is especially widespread in arid and semi-arid regions, where irrigation systems may be the main source of water for all purposes. The use of irrigation water for cooking and consumption, despite its often questionable quality, may even diminish hygiene-related diarrhoeal diseases, as water quantity is believed to be more important than quality (van der Hoek et al. 2002).

Unfortunately, water-related diseases transmitted through vectors or intermediate hosts sometimes increase with irrigation development. Canals and drains may create ideal breeding sites for malaria mosquitoes or for snails, bringing both the vectors and the disease closer to people. Many field studies have described the influence of irrigation on the spread of these water-related diseases (for overviews see e.g. Oomen et al. 1988 and 1990; Bolton 1992; Hunter et al. 1993; Steele et al. 1997; HarmancioÈlu et al. 2001).

Specifically, many studies report on large-scale irrigation and malaria. Breeding sites for *Anopheles* malaria mosquitoes are found in clear surface water well available in irrigation systems and an increase in vectors usually leads to an increase in malaria. Wet rice fields are ideal breeding sites and rice field breeding *Anopheles* account for a great deal of the malaria transmission in rice-growing areas of the world (Gratz 1988). Irrigation often facilitates double or even triple cropping of rice, allowing for year-round transmission. As a result, mosquito abundance and density increases while the mosquitoes may live longer, allowing malaria parasites to complete their developmental cycle in the adult insect so they can be passed on to another host. Mathematical modelling has shown that these two factors together with possible changes in feeding habits, determine whether epidemics break out. Or it could lead from a situation of low and irregular transmission to a situation with continuous high transmission that will put a heavy toll especially on young children, who have not yet built up any resistance (Bradley 1995). The linkages between irrigated agriculture and malaria are complex: African case studies show that malaria transmission may increase, decrease or remain largely unchanged as a consequence of irrigation (Ijumba and Lindsay 2001). In West Africa for instance, intensified rice cultivation in the semi-arid savannah has led to an increase in *Anopheles* but with the high population densities, the life span of the mosquitoes was reduced and less mosquitoes were found infected with malaria. Moreover, mosquito abundance was high, creating a demand for bed nets, which farmers could afford through their improved income. Consequently, malaria transmission did not increase with irrigation development in several West African countries (e.g. Parent et al. 2002b). In Ethiopia, the construction of small dams in Tigray led to increased spread of malaria, even at higher altitudes. Seasonal transmission changed to year-round transmission because of the continuous availability of surface water. Children living near small dams had a 7–14 times higher risk of getting infected than children living further away (Ghebreyesus et al. 1999). However, this effect may be reduced over time as people benefit economically from irrigated agriculture and gain access to medication and preventive measures.

The high incidence and wider spread of disease resulting from an increase in vectors or intermediate hosts is observed for several water-related infections other than malaria. Mostly the mechanisms that play a role in increasing transmission rates are complex and dynamic. The farming system and subsequently the entire biological and human environment are often drastically changed with the introduction of irrigation. The process of mutual influences and interactions leading to disease transmission then becomes fundamentally different (Boxes 1 and 2).

Box 1. Complex health hazards of irrigation development in northern Senegal

In the lower Senegal river basin, the replacement of traditional earthen dams by large concrete dams in the 1970s influenced the hydrological and ecological situation in the valley. At the same time, the sugar factory in the town of Richard Toll expanded. Since the construction of the dams, a canal that had stable and high water levels replaced the Meandering River transporting water from Lake Guiers to the sugarcane fields. In the old riverbed, dead arms with plenty aquatic vegetation provided excellent breeding sites, massively invaded by *Biomphalaria* snails, intermediate host of *Schistosoma mansoni*. The sugar factory attracted thousands of labourers from all over the country. In twenty years, the population in Richard Toll increased more than ten-fold from 5000 to 60 thousand in 1994. Water supply and sanitation facilities for the booming population were inadequate and, as a consequence, river and irrigation canals were the only sewers and the main sources of water for many people. The entire health situation has deteriorated. Malaria was the most important public health problem in the area before the construction of the dam and the irrigation system. Now schistosomiasis has become an increasing burden to the local health system, with almost the entire population infected with very high worm loads. Other health problems that simultaneously increased are typhoid fever, cholera, rift valley fever, sexually transmitted diseases and malnutrition (Kongs and Verlé 1994; WASH 1994; Stelma 1997).

Multiple use of irrigation water

The use of irrigation water for non-agricultural purposes

In most open canal irrigation systems, water is used not only for agricultural purposes, but also for all kinds of agricultural, domestic, municipal, industrial and recreational purposes

Box 2: Malaria and schistosomiasis in Gezira, The Sudan

Oomen et al. (1988) gave extensive details on the history of malaria and schistosomiasis in The Sudan. Since the Gezira Irrigation System began in 1924, malaria has been closely linked to agricultural development. During the first 25 years reasonable malaria control was possible through good water management and larviciding. After 1950, when the irrigation system expanded and created more breeding sites, an intensification of cropping added water continuously to the larvae-producing minor canals. At the same time, large-scale applications of chemicals both against agricultural pests and for malaria control had caused pesticide resistance in malaria mosquitoes. Together this led to severe malaria outbreaks in 1973 and 1974. Later in the 1970s the communications and control systems in the main canals broke down. Combined with heavy aquatic growth due to inadequate maintenance, all canals had to be full to deliver water to the crops. Without precise regulation they were prone to overflowing. Another complicating factor was the large labour forces that come from malarious areas. These people were often outside health programmes and could easily bring infections into the area.

The Gezira irrigation systems have resulted in a similar increase of schistosomiasis. The same minor canals that favoured mosquito development also stimulated high snail populations most of the year. These canals with clear water and dense vegetation provided night storage and were close to villages, so water contact was high. Urinary schistosomiasis has increased from less than 1% before World War II to affecting almost a quarter of the adults and half of the children in the 1950s. Intestinal schistosomiasis rose even more from 5% in 1949 to 86% in 1973, in children of 7 to 9 years old, often the group with highest infection rates. Another vulnerable group consisted of the canal cleaners, who stayed daily for long hours in the infested water (Hunter et al. 1993).

(van der Hoek et al. 1999). These activities may influence the water quantity, quality or both (van der Hoek et al. 2001a). At river basin level, the allocation of water resources to different sectors in an approach of integrated water management is becoming common practice (e.g. Berkoff 1994; Heathcote 1998). Water from large dams and reservoirs is often used for hydropower, industry, municipal water supplies, and irrigation. In inter-sectoral negotiations over water, irrigation often comes after energy, municipal water supply and industrial supply, because of the low expected revenues from irrigated agriculture. This could change if all actual uses of water would be included in the calculation of economic benefits of irrigation (Meinzen-Dick and van der Hoek 2001).

Often, the multi-purpose use of irrigation water is not formally recognised and, for water quality reasons, perceived as a sensitive matter. An irrigation agency or water users association may ignore or even deny the *ad hoc* or systematic use of irrigation water for unplanned purposes. Other activities such as fishing in canals are hardly ever considered a problem because these normally would not interfere with the functioning of the irrigation system. The use of canals for laundry is usually tolerated too, or even facilitated through special steps that prevent damage to the canals. Water from irrigation canals can also contribute to the development of local economic activities, be it small-scale and informal such as butchers, car washing or market places, or medium-scale with formal water rights such as ice factories in Pakistan or brick factories in Morocco. These rural industries may contribute to regional income generation. Irrigation canals can also be sources of high quality protein and micronutrients in the form of aquatic plants, fish, crustaceans and snails. The presence of an irrigation system enables people, often women, to divert water to their home gardens. These gardens may have trees bearing nutritious fruit, giving shade and providing wood for fuel. Livestock rearing, be it cattle, sheep, goats or chicken, may depend directly on water from irrigation systems, in addition to profiting from the higher availability of fodder from crop stubble. In India and Pakistan for instance, milk production is significantly better when irrigation water is available than when saline groundwater is the only source (Meinzen-Dick 1997).

In semi-arid and arid countries, where irrigation systems are often the only available source of water for all purposes, tanks for community water supply may be fed directly from the irrigation system. In many villages in the Punjab of Pakistan and in Central Morocco, such tanks may be the only available source of water (Laamrani et al. 2000a; Ensink et al. 2002). The water taken from these tanks is sometimes treated at home, but often it is used for drinking, cooking or other household uses without any treatment or precaution (Jensen et al. 2002). When irrigation water is used for human consumption without any treatment, faecal-orally transmitted diseases such as diarrhoea, dysenteries, poliomyelitis and hepatitis-A may spread. Eggs or larvae of intestinal parasites are, in the absence of sanitation facilities, often excreted with faeces close to irrigation canals, especially when people use water for anal cleansing. Crops may be contaminated during irrigation or the water may be used further down the system for washing, cooking and drinking. Water contaminated with excreta increases exposure to schistosomiasis. Still, the higher availability of water, regardless of its sometimes-disputable quality, has a beneficial impact on children's health (van der Hoek et al. 2002).

Implications for planning and design of water resources development

Environmental control recommendations

In the literature, it has been argued that designing irrigation systems that avoid stagnant water could prevent negative health impacts of irrigation (see e.g. Speelman and van den Top 1986; de Weil et al. 1990; Tiffen 1991; Hunter et al. 1993; Slootweg 1994). However, few recent examples are available of actual implementation (Laamrani et al. 2000b; Laamrani and Boelee 2002). Measures for environmental control have been applied for ages in many countries till the first half of this century (Takken et al. 1990; Konradsen et al. 2002). With the introduction of DDT in the 1940s, environmental management seemed no longer necessary. Excessive spraying of fields, bushes, and houses replaced the inter-disciplinary co-operation and at that time almost eradicated malaria in some countries. In a similar approach, the snail host of schistosomiasis was attacked with molluscicides. Consequently, increased resistance of vectors to pesticides and unwanted effects on non-target organisms occurred. Drugs that are more efficient have been developed, but the distribution is difficult, re-infection is not prevented and parasites become resistant to the treatment.

Nowadays the health sector has come to rely on environmental management again as a part of integrated disease control approaches (Boelee 2003). Most of the recommendations are focused on preventive measures that can be incorporated into the design of new irrigation systems. Good construction practices are crucial in the implementation of a new irrigation system. Fields that are evenly laid out require less water than poorly prepared lands, while puddles and other breeding sites are less likely to form. Canals with the right elevation, size and slope will be less prone to erosion and can convey water at higher velocities without overtopping. For Ethiopia, this offers a great opportunity for integrated planning and design of water resources development projects. Apart from avoiding the characteristics that foster the development of vectors and intermediate hosts, the location of villages and drinking water supply are important factors. The distance between irrigation infrastructure and residences may determine how often and how intensely the population is exposed to vectors or infested water. For several mosquito and fly species, the flight range is known and when houses are located at a larger distance from the breeding sites, people will be less exposed to possibly infective bites.

In existing irrigation systems, the main options to control vector breeding and water-related diseases lie in maintenance and water management. Good cleaning and preventive maintenance of all irrigation infrastructures such as canals, structures and drains will reduce the breeding of vectors and intermediate hosts, and improve irrigation performance. The periodic removal of aquatic weeds from canals reduces friction and thus increases conveyance efficiencies, while it can significantly control vector mosquito larvae and aquatic snails as well. IWMI is currently evaluating the impact of rehabilitation of a natural canal on malaria mosquitoes (based on recommendations by Konradsen et al. 1998; Matsuno et al. 1999).

In Asia, where vectors are restricted to rice fields, a locally adapted farm water management system has been shown to reduce mosquito and snail populations (van der Hoek et al. 2001b). With the so-called intermittent irrigation method, exact water quantities are applied at field level. This requires accurate water deliveries from the canals and influences the organisation of water management up to system level (Mutero et al. 2000).

Adequate facilities should be provided to increase the safe use of irrigation water for other purposes and hence improve health. Especially in arid and semi-arid regions, separate drinking water supply may not always be feasible. In Ethiopia, the reverse situation also occurs, as sometimes overflow from drinking water systems are used for the irrigation of coffee plants. In both cases it could be considered to acknowledge and incorporate other water uses in irrigation systems. Instead of planning agricultural water systems separately from drinking water supply, the different sectors should work together at national and local level and plan for integrated multi-purpose systems. This would reduce overall investments and contribute significantly to improving the health of rural populations.

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Research and development capacity building issues in the water sector of Ethiopia

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Abstract

Cognisant of the fact that research and development in the water sector is minimal and fragmented with little or no impact on the development of the sector, the National Mines, Water, Energy and Geoinformation Science and Technology Council designed a terms of reference for a consultancy study of the problem. The Ethiopian Science and Technology Commission and the Ministry of Water Resources jointly submitted a project to the Government for approval and Metaferia Consulting Engineers PLC was commissioned to carry out the study in July 2000 through funds secured from the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Government.

The consultant's findings have led to the conclusion that the establishment of a Water Resources Research and Development Institute is of crucial national importance for integrated management of R&D in the water sector. The institute is proposed to be an autonomous organisation having the overall responsibility and power for co-ordinating, guiding, funding, prioritising and undertaking R&D activities in the water sector at national level. The long-term (21–50 years) organisational objective of the institute is to establish a national R&D institute capable of undertaking most of the research needs of the water sector with a few centres of excellence being co-ordinated and funded by it.

The need for such an institute and its proper development and management is not only mandatory, but also urgent. This is because of the fact that gaps in the understanding of the characteristics of the water resources of the country limit the opportunities for judicious development of the sector, a task, we cannot afford to postpone for obvious reasons. The trans-boundary nature of the country's water resource base further complicates the situation. A well-managed R&D capability in the sector will therefore significantly contribute towards practical and multi-disciplinary solutions for such structural constraints.

The major short-term activities of the proposed institute include the legal and physical establishment of the institute; establishment of linkages with relevant national and international organisations; undertaking of R&D activities through its own programmes and co-ordination and funding of R&D activities of other centres in the sector.

Introduction

Ethiopia has a total area of about 1.13 million square kilometres and a total population of 64 million that is growing at an average rate of 2.95% per annum. Almost all economic and social indicators show that the country is one of the least developed countries in the world with an annual per capita income of about US$ 110. Agriculture accounts for about 50% of GDP and 90% of export earnings and is the means of livelihood for about 85% of the entire population. The contribution of the industrial sector to GDP is only about 12%. The dependence of the country on imported capital goods is very high. The import of manufactured consumer goods and capital goods, and some intermediate input for the manufacturing sector dominate the foreign trade sector. The export side is almost totally composed of primary agricultural products mainly: coffee, oil seeds, livestock and related products.

Traditional methods and tools of production predominantly characterise the agricultural sector of the country. Inputs from modern science and technology are insignificant. Recurrent drought and significant loss of soil due to environmental degradation have made the country a land of persistent poverty and famine. All socio-economic problems of the country are deep rooted largely in the absence of well-established scientific and technological base to generate and/or select and adapt scientific and technological knowledge to solve its development and environmental problems.

Historical background of R&D in Ethiopia

The systematic application of modern scientific methods to create and use modern knowledge in Ethiopia is of a relatively recent origin. Hence, the history of research and development in Ethiopia can go back only to the early 1950s when the Junior Colleges of Agriculture and the University College of Addis Ababa (UCAA) were established. Various records show that expatriate staff of the Colleges and the University College did most of the research published from 1960–70 as the teaching was started with only expatriate staff members. The research carried out during that time was mainly of theoretical nature. However, a small but growing body of Ethiopian scholars and scientists had begun to apply modern methods of scientific investigation to problems within Ethiopia by the early 1970s. And this had laid the foundation for the present R&D activities undertaken by the institutions of higher learning and other specialised research organisations (Bhagavan 1989).

The major institutions involved in the national R&D system of Ethiopia include higher education institutions where research is carried out to generate new knowledge. Most (though not all) of the research work undertaken in the universities is basic research. There are some specialised research institutions and/or centres within the Addis Ababa University (AAU) and the Alemaya University where multi-disciplinary research activities are carried out. There are also national institutions that carry out R&D for the government. The Ethiopian Agricultural Research Organization (EARO), together with the regional agricultural organisations and the Ethiopian Nutrition and Health Research Institute (ENHRI) are the major ones engaged solely in R&D activities. The capacity building efforts of these institutions and the results obtained from their efforts so far are in fact appreciable.

Although the government allocates annual budgets to R&D institutions in the agriculture and health sectors, much of the projects and programmes undertaken by the universities are largely dependent on funds from foreign donors. The Ethiopian Science and Technology Commission (ESTC) channels part of the funds for the R&D activities undertaken by these institutions from the government treasury and/or bilateral and multilateral co-operations. The funds obtained from external donors are used mainly for import of equipment, instruments and other consumable supplies and for research training and travel of researchers abroad. Local funds mostly cover just salaries and local travel costs.

The local research grant scheme

The local research grant scheme, which has been instituted by the ESTC since 1999 is one of the mechanisms devised to make available government funds for the research community. The major objective of this grant is to encourage institutions and young researchers to engage in applied research. Through this scheme, a project can be granted up to Ethiopian Birr (ETB)[1] 25 thousand for research and up to ETB 50 thousand for prototype development. ETSC granted about ETB 9.5 million up to the 2001/2002 fiscal year for about 438 research and development projects. The scheme has definitely played a useful role in initiating R&D activities in a number of government institutions. It has also enabled new graduates to acquire experience on how to propose, plan, and undertake R&D project. Some useful results and information for further research have also been obtained from the scheme (ESTC 2002a).

The ESTC-SIDA/SAREC research co-operation

The most important source of research funding in Ethiopia to date is the Ethio-Swedish (ESTC-SIDA/SAREC) research co-operation programme, which began in 1979/80. This Swedish support aims at manpower training and research capacity building in Ethiopia. The participants in the Ethio-Swedish Research Co-operation framework include universities and autonomous research establishments within ministries on the Ethiopian side and university departments on the Swedish side. The co-operation supported about 70 research projects and the country has received over ETB 300 million in the last 22 years.

The Ethio-Swedish research co-operation has made a significant contribution in building research capability and strengthening the higher education sector of the country through MSc/MA and PhD postgraduate training programmes. It has also impact in the various research areas. For instance, registration of the Ethiopian plant species has been done through the Ethiopian Flora Project. A considerable capacity in selection and testing of medicinal and economically important plant species has also been built at the Chemistry Department of the Addis Ababa University through the Natural Products Chemistry

1. In 2002, US$ 1 = ETB 8.50.

Program. The research capacity built in the area of pest control through non-chemical integrated pest control at Awassa College of Agriculture is also one of the commendable achievements. In general, the SIDA/SAREC collaboration has contributed to enhancing scientific research tradition in the country, building and strengthening research capacity in relevant fields, producing an increased number of qualified researchers and upgrading of R&D infrastructure (ESTC 2002b).

Other organisations that provide research support in Ethiopia include:

- International Atomic Energy Agency (IAEA)
- International Foundation for Science (IFS)
- United Nations Educational, Scientific and Cultural Organization (UNESCO)
- International Development Research Centre (IDRC) of Canada
- United Nations Development Program (UNDP)
- Russian Academy of Science, Third World Academy of Sciences (TWAS)
- Food and Agriculture Organization of the United Nations (FAO)
- European Union (EU)
- German Academic Exchange Service (DAAD)
- German Development Cooperation (GTZ) and
- International Development Association (IDA).

R&D in the water sector

Water scarcity and degradation in water quality are growing concerns for many countries around the world and the demands and pressures on global water resources are accelerating rapidly. Fresh water is limited and, for many people, insufficient to meet their daily needs, and yet global demand for water is expected to double within the next 15 years. According to World Bank estimates, US$ 70–80 billion are invested each year in the water sector in developing countries. If water consumption patterns continue at the present rate, it is estimated that two out of every three people will be living in a water-stressed environment by 2025 (IAEA 2002). The solution to these global water resource and water quality challenges is dependent on the development and sustainable management of water resources wherever and in whatever form they occur. Sustainable development and management of water resources are, in turn, critically dependent on our capability to generate new knowledge and/or new applications of the existing knowledge through scientific research.

Unlike the agricultural and health sectors, institutionalised water research is not known in Ethiopia. The first attempt to initiate R&D activities within the water sector was in fact made in 1978 when the Rural Pumping Technology Research Group, later renamed the Research and Development Services, was established under the then Water Works Construction Authority. The activities of the service were limited to the area of R&D on water lifting systems—mainly on hand and wind pumps. The service does not in fact exist at present. Apart from the R&D efforts of the service, higher education institutions such as the Addis Ababa University and Arbaminch Water Technology Institute, the Ministry of Water Resources and the Geological Survey of Ethiopia undertake limited R&D activities. Research areas covered by these institutions include multi-purpose water resources development, water resources potential evaluation, defluoridation and water treatment. Research activities in irrigation systems, irrigation water demands and crop–water interrelationships undertaken by the Melka Werer Center of the Ethiopian Agricultural Research Organization are also worth mentioning. Research carried out from 1982 to 1985 by the Water Resources Development Authority on ground water level rise and soil salinity of the Amibara Irrigation Development project has also resulted in some useful outputs (ESTC 1998).

Nonetheless, examination of the R&D efforts that have been carried out by various institutions in the water sector reveals that the efforts are very limited when viewed from the point of the water resources potential and the problems related to its management. The problems observed include absence of an institutional body to co-ordinate and undertake R&D activities in the water sector, inadequate recognition of the role of R&D in water resources management, absence of mechanisms to disseminate research results, dependency on foreign funding and inadequacy of the linkages between R&D and development activities in the sector.

Consultancy study on R&D activities in the water sector

The National Mines, Water, Energy and Geoinformation S&T Council recognised the fact that research in the water sector is at its infancy stage, and it identified the issue as its top priority. Hence, the Council designed a terms of reference for a consultancy study to address the problem. Following this, the Ethiopian Science and Technology Commission and the Ministry of Water Resources jointly submitted a project to the government funding and the study was carried out by Metaferia Consulting Engineers PLC from July 2000–October 2002 through funds secured from the government and UNESCO.

Objective and scope of the study

The main objective of the study is to assess and review relevant information and, based on the findings, to provide recommendations for the development of R&D capability and its institutionalisation in the water sector. The major activities accomplished in the study include:

1. Review of water resources potential, utilisation, and R&D policy framework
2. Evaluation of the water sector R&D needs
3. Formulation of R&D strategy and prioritisation of R&D programmes
4. Formulation of institutional framework and
5. Preparation of implementation strategy and programme.

Major outputs of the study

Understanding of the sectoral situation

The review of the existing situation has revealed wide-ranging issues including the problems of drought; inadequate capacity for resource assessment, operation and maintenance; lack and inadequacy of standardisation; unavailability of skilled manpower; low level of participation by stakeholders; environmental problems of the sector and, of course, lack of adequate R&D capability. The study concluded that the R&D activities of the sector are fragmented, un-co-ordinated and lacking any visible achievements so far.

Proposal for a consolidated water R&D policy

The analysis of the existing policy and strategy frameworks, with relevance to R&D in the water sector, revealed the need for a consolidated R&D policy and the study has come up with some important guiding principles, and 'policy elements', together with appropriate strategies. The general policy framework is the promotion of water resources development through the establishment of appropriate institutions with proper management, including co-ordination of R&D activities/projects at the national level. The identified policy elements encompass:

1. management structures
2. availability of adequate and dependable budget
3. enhancement of stakeholders participation
4. effective support to actual water resources developments
5. enhancement of water quality
6. effectiveness and efficiency of resource utilisation
7. means of water allocation and utilisation and
8. information and knowledge build-up in regard to international waters and review of institutional frameworks, including international aspects that impact on the water resources of Ethiopia.

Identified and prioritised R&D programmes

The constraints facing the management of the water resources of Ethiopia are the summations of a number of problems each of which require appropriate solutions that are technically feasible, economically viable and socio-politically acceptable. The solution to these questions can only be found through a concerted and well-formulated research programmes that are practical and targeted towards development of technologies that will enhance sustainable development and integrated management of water resources within the framework of sound environmental conservation practices. To achieve this overall objective of R&D in the water sector, the study has identified wide-ranging and multi-disciplinary topics that need to be addressed in a well-co-ordinated national effort. These are classified into four major divisions, according to their respective fields of research. The four fields of research are: water resources assessment and management; water resources development; engineering and technology; and socio-economics or the social sciences. Twenty-three R&D programmes have been identified and classified within the four divisions based on disciplinary approach (see Table below).

Prioritisation of R&D programmes

Categories/divisions	First priority	Second priority	Third priority
Water resources assessment and management	Water quality management	Ground water hydrology Watershed management	Surface water hydrology Climatic characteristics
Water resources development	Water supply Irrigation	Water supply for livestock Sanitation Multi-purpose projects	Rainwater harvesting Hydropower Drainage
Engineering and technology	Hydraulic structures	Choice of technology Technology management	Traditional technology Technology development Construction site and materials investigation
Socio-economics	Policy and legislative issues	Finance and economics	Institutions and stakeholders Capacity building
Total	5	8	10

The R&D programmes are prioritised to ascertain that they are in line with the current sectoral priorities of the national science and technology policy, the water resources management policy and other relevant government policies and strategies.

Prioritisation of R&D programmes

The consultants have categorised the R&D programmes into three priorities within each of the four major R&D divisions (see Table above). Accordingly, the high priority programmes include water quality, water supply, irrigation, hydraulic structures, and policy and legislative issues. Implicit within these priorities is the need to address urgent developmental needs of the sector, with particular emphasis on meeting the basic needs of the population.

It should be emphasised that all of the 23 R&D programmes are important and need to be undertaken both for their own significance and for their integrative requirements with other R&D programmes. It is anticipated that the responsible body can revise and update the prioritisation of programmes according to changing needs and circumstances. As such, the prioritisation undertaken, by the consultants, should not be taken as an absolute rather than as a reasonable starting point to focus on.

Establishment of the water research and development organisation

The overall review and analysis of the national water sector R&D capabilities, and its minimal achievements have led the consultants to the conclusion that the establishment of a water resources research and development institute is of crucial national importance. The need for such an organisation in the water sector is not only apparent, but is also becoming more urgent as sectoral objectives and planned development programmes are receiving enhanced attention by the government, the public and concerned international bodies. The increased sectoral emphasis is a direct outcome of its substantial resource base and its potential to significantly contribute towards the improvement of the desperate socio-economic status of the country.

The need for a comprehensive and integrated management of R&D in the water sector is demonstrated further by the lack of awareness about research activities undertaken and the results achieved. Co-ordination and follow-up of R&D activities in the sector is therefore critical as the existing national capability is, with a few exceptions, negligible, particularly in view of the requirement and the level of development achieved by other countries such as Egypt and India. The consultants have therefore recommended the establishment of water R&D institute with the following objectives and responsibilities.

Objectives of the Institute

The overall objective of the proposed water R&D institute is to contribute towards the implementation of the country's long-term policies and development objectives within the sector itself, and in related development programmes. The specific objectives include:

- contributing towards strengthening the national capability to undertake R&D activities in all fields of the water sector
- undertaking, and cause the undertaking of, multi-disciplinary research to resolve problems, alleviate constraints and maximise opportunities in the development of the country's resources
- taking the overall responsibility for all water sector R&D undertakings through selection and prioritisation of research, funding and co-ordination
- promoting utilisation of research results to enhance sectoral development and
- operating as depository and documentation centre for data, information and research undertakings related to the water sector.

Duties and responsibilities of the institute

The major duties and responsibilities of the envisaged R&D institute include:

- initiating and conducting R&D on water resources particularly in the fields of assessment, management, development, engineering, technology and socio-economics

- guiding, planning, prioritising, funding, co-ordinating, integrating and monitoring all R&D activities in the water sector
- studying the application of various research results carried out in other countries, and the maintenance of a collection of materials, literature and scientific data relating thereto
- disseminating research findings through reports, publications, workshops, seminars, and other appropriate media; and acting as a forum for constructive dialogue on water resources development and management
- operating as a national depository and documentation centre for all research activities that are related with water resources development
- undertaking effective training of R&D manpower, locally and abroad, as necessary, on the basis of the sub-sectoral needs and plans to produce the desired quality and quantity of skilled manpower and
- establishing and strengthening R&D co-operation with international organisations and foreign governments in such a way as to contribute to national water sector R&D capability building.

Organisational requirements of the institute

The Water R&D Institute is proposed to be an autonomous organisation having the overall responsibility and power regarding all national R&D efforts in the water sector. The organisational set-up is formulated in view of the development potential and needs of the water sector; the requirements of a R&D organisation; existing situations and intentions; the problems and constraints of the existing limited research capabilities; and formulation of conducive career structures and incentives. Four alternative organisational set-ups were considered before the elaboration of the selected one. The difference between the alternatives was in the extent of R&D activities carried out by the institute itself; and those carried out in various organisations, but co-ordinated and funded by the institute. The chosen alternative comprises the following five R&D programmes to be established directly under the institute at its initial stage of formation:

- water quality management R&D programme,
- water supply R&D programme
- irrigation R&D programme
- hydraulic structures R&D programme and
- policy and legislative issues R&D programme.

The institute foresees, in time, to develop almost all R&D capabilities within itself, while other continuing co-ordination and funding of R&D activities being undertaken by others.

Funding requirements of the institute

The funding requirements, for the establishment and subsequent operation of the R&D organisation, will be comprehensive and all encompassing. As the establishment is, largely, for new and non-existent requirements, the development will necessarily be phased over a long-term period. The short-term financial requirements of the proposed institute have been estimated to be in the order of ETB 62.9 million. This amount does not include budget allocations for actual R&D activities/projects during the five-year period. The requirement will depend on the type and number of research undertakings, which can only be determined by the institute, probably starting in the second year.

The long- and short-term programmes

The long-term (21–50 years) organisational objective is to establish a national R&D institute capable of undertaking most of the research activities of the water sector. This involves:

- a gradual build-up of institutional capability, starting with establishment of the institute, co-ordination and funding of R&D activities by existing organisations
- undertaking studies for the establishment of own capabilities, starting with selected and critical fields of research and for gradual expansion to encompass all the research fields envisaged to be handled by the central institute. Those few fields of research that remain in the centres of excellence shall be strengthened, coordinated, and funded by the Institute.

The major short-term (five years) activities of the proposed institute include:

- establishing its legal and physical framework
- establishing linkages with relevant national and international organisations for technical co-operation and funding
- undertaking R&D activities, both through its own programmes and through existing centres in the various organisations
- co-ordinating and funding of all R&D activities in the water sector
- preparatory works to construct the institute's headquarters
- undertaking organisational matters including staffing, funding, collection of information and data and
- working the details of the institute's management, administrative and financial systems including manuals and guidelines.

The institute will have to start its short-term activities in rented premises, until it builds its own headquarters complex.

Conclusions

The activities that have been carried out towards building capacity in water resources management R&D in Ethiopia are encouraging. The consultancy study has evaluated the prevailing situation and clearly indicated the way forward. The logical next step is the implementation of the results of the study as soon as possible. It is strongly recommended that all current and future bilateral and multilateral co-operations in the area of water management R&D should focus on building the organisational, infrastructural, and manpower capacities of the proposed water R&D institute. Training of the appropriate research personnel in the desired quantity and quality should in fact be at the core of such collaborations. Another important step that needs to be taken as soon as possible is defining the framework of the envisaged guidance, co-ordination and funding of the R&D activities undertaken by the various federal and regional institutions. This has, of course, to be worked out with the participation of all the stakeholders.

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Challenges and opportunities in capacity building for water resources development and research in Ethiopia: The AWTI experience

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Abstract

This paper presents the past and present activities and contributions of the Arbaminch Water Technology Institute (AWTI) towards water resources development capacity building, particularly in human resources development and research. The crucial bottlenecks for inadequate undertakings in water resources research in Ethiopia are identified as insufficient institutional set-up, inadequate skilled human resources, and insufficient finance and facilities. Approaches such as human resources capacity building combined with research-oriented teaching and sufficient emphasis for water resources research are the key issues for the way forward. Furthermore, the establishment of a water research institute addressing various sub-sectors of water needs is emphasised.

General

The Arbaminch Water Technology Institute (AWTI) was established in 1986 with the general objective of promoting the advancement of water resources development of the country.

Among the many specific objectives, the main ones are:

- providing theoretical and practical education designed for producing low, intermediate, and high level manpower in various aspects of water technology
- conducting research that can ensure the utilisation of water resources for the nation's progress and development and
- preparing, planning and conducting refresher courses in response to the specific training needs forwarded by relevant water sector organisations

The programmes of the institute have undergone certain modifications now that the institute is in the state of transformation to a university.

The future objectives and missions of the institute as a full-fledged university (i.e. Arbaminch University (AMU), which is under articulation), include: focusing on technical subjects in training and educating the manpower needs among others in water technology, engineering, applied sciences and business and management, which have high relevance for capacity building programmes in Ethiopia.

The AWTI contribution in capacity building

Although the institute will in future grow to a university level, it will continue and retain its unique set-up in eastern Africa as a water technology institute. Since 2001, the institute has opened additional water related programmes in Meteorology in BSc degree and advanced diploma levels, and Hydraulic/Hydropower and Irrigation Engineering in postgraduate programmes.

Since its establishment, the institute has trained a substantial number of professionals and skilled manpower, which would serve the water sector and conduct a number of research projects. The alumni have found wide acceptance within the country and abroad. Table 1 shows the achievements in the number of graduates who are trained at AWTI to date, which shows a total of 1371 engineers and aid engineers of which over 95% are related to the water sector development. Furthermore, there are over 1100 admitted students in water related fields at AWTI.

In addition, AWTI has contributed significantly in training water and related technicians serving in the country. In this regard, in about 22 short-term courses leading to certificates training and refresher programmes, about 1285 people are trained for a period of three to nine months.

Water resources research challenges in Ethiopia

Major drawbacks

Water resources research in Ethiopia is not adequately addressed, though there is tremendous need for it. Research is a vital tool for the exploitation of sustainable water resources. The necessities and preconditions are not set for water resources research to be effectively conducted for meaningful contribution in the sector. Among the necessary requirements are: institutional capacity, financial, human resources and facilities.

Institutional arrangement

- until recently the water sector in general was not given adequate emphasis and did not mature institutionally to attain the status it deserved
- the sector arrangement was not stable, and institutional arrangements within the sector have not been permanently established
- almost no regard was given to research:
  - there is no establishment within institutions such as the then Water Resources Commission/Natural Resources and Environmental Protection or the existing

Ministry of Water Resources. The office of Research and Publication in Arbaminch Water Technology Institute has no financial resources of its own.

– there is no independent institute of research for the water sector

- whatever existed as research are results from study documents geared towards project development or *ad hoc* or sporadic research conducted individually or institutionally mainly focusing on something else such as education and training.

Table 1. *Number of students, by discipline, who graduated from the Arbaminch Water Technology Institute (AWTI).*

Field of study	Period since first graduation	No. of graduates
Degree		
Hydraulic Engineering	1991–1995, 1998–2001	231
Irrigation Engineering	1991–1995, 1998–2001	179
Sanitary Engineering	1992–1995	65
Water Resources Engineering	1996–1998	106
Civil Engineering	2001	39
Electrical Engineering	2001	17
Mechanical Engineering	2001	20
Total		657
Advanced diploma		
Irrigation and Drainage		41
Water Supply and Sewerage		165
Hydraulic Engineering		156
Irrigation Engineering		47
Sanitary Engineering		75
Water Resources Engineering		26
Civil Engineering	2001	27
Building Technology	2001	41
Total		578
Diploma		
Hydrology Technician	1988–1990	52
Water Laboratory Technician	1988–1990	39
Soil Laboratory Technician	1988–1990	45
Total		136
Grand Total		1371

Financial resources

The financial resources for water resources research purposes in Ethiopia are usually obtained through either the Ethiopian Science and Technology Commission (ESTC) on the Ethiopian Government side, or from non-governmental organisations (NGOs). The other sources, which might be available, are not directly accessible to researchers.

Human resources

Human resources for the purpose of research is not adequately developed and organised. Those institutions like AWTI have no adequate manpower to cover all the teaching, training and research activities. There is always a tendency to provide research a last priority, thus, research suffers as a consequence.

Facilities

Research facilities needed for the purpose of applied research are not established in a given centre. Research facilities like physical modelling facilities, numerical modelling facilities etc. would be needed. Those institutions, established with relevance to water, have serious deficiency not only in faculties but also in facilities and infrastructure to competitively undertake research.

Thus, to undertake a meaningful research contributing towards a water resource development, the above major drawbacks need to be addressed. It is important to mention here that currently there is enough recognition for the water resource sector in Ethiopia. For example, water is considered as a third important pillar for the Agricultural Development Led Industrialisation (ADLI) strategy of the country, next to labour and land. There are also many other useful policy statements relevant to research and development like that included in the Water Resources Management Policy and ESTC Priority Programmes.

The need for water resources research

While on the one hand Ethiopia is a water tower of Africa, it is also a drought affected and water scarce country. Water is indeed the most important resource that needs to be researched, developed and utilised for the well-being of the Ethiopian people and to speed up socio-economic development.

Water resource has positive and negative roles. Positively it can be used for drinking, irrigation, hydropower etc. Water can also negatively influence socio-economic development in the form of flood, erosion, sedimentation etc. To appropriately utilise water means to enhance the positive and minimise the negative roles of water. To utilise water in a sustainable manner, it is necessary to understand the quantity and quality in space and time through studies and research and technological, financial and human resource potential.

In Ethiopia, since there is no established research endeavours contributing towards sustainable use of the water resources, it is high time to move ahead and give due emphasis for water resources research.

Research and dissemination activities in AWTI

General

Although highly imbalanced by the teaching need, there is a strong interest in AWTI to conduct research. There are some completed research projects mainly focused on the southern part of Ethiopia. These outcomes including other research outputs are disseminated through a yearly symposium on 'Sustainable water resources development in Ethiopia'. This symposium is now in its seventh cycle. Proceedings of the previous workshops can be obtained from AWTI.

ESTC and the German Development Cooperation (GTZ) mainly support the research activities conducted in AWTI. Almost all of the sponsorships are not with earmarked budget but with competitive application. Most of the research undertakings are also geared with research based human resource capacity building and research-oriented teaching in collaboration with partner universities abroad.

To look into the research activities in AWTI, the following few paragraphs show an example of group research activities undertaken with the support from GTZ. The joint title of this group research can be described as 'Abaya and Chamo basin water resources research'. The research has got a number of components (Figure 1).

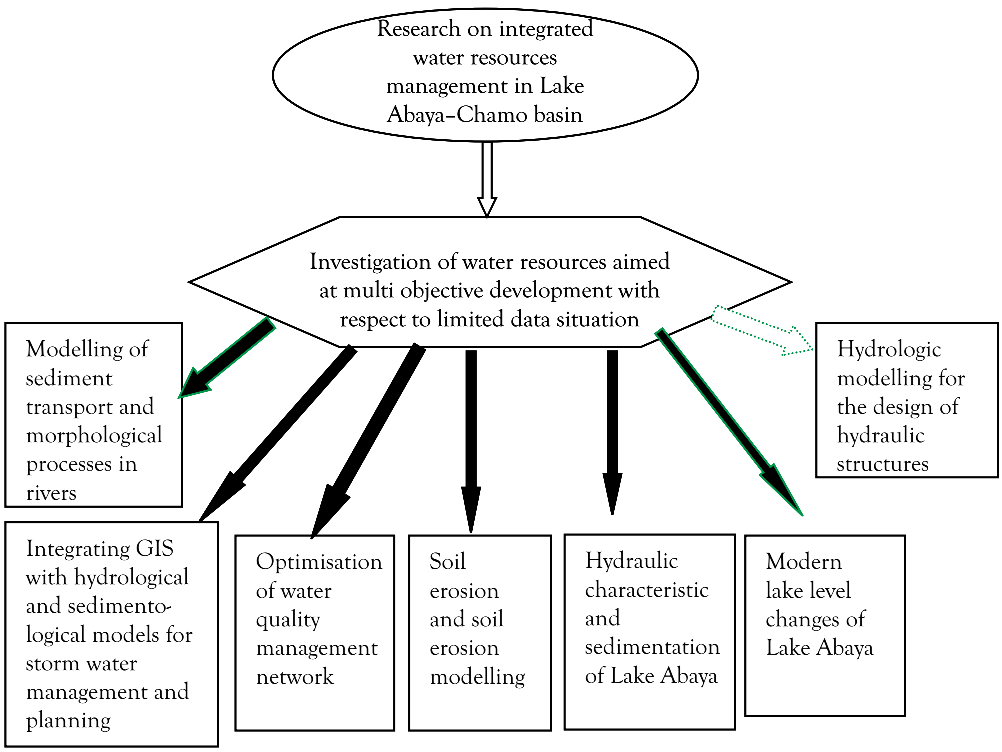

Figure 1. *Ongoing research projects (in rectangles) based on the initial concept and completed project entitled 'Investigation of water resources aimed at multi-objective development with respect to limited data situation'.*

Results of Abaya–Chamo basin research

The Abaya–Chamo lakes drainage system, physical characteristics, meteorological and hydrological data, water use information, potential information, interaction of nature and man etc. were not known or not put together in a systematic manner usable to any meaningful purposes such as development or research. Figure 1 shows the conclusion of the first investigation, and what has been identified as possible research areas.

Systematic and appropriate methodologies are followed and results in water resource assessment under limited data situation are obtained. The outcome helps to comprehensively understand the water resources, assess the available potentials and design projects whereby the use of this vital resource can be enhanced and impacts can be evaluated. These have been undertaken by using the Abaya and Chamo lakes drainage region, which is the sub-basin of the Ethiopian Rift Valley lakes basin, as a case study (Figure 2). The assessment started from basic identification of the rivers and drainage system.

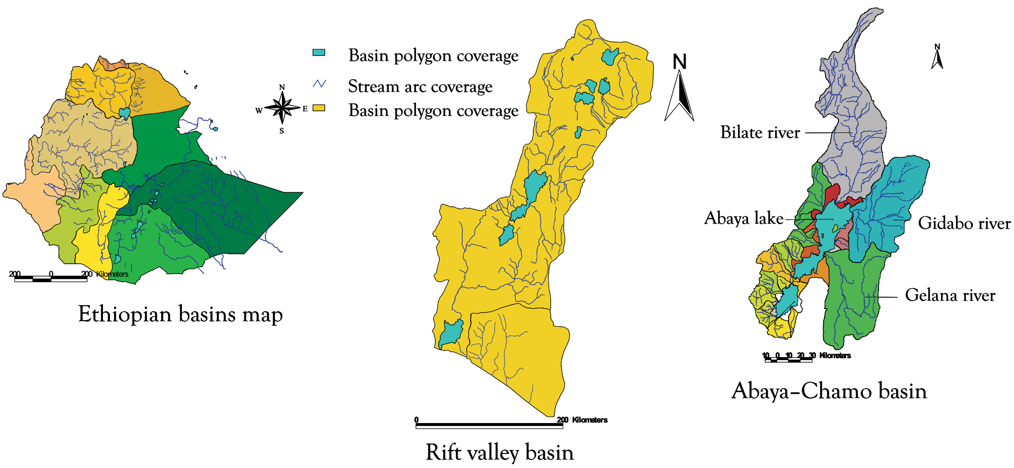

Figure 2. *The Abaya and Chamo Lakes drainage region.*

The region has been modelled using the geographic information system (GIS) and hydrologic model. Subdivision of the drainage areas into sub-basins/watersheds enabled identification of gauged and ungauged sites and thereby derivation of detailed physical parameters, which can be used as inputs to various hydrologic and hydraulic modelling. The basic development of the drainage area under GIS enabled easy addition of layers for updating and management of additional water resources data and analysed information. Using echo-sounder and Global Positioning System (GPS) both Abaya and Chamo lakes have been surveyed. Through transferring the data into digital form, various morphometric characteristics and water resources capacity curves of the lakes have been derived for the first time.

Using the collected and compiled data, spatial distributions of parameters such as rainfall and temperature elevation are developed. Homogenous regions based on rainfall have been identified. Evaluation of simplified relationship of rainfall and runoff provided inadequate basis for runoff estimation. A new conceptual, two-parameter, rainfall–evaporation–soil moisture–runoff–monthly water balance model is developed, calibrated and evaluated. The model is particularly useful for simulating runoff in cases of limited hydrometeorological and physical data and where climatic conditions lead to large rainfall variations. The results of both calibration and validation show that the model performs quite well, and is employed to generate runoff for ungauged areas and extension of runoff data.

Various procedures and methodologies are derived or adopted to estimate parameters in assessment of demand and potential and design of water projects. These include estimation of expected runoff, its reliability and methods of its control; regional flood growth curves which can be used to estimate magnitude of flood for small structures in the region; expected water demands in drinking water supply and irrigation; and general identification of irrigation and hydropower sites. Through developing a general lake/reservoir water balance model, simulation of the lakes' water level and other time varying parameters (such as area and volume) are made possible. The model is used in assessment of various scenarios and impacts of various existing and future uses and sediment inflow conditions. Furthermore, based on the prevailing conditions suggestions are highlighted how to reverse the current deteriorating situations.

The adopted or developed underlying theories and obtained results could be applied to other areas. Due to the fact that data are limited, the results have characters of assessment. However, the results show clearly the sensitivity and vulnerability of the entire system. Developed results provide wide understanding of the water resources system, the availability of potentials, certain guidelines for the execution of projects, how impacts can be evaluated, how urgently proper management system are needed and have to be developed. Furthermore, the results of this research have strongly indicated the need for further research and already founded basis for certain new research projects as schematised in Figure 1.

The way forward and conclusion

In looking forward, water resources research in Ethiopia, which enhances development of the country, should be given recognition. Sustainable development towards food and water security can only be achieved through proper control and utilisation of water resource whose technicality is supported through applied research, in combination with land, human and financial resources. As can be seen in Figure 3, the rivers of Ethiopia are having large flow volume throughout the year. To make use of water for development, water distribution should be evened out temporally.

Sustainable and judicious development of the water resource of Ethiopia demand, among other things, good scientific and technical capabilities which help to curb a number of problems related to using the available water resources potential.

Water resources development that is not sustainable is ill planned. Fresh water resources are scarce and finite. Consequently, there are many ways to jeopardise the future use of water, either by over-exploitation or destroying resources. Besides physical aspects of

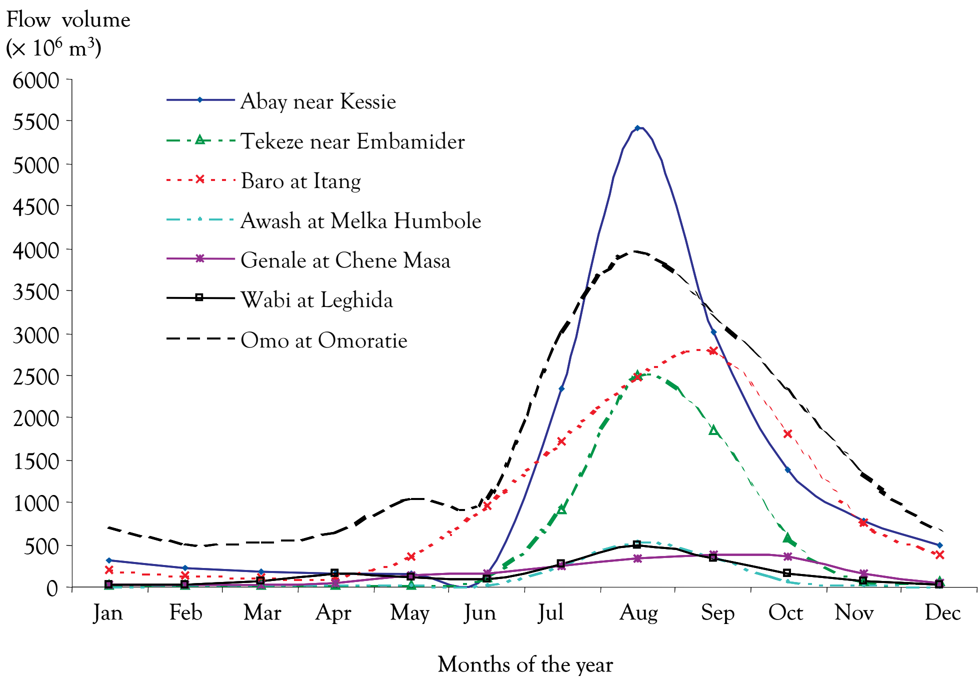

Figure 3. *Average monthly flow of some major Ethiopia rivers.*

sustainability, there are social, financial and institutional aspects. Sustainability can be defined as:

- technical sustainability (balanced demand and supply)
- financial sustainability (cost recovery)
- social sustainability (stability of population, demand and willingness to pay)
- economic sustainability (sustaining economic development or welfare and production), institutional sustainability (capacity to plan, manage and operate the system) and
- environmental sustainability (no long-term negative or irreversible effects).

Such aspects could be checked and controlled through study and research.

Although it is imbalanced and erratic in its spatial and temporal distribution, Ethiopia is blessed with ample amount of water resources that can be developed and utilised for the wellbeing of the nation and its society. It is, however, unfortunate that this resource is not yet exploited to the required level to secure the need for clean water, the demand for food, the needs to provide the energy supply to enhance industrial growth and protect the balance of deteriorating environment. In general, the ability in Ethiopia to use and enhance the positive role of water and reducing the negative impacts has been very limited.

Today, the water sector has been taken as one of the top priorities by the government. The sector strategy has also identified goals to be achieved in the near future to register results. The endeavours should, therefore, be supplemented through appropriate research, sustained through financial, manpower, and institutional and technical facilities.

Comparative advantages and research interest areas of the Department of Civil Engineering, Addis Ababa University

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Summary

The Department of Civil Engineering (DCE) was established in 1955 as part of the College of Engineering. To date more than 1700 students graduated with a BSc degree in civil engineering, and more than 45 students with an MSc degree specialising in structure, hydraulic engineering and geotechnical engineering.

Currently the department runs a BSc degree programme in civil engineering (with 237 students already in the 3rd, 4th and 5th years), and three MSc programmes in the areas of hydraulic engineering (11 students), geotechnical engineering (26 students), and structural engineering (20 students).

The department has a very strong staff in the water sector. Out of 18 instructors with PhDs, 8 are in the water sector creating a good composition in the hydrology, irrigation, hydropower, water resources engineering, sanitary engineering, hydraulic engineering areas.

The department is planning to launch two new MSc programmes in:

(1) Road and transportation engineering and,

(2) Construction technology and management.

Current activities of the department related to the water sector

Research

Currently the department runs research in integrated water resources development using a case catchment area of about 200 km^2 near Addis Ababa. The research project has three components: the first is soil erosion and sedimentation study, the second is the study on surface and groundwater resources assessment, and the third is a study on sanitation and water supply.

Training

There is also a work-in-progress to open a new department in water and environmental engineering, which envisaged running a BSc programme in water and environmental engineering and three MSc programmes in:
(1) Irrigation engineering
(2) Hydropower engineering and
(3) Sanitary and environmental engineering.

Historical background

The Department of Civil Engineering was established in 1955 as part of the College of Engineering. In 1961 the College of Engineering (the current Faculty of Technology) came under the central administration of the University College of Addis Ababa (UCAA) later named Haile Selassie I University (HSIU), and currently known as the Addis Ababa University (AAU). The department was first located in the premises of the Technical School at Mexico Square and moved to Arat Kilo Science Faculty in 1965. In 1969, it was transferred to its present location around the Amest Kilo area. In 47 years of the department's endeavours, more than 1700 undergraduate and 45 postgraduate students have obtained their BSc and MSc degrees in civil engineering respectively.

Programmes of the department

Educational programmes

The department provides a variety of courses, which can be studied either in a full time five-year regular day programme or in an eight-year continuing education (evening) programme leading toward a BSc degree in civil engineering. A five-year evening programme is also provided leading to an advanced diploma in civil engineering.

Moreover, the department offers a two-year full-time postgraduate programme leading to an MSc degree in geotechnical, hydraulic, and structural engineering. Preparations have been finalised to launch MSc programmes in road and transportation engineering and construction technology and management.

Research activities

Research is carried out in the department both in groups and individually. Major research interests of the staff members are the following:

Rainfall-runoff modelling
- groundwater modelling
- application of GIS in hydrology and water resources

- sediment transport mechanisms and modelling of erosion in watersheds
- water quality modelling
- performance of concrete
- concrete mix design using ordinary Portland cement
- precast slab-beam system
- improvement of quality of blocks
- management in construction
- structural design and optimisation
- fire safety for buildings
- low-cost housing
- dynamic soil-structure interaction
- reinforced-earth technology
- preparation of design aids for hollow reinforced concrete sections

Recently completed projects include:

- determination of optimum operating policy for Koka dam, Ethiopia
- use of scoria for the preparation of structural concrete
- use of geotextiles for stabilising soils
- evaluation of approximate methods for the analysis and design of columns under biaxial bending
- establishment of the Intel Developer Forum (IDF) curves for northern Ethiopia.

Moreover, academic staff members prepare teaching materials and textbooks for the various civil engineering courses offered in the department.

Facilities

The northern campus of the Faculty of Technology accommodates about 800 students. The Department of Civil Engineering shares the available facility with other departments of the faculty.

Laboratories: The department has laboratories for soil testing, structural testing, material testing, hydraulics and hydrology, sanitary, highway and surveying. These laboratories are used for educational/consultancy purposes.

Computers: The department has its own computer centre with Internet connections for staff and postgraduate students. Undergraduate students share the Internet connection facility of the Faculty of Technology.

Libraries: Two libraries for general and postgraduate readings with about 15,300 volumes are found in the northern campus of the Faculty of Technology. One may consult other libraries of the AAU that consists of a Central Library (Kennedy Library) located in the main campus, other eleven specialised branch libraries, and one periodical reference library. The postgraduate library of the Faculty of Technology is also equipped with computers with Internet connections.

Staff profile

Currently, the Department of Civil Engineering has 30 academic staff on duty, of whom one is a Fulbright professor and another one is Emeritus, and one is an expatriate professor. Three academic staff members are on study leave. The department's supporting staff profile includes one secretary and six technical staff. The current (2002) department's staff qualifications and specialisations are given in Table 1.

Table 1. *A profile of the staff qualifications and specialisations of the Department of Civil Engineering (academic year 2001/2002).*

	Qualification		
Specialisation	PhD	MSc	BSc
Construction management and materials	1		1
Geotechniques	4	–	1
Hydraulic and water resources engineering	7 (2)	1	–
Road and transport engineering	1 (1)	1	1
Structural engineering	6	1	1
Sanitary and environmental engineering	2	1	1
Total	21 (3)	4	5

N.B. The value in parenthesis shows the number of staff on study leave abroad working toward the degree.

Students' admission and entertainment

Admission to the Department of Civil Engineering is very competitive, and is based on freshman and pre-engineering academic achievements.

Regular students are privileged to lodging, food and medical services. Facilities for several outdoor sports and indoor entertainment are available.

Strategic plans

General

a. upgrade and streamline the curricula of the current undergraduate and postgraduate programmes and develop new programmes relevant to the needs of the country
b. strengthen research focusing on priority sectors of national development
c. develop and offer short courses to industries on various topics
d. open other postgraduate and undergraduate programmes
e. give consultancy services to the public and private institutions.

Current activities of the department related to the water sector

Research

Currently the department conducts water related research in three main areas.

1. In integrated water resources development using a case catchment area of about 200 km^2 near Addis Ababa. The research project has three components: the first is soil erosion and sedimentation study, the second is the study on surface and groundwater resources assessment, and the third is the study on sanitation and water supply (rural and urban). The research teams have established six-soil erosion surface runoff measuring stations in the watershed of the Beresa River.
2. Study of the flow characteristics of selected rivers in Ethiopia
3. Study in IDF curve establishment for southern Ethiopia
4. Flow estimation for ungauged rivers.

Training

There is also a work-in-progress to open a new department in water and environmental engineering which envisaged to run one BSc programme in water and environmental engineering and three MSc programmes in irrigation engineering, hydropower engineering and sanitary and environmental engineering.

Comparative advantages of the department

The comparative advantages of the department are: (1) its highly qualified and experienced academic staff who know the country's problems very well, and (2) research experiences through currently running research projects especially in integrated water resources development on an experimental watershed.

Research interest areas on short- and long-term basis:

1. micro scale—household/community and farm-level integrated water and land resource development through:
   - integrated micro watershed soil conservation (reducing soil erosion and enhancing soil moisture)
   - water harvesting (hydrology and technology)
   - adaptation and use of low-cost (affordable) micro-irrigation technologies including gravity drip irrigation system (for vegetable, fruits and crop production).
2. medium scale—Integrated watershed and natural resource management

- flood forecasting
- study on irrigation and drainage scheme design and management
- water harvesting for small-scale irrigation and water supply for pastoral areas

3. large scale—River basin management including
   - application of decision-support tools for water management
   - drought and flood forecasting
   - climate variability and its implications for long-term productivity
   - design and management of large-scale irrigation schemes and other major water infrastructure.

Conclusion

The Department of Civil Engineering has a long-time experience in research and teaching. It currently runs a number of research projects. In the water sector, currently the department conducts research on integrated water resources development on selected case watershed, on IDF curve establishment for the country, and on monthly flow estimation for un-gauged watersheds.

There is also a plan to open different new departments in water and environmental engineering at undergraduate and postgraduate levels.

The department is also planning to conduct joint research on household/community and farm-level integrated water and land resource development.

Overview of the Ethiopian Rainwater Harvesting Association (ERHA)

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Background

The global concern

Water is a finite and limited resource upon which human well-being and socio-economic development depend. Given its limited availability and importance, efficient and effective use of water resources is necessary for sustainable economic and social development. Access to water of adequate quality and quantity is a fundamental human need and recognised as a basic human right.

Water and water development are irretrievably connected with land use management, rural and urban settlements, and agricultural and industrial development. This calls for the necessity to integrate water management with these sectors in ways which are to the best interests of a nation and its people. Such integrated water management are, in turn, most readily achieved by recognising the need for efficient management at the lowest appropriate level, and that water development decisions are best made in acknowledgement of the real value of the water (UNDP 1990; DANIDA 1991; ICWE 1992).

Freshwater resources have been dwindling over the years, both in terms of quality and quantity, while the demand for high quality water has been steadily increasing. Studies carried out on a global basis indicate that only a small percentage of the available water is of good enough quality for human use. As an element of social and industrial development, water use has increased dramatically in importance. Thus, not only do we have increased water use due to an increase in population size but there is also an increased importance of water as a key determinant of development. In the past fifty years, the world's population has doubled, as did the per capita water consumption rate from about 400 m^3/year to about 800 m^3/year (Engelman and Le Roy 1993).

The countries of Africa, however, have been experiencing an ever-growing pressure on their available water resources, with increasing demand and costs for agricultural, domestic and industrial consumption. Of the 19 countries around the world currently classified as water-stressed, more are in Africa than in any other continent. In the African context, natural occurrences of hazards such as drought, desertification, and climate change and the influences of human activities like agriculture, population growth, industrial development, and land use changes are considered to constitute the major causes of the continuing deterioration of freshwater resources. These pressures have caused both environmental deterioration (including pollution of freshwater systems) and overexploitation of important water catchments, resulting in lowered groundwater levels.

Falkenmark et al. (1990) have proposed a water scarcity index based on an approximate minimum level of water required per capita to maintain an adequate quality of life in a moderately developed country. One hundred litres per person per day is considered the minimum for basic household needs to maintain good health in this index. The experience of moderately developed and water efficient countries shows that roughly 5 to 20 times this amount is needed to satisfy the requirements of agriculture, industry and energy production. On the basis of these premises, a country whose renewable freshwater resource availability on an annual per capita basis exceeds 1700 m^3 will suffer only occasional or local water shortages. When freshwater availability falls below 1000 m^3/person per year, countries are likely to experience a chronic water scarcity in which lack of water begins to hamper economic development and human health and well-being. When renewable water supplies fall below 500 m^3/person per year, countries will be likely to experience absolute scarcity. Using Falkenmark's definition, the situation in African countries with regard to water scarcity shows that six African countries were already in a position of water scarcity or water stress in 1990. This will increase to 16 by 2025. Of 20 African countries that have faced food emergencies in recent years, half are either stressed by water shortages or are projected to fall into the stress category by 2025 (Engelman and Le Roy 1993).

Water stress has several repercussions. Socially, human health is at risk, and water-related conflicts are imminent. Economically, the cost of production and delivery of a unit quantity of water has escalated, thus diverting investments from other productive areas. Environmentally, sustainability of the ecological systems is threatened by overexploitation or pollution. Some water-related problems are local, but others are regional. Most of the water systems in Africa that are able to endure marked seasonality in climate are international, while local water sources are generally prone to drought. Because nearly two-thirds of the continent is arid to semi-arid, poverty and insufficient agricultural production put pressure on freshwater management almost across the continent. A large proportion of Africa's population is affected by water shortages for domestic use.

Currently, responses to water stress risks range from traditional coping strategies practised by individual families to global initiatives of networking, discussion forums, research and training. International organisations have played a major part in catalysing development in the water-resource sector, creating awareness and focusing sharply on the problems and challenges in the sector by contributing funds; providing technical assistance and training; and facilitating research, networking, and information dissemination. In Africa, enhanced awareness of the problems, challenges, and opportunities in the sector have been accomplished to some extent through international conferences, from which workshop proceedings, protocols and binding statements have been produced to guide efforts of mitigating water scarcity.

According to UNEP-IETC (1998), some of the key water resource management issues on which contemporary research and development endeavours to address the prevailing problems have been focused are:

- identifying models for alternative technical and management systems to address the need for integrating the various socio-economic activities with sustainable water use

- promoting different adaptation options at grassroots level including water-harvesting technologies and more efficient water use systems
- establishing and strengthening local, regional and global alliances among individual professionals and practitioners, interest groups and civil societies through networking and information exchange on issues that address water scarcity
- identifying and revitalising indigenous technologies and practices of traditional communities to augment their water supplies and agricultural production
- advocating and facilitating a decentralised and inter-sectoral approach to water resources management at the appropriate lower levels in line with local interests and by mobilising local resources and
- facilitating people's attitudinal and behavioural changes towards creating a greater opportunity to ensure sustainable development of resources, increase awareness, involvement and responsibility among users.

Status of water resource potentials and constraints in Ethiopia—Should we bother?

The natural resource bases of Ethiopia seem to have a potential for supporting a far greater number of the population. Ethiopia's geographic location and its natural endowment of favourable climate have provided it with a relatively higher rainfall in the region. The country's annual surface runoff is estimated at about 122 billion m^3 forming 12 major river basins, much of which are, however, carried away across the borders by trans-boundary rivers. By virtue of its mountainous topography and higher altitudes relative to the surrounding areas, Ethiopia is usually referred to as the 'water tower' of North and Eastern Africa. Only a little part of its ground water potential, estimated at 2.9 billion m^3, is exploited. Ethiopia also has an irrigation potential of about 3.5 million hectares, while its hydropower potential stands second in Africa. All these imply the availability of adequate level of water resource base which, with optimum development, is capable of providing well beyond the food, water supply, energy and export requirements of Ethiopia.

Nevertheless, the use of these water resources to meet the socio-economic needs of the Ethiopian people is very limited due to various constraints. The major limitation lies in the uneven distributions and mismatch of the available water resources with the agro-ecological and settlement patterns of the country. Moreover, despite Ethiopia's high aggregate annual rainfall, it falls either too early or too late with a characteristic high intra- and inter-annual variation in quantity and in terms of the spatial and temporal distributions of the seasonal rainfall.

Annual rainfall in the country ranges between 2700 mms in the south-western highlands and less than 200 mms in some parts of the northern and south-eastern lowlands with a further decrease to 100 mm in the north-eastern lowlands. The southern, central, eastern and southern highlands of the country have a bi-modal rainfall pattern while the south-western and eastern areas are characterised by a mono-modal rainfall. Ethiopia has five major agro-climatic zones, which are broadly defined on the basis of altitude ranges, viz.

Bereha, Kolla, Weyna-dega, Dega and *Wurch*. Because of the favourable climate and absence of many tropical diseases, the highlands of Ethiopia are favoured for settlement. The Ethiopian highlands (areas above 1500 metres above sea level) harbour about 88% of the human and 65% of the livestock population.

As the population density in the highland areas continued to increase more and more marginal lands were put under cultivation which eventually resulted in the severe degradation of the agro-ecological resource base and declining agricultural production. Consequently, population expansion increased towards the extensive lowland (arid and semi-arid) areas. Unfortunately, these areas are usually constrained by, among other things, shortage of rainfall for optimum agricultural production. This calls for the use of suitable technologies for improved and sustainable agricultural production (MOA 2001). Available information indicates that nearly 70% of the total arable land in Ethiopia receives an annual rainfall of less than 750 mm. The areas with an annual rainfall of 500–750 mm are believed to support optimum levels of agricultural activities, if the annual rainfall distribution is undisturbed and proper land management is applied. As of late, however, the annual rainfall distribution of most parts of Ethiopia, including the highlands, is not only lacking in uniformity but also highly unpredictable in terms of inter-annual variations. Therefore, overcoming the limitations of these arid and semi-arid areas and making good use of the vast agricultural potential under the Ethiopian context is a necessity rather than a choice, which requires appropriate intervention to address the prevailing constraints.

Research findings and practices in many other countries and traditional farming practices suggest possibilities for making good use of areas with an annual rainfall as low as 200 mm. This is achieved through the application of different technologies that can improve the efficiency of moisture use which, if used at the right setting, can improve situations. These include, among other things, improved water control and rainwater harvesting. For the risk-prone areas such as those affected by recurrent drought, the main opportunities for improving water use include small-scale irrigation, rainwater harvesting and, above all, better use of available moisture in the rainfed farming systems on which the bulk of farmers continue to depend.

Rainwater harvesting, in a broad sense, is the collection of the raindrops/runoff for domestic consumption and/or food production purposes, which will otherwise cause soil erosion. It could also be described as an act of maximising the use of the available rainfall by applying different techniques. In fact, rainwater harvesting practices and their recognition as alternative options to supplement other water sources is not new in Ethiopia.

The history of rainwater harvesting practices in Ethiopia dates back as early as 560 BC, during the Axumite Kingdom. In those days, rainwater was harvested and stored in ponds for agriculture and water supply purposes, which are evidenced with documented literature and visual observations on the remains of ponds that were once used for irrigation during that period. Even these days, there are several traditional rainwater-harvesting technologies in Ethiopia, which have been used by communities in areas of water shortage. For many traditional communities in rural areas where natural sources of water are lacking, collection of rainwater from pits on rock outcrops and excavated ponds are common practices. In many semi-arid lowland areas of Ethiopia, where rainfall is not adequate for crop growth, farmers use runoff irrigation as a source of life-saving irrigation supplies.

The promotion and application of rainwater-harvesting techniques as alternative interventions to address water scarcity in Ethiopia was started through government-initiated soil and water conservation programmes. It was started as a response to the 1971–74 drought with the introduction of food-for-work (FFW) programmes, which were intended to generate employment opportunities to the people affected by the drought. The earlier rainwater harvesting activities included, among others, construction of ponds, micro-dams, bunds, and terraces in most drought-affected areas in Tigray, Wello and Hararghe regions (Kebede 1995). Non-governmental organisations (NGOs) involved in Integrated Rural Development Projects (IRDPs) and the water sector in many parts of the country also undertake rainwater-harvesting interventions. These interventions include conservation of rainwater by making use of physical structures and rainwater harvesting for domestic and irrigation purposes through pond and micro-dam construction and roof catchment schemes.

Despite the enormous potential of its natural resource bases and the development efforts being made by the various actors in the country, Ethiopia's chronic food shortages and drought-induced famines have continued to be common phenomena during the past few decades (Asmare 1998). In the last two decades in particular, Ethiopia has been a regular recipient of food aid from international aid sources. One of the latest estimates shows that about 52% of the country's population are food insecure, facing chronic and recurring disaster-induced food shortages (Dagnew 2000). According to the estimation made in 1995/96, on the whole, 45.5% of the Ethiopian population are living in absolute poverty, with a relative coverage of 47 and 33% of the rural and urban populations, respectively, (FDRE 2000). Since about 85% of the country's population dwell in the rural areas, poverty is primarily a rural phenomenon. In Ethiopia, an average of only 25% of the population is supplied with potable water which is only 19% in rural areas; while the sanitation is in much worse condition where 92% of the population do not have access to adequate sanitation facilities (NGOs on PRSP 2002).

For Ethiopia, much of whose river waters are carried away across the borders by trans-boundary rivers, the issue of augmenting the available water resources to meet the socio-economic needs of its people becomes a necessity and timely in light of two major reasons. Firstly, attainment of food security through enhancing the productivity of the agriculture sector, with a primary emphasis on building the productive capacity of the smallholder farmers, has been an overriding objective of the Government's Poverty Reduction and Food Security Strategies (FDRE 2000, 2002). In line with this, the Ministry of Agriculture (MOA) has been making some efforts towards the development and promotion of rainwater-harvesting technologies as part of its extension programme. Secondly, based on the current trend of population growth, by the year 2025, Ethiopia will have nearly 120 million people and the per capita water availability will drop to about 947 m^3/person per year (Falkenmark et al. 1990; UNEP/IETC 1998). This situation, according to Falkenmark's (1990) definition of water scarcity, will make Ethiopia among the eight African countries facing water scarcity by 2025 (UNEP/IETC 1998).

The above facts strongly support the need to focus on development and promotion of rainwater-harvesting technologies as one of the alternatives to enhance water availability for different uses including domestic water supply, sanitation and food production.

The need for intervention

Currently, Ethiopia's population is facing serious challenges of resource depletion and the need to survive under stress. Ethiopia has to strive to improve its health and sanitation by improving the existing low level of clean water supply coverage, whilst its natural water resources have been either deteriorated beyond repair or subjected to extreme pressure due to the ever-increasing population. Ethiopia has to feed itself by enhancing its agricultural production, yet its predominantly rainfed agriculture has been constrained by the unpredictable variability of the rainfall pattern. Obviously, this situation brings about the need to maximise the use of existing or unexploited sources of freshwater. There are many modern and traditional alternative technologies for improving the utility and augmenting the supply of water being employed in various countries, but with limited application elsewhere due to lack of information transfer among water resources managers, planners and end-users.

Given the good potential of Ethiopia's agroclimatic resources, the prevailing limitations in terms of rainfall distribution and amount could be effectively addressed if rainwater harvesting is seriously taken. Applications of rainwater-harvesting techniques, however, are constrained by the limited availability of information on the technologies and relevant traditional practices, lack of resources to conduct local specific research on the performance of available techniques and inadequate attention to avail and promote suitable extension packages to the end users. In Ethiopia, only little has emerged from research that is suitable for marginal and drought-prone areas, as few resources have been devoted to this topic, perhaps reflecting the ill perceived profitability of such investments (Ephraim 2001).

For effective and efficient use of rainwater harvesting to address domestic supply and food production, all concerned should give timely and adequate attention. Among other things, such responses include:

- facilitation of wider public involvement in dialogues and discussion forums to address the water scarcity issue which will eventually inculcate a mass transformation demonstrated through conscious actions of efficient and effective water use habits of community members
- focusing research and training initiatives as a basis for knowledge building on the different aspects of rainwater-harvesting technologies at all levels
- emphasising on information availability, accessibility and dissemination to strengthen the awareness and skills of professionals, practitioners and end-users
- integration of water resource management to the different sectoral initiatives as a cross-cutting issue and
- facilitation of an enabling environment for collaborative initiatives and partnership with the different development actors and interest groups.

The Ethiopian Rainwater Harvesting Association (ERHA)

Increased global concern about the ever-dwindling availability of freshwater resources has recognised, among other things, the need for improved management of this most precious of commodities and identification and promotion of freshwater augmentation technologies. To mitigate the threat from water scarcity, there have been extensive efforts and attention given towards rainwater-harvesting technologies because of its potential as a viable option to address the problem. Accordingly, rainwater harvesting for both domestic and food production purposes has been increasingly picking up as an alternative source of water in sub-Saharan Africa where past efforts to get water at closer locations to the needy people have been largely unsuccessful.

In connection with this, a number of associations, forums, networks and partnerships have been evolved at global, regional and country levels for the sole objective of advancing the rainwater-harvesting alternative. As of late, rainwater-harvesting associations have emerged in most southern and eastern African countries to spearhead rainwater-harvesting activities in their respective countries. The Ethiopian Rainwater Harvesting Association (ERHA) is one of such organisations established by concerned Ethiopians as an expression of their genuine interest to take part in the efforts to tackle the ever-worsening threats of water scarcity.

Establishment of ERHA

The beginning of establishing rainwater-harvesting associations in many countries of the southern and eastern Africa traces back to the efforts of the Regional Land Management Unit (RELMA) of SIDA. RELMA's different activities aimed at improved food security included rainwater harvesting as one of the opportunities to enhance food security in the region. By the emergence of the Kenyan Rainwater Association (KRA), being the first of its kind in the region, RELMA began to encourage and support expansion of the same trend in the other countries through organising experience sharing workshops, study tours and networking. A number of training workshops were conducted on issues of rainwater harvesting including those held in Arusha (Tanzania), Machakos (Kenya), Mbarara (Uganda) and Nazareth (Ethiopia). Some Ethiopian participants who had the chance to attend the Arusha workshop had helped in organising a similar workshop at Nazareth in Ethiopia.

ERHA was founded on 17 December 1999 in Addis Ababa. The founding members of ERHA, totalling about 60 in number, consisted of individuals with diverse professional backgrounds including water and related fields of engineering, agriculture, health, education, environment and other fields of natural and social sciences. Members are also employees of educational and research institutions, governmental organisations, NGOs industrial organisations and private engineering/consultancy firms. The Secretariat Office began its operation with a single staff member in a temporary office obtained from Water

Action, a local NGO working on water development, sanitation and environmental activities.

ERHA is a non-governmental, non-political and non-profit-oriented national organisation consisting of individuals with genuine interest in promotion of rainwater-harvesting technologies to address shortage of water for domestic supply and food production.

ERHA's overall objective is to contribute towards enhanced and sustainable food security status in Ethiopia through promoting feasible rainwater-harvesting technologies for sustainable development and conservation of natural resources.

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Appendix I

Ethiopian Rainwater Harvesting Association (ERHA)

Background

The problem:
- Increased global concern about the ever-dwindling availability of freshwater resources

The need:
- Improved management of water resources
- Identification and promotion of freshwater augmentation technologies
- Attention towards the potential held in rainwater harvesting technologies as a viable option to address the problem

Actions needed:

Evolvement of collective efforts for existing associations, forums, networks and partnerships at global, regional and country levels for the sole objective of advancing the rainwater-harvesting alternative.

Establishment, governance and statuary functions

ERHA was founded on 17 December 1999 and registered as a national association with the FDRE's Ministry of Justice on 5 December 2001. ERHA's Secretariat Office was established and put to function as of 1 July 2002.

Status

The Ethiopian Rainwater Harvesting Association (ERHA) is a non-governmental, non-political and non-profit-oriented national organisation consisting of individuals with genuine interest in rainwater harvesting activities at all levels.

Membership

- The founding members of ERHA, totalling about 60 in number, (comprised of individuals with diverse professional backgrounds and employed in educational and research institutions, government organisations, NGOs industrial organisations and private engineering/consultancy firms.
- Membership is open to all interested individuals who accept the Memorandum of Association of ERHA.

Governance

- ERHA is governed by its constitution that conforms to the legal requirements of national associations in Ethiopia.

Organisational structure

- The organisational structure of ERHA consists of the General Assembly, Executive Body and the Secretariat
- The General Assembly of all members is the supreme body of ERHA
- The Executive Body, consisting of eight members elected by the General Assembly for three years term of office, provides the overall leadership of the association as per the powers and duties vested in it by the General Assembly.
- The Secretariat, headed by an Executive Officer accountable to the Executive Body, carries out the day-to-day organisational functions to meet the objectives of the association.

Objective and functions of ERHA

Objective

ERHA's overall objective is to contribute towards enhanced and sustainable food security status in Ethiopia through promoting feasible rainwater-harvesting technologies for sustainable development and conservation of natural resources.

Functions

To realise its objectives, ERHA:
- facilitates/provides professional inputs needed to use rainwater harvesting for different uses
- studies and promotes different rainwater harvesting techniques and
- provides training, advisory and other technical support to governmental organisations, NGOs and end-users towards developing, adapting and disseminating rainwater-harvesting technologies.

Membership

- as per Article 4 of its Memorandum of Association, ERHA is a membership organisation comprising individual members who express a desire to co-operate and take part in the furtherance of its objectives and comply with its Constitution and Bye-laws.
- ERHA believes that its strengths and effectiveness emanates from a wider membership and diversity of backgrounds that are committed to serve the common cause it has been established for.
- new membership is open to all interested individuals who accept the Memorandum of Association of ERHA.
- membership fee for an individual member is Ethiopian Birr (ETB) 100 (about US$ 12) per annum.

Networking and partnership

- ERHA recognises the need and the mutual benefits gained from joining efforts with other organisations working towards similar objectives.
- ERHA has been actively involved in establishing networking and partnership with rainwater harvesting associations in other countries.
- currently, ERHA is a member of Southern and Eastern African Rainwater Network (SEARNet) and Greater Horn of Africa Rainwater Partnership (GHARP).
- ERHA will also continue to take the initiative towards joining existing/emerging networks and forums to strengthen its organisational capacity through mutual collaborations and exchange of information on rainwater harvesting issues.

Achievements

- established networking and partnership with rainwater harvesting associations (RWHAs) in other countries and actively involved in strengthening sub-regional initiatives towards the same
- conducted a case study on evaluation of rainwater harvesting systems in collaboration with GHARP
- completed registration process and secured legal recognition by the Ethiopian Government
- established the ERHA Secretariat Office and recruited an Executive Officer
- launched publicity activities on the establishment of its secretariat (through letters, e-mails, … etc.)
- project development and fund raising
  - GHARP Project (Case Study and individual budget to support the Secretariat Office).
  - action plan for using its allocated budget of the first year (July 2002–June 2003) of the Programme on Networking for 'Green Water' Harvesting in Eastern and Southern Africa and South Asia
  - project proposal for Sponsored Programs Development (SPD)
- members' registration and support

Constraints and challenges

- limited availability of resources (human, material and finance) to sustain and support ERHA's Secretariat Office and effectively work towards realising its intended objectives
- limited access/linkage with funding agencies
- unfavourable socio-economic conditions (e.g. low income level, small land holding size, low level of access to services, … etc.) limit the receptiveness of the potential targets/users of rainwater-harvesting technologies (i.e. farmers and urban poor)
- non-conducive policy environment (e.g. land tenure, lack of (inadequate) incentive for development of the private sector, limited governmental organisations–NGOs

collaborations, inconvenient governmental organisations regulations regarding NGO operations, ... etc.)
- underdeveloped status and low investment capacity of the Ethiopian private sector to play its part in the promotion of rainwater-harvesting technologies
- reluctance of existing funding partners to provide support for such basic needs as staff salary and office rent.

Opportunities

- increased global awareness (mainly international development organisations) of the need and the concern for enhanced management of water resources
- emerged associations, forums, networks and partnerships at global, regional and country levels and the prevailing collaborative spirit towards advancing rainwater-harvesting alternative
- latest developments in the governmental organisations and professionals in recognising rainwater harvesting as a viable option to address water shortage problems
- availability of indigenous rainwater-harvesting techniques and practices with promising potentials to address water shortage problems and
- interest of individual professionals and practitioners on issues of rainwater harvesting and to join ERHA.

Immediate plan

Strategic plan development

- developing organisational policies, guidelines and operational manuals
- developing training materials and organising training on rainwater-harvesting technologies for relevant governmental organisations and NGO staff, private companies/individuals (e.g. consultants, contractors, artisans, ... etc.)
- strengthening and expanding networking within and outside the country
- mobilising resource to implement the various intended activities (preparations of project proposals and fund raising)
- organising general assembly meeting of all ERHA members
- expanding membership into the regional states
- conducting studies on traditional rainwater-harvesting technologies in the country
- organising training on rainwater-harvesting technologies
- awareness raising and promotion activities (workshops, seminars, radio/TV programmes, newspapers, exhibitions, ... etc.)
- developing a resource centre for rainwater-harvesting technologies and provision of information services.

Policies and institutions to enhance the impact of irrigation development in mixed crop–livestock systems

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Abstract

Improvement in access to water serves as a powerful tool to increase income, diversify livelihoods and reduce vulnerability, since irrigation water creates options for extended production across the year, increases yields and outputs, and creates employment opportunities. In the mixed crop–livestock systems, irrigation can increase livestock feed supply through increased crop residues of food–feed crops, thus relieving the pressure on grazing lands and improving livestock productivity. In sub-Saharan Africa (SSA), inadequate growth in food production and increasing water scarcity pose serious challenges to future agricultural and economic development. Water for food has been identified as a critical challenge for society in the 21st century. The challenges arising due to increasing water scarcity can be addressed through two strategies: supply management (policies and actions to locate, develop, and exploit new sources of water for irrigation, household and industrial uses) and demand management (incentives and mechanisms that promote efficient use and conservation of water). Irrigation water development in Ethiopia during the imperial and military regimes focused on the development of large-scale irrigation schemes. This trend was reversed by the current government, which emphasised the development of small-scale schemes. However, the history of irrigation development has been characterised by emphasis on technical and engineering aspects, with inadequate attention accorded to policy, institutional and socio-economic factors. The lessons from the experience of irrigation development in SSA in general, and Ethiopia in particular, show that:

- a pluralistic approach to water development (which includes carefully selected and managed large-scale schemes, and farmer managed small-scale projects)
- provision of supportive legal framework and secure water rights
- development of local management and leadership capacity and
- active involvement of beneficiaries in design, implementation and management of schemes could enhance the impact of irrigation on farm household income, natural resources management, and the local and national economies.

Project engineers should continuously interact with agronomists, economists and other social scientists from the beginning to prepare a comprehensive *ex ante* assessment of irrigation projects. Moreover, policy and institutional interventions to enhance the impact of irrigation also need to be based on the objective of enhancing the contribution of irrigation to

sustainable livelihoods of rural people. This could be done by enhancing the contribution of irrigation to household asset building by strengthening market access, promoting high-value crops, and improving systems for providing extension and technical support to smallholder irrigation. The best place to start perhaps is to ensure access to farm inputs and markets.

Introduction

Water plays a critical role in the sustainable livelihoods of rural people. Improvement in access to water serves as a powerful tool to diversify livelihoods and reduce vulnerability for small producers, since irrigation water creates options for extended production across the year, increases yields and outputs, and creates employment opportunities. Increased household income may be spent locally thus helping to stimulate the rural economy. Participation in water users associations (WUA) widens social networks and empowers people, thus facilitating the creation of social capital.

In mixed crop–livestock systems, irrigation can increase livestock feed supply through increased crop residues of food–feed crops, thus relieving the pressure on grazing lands. Irrigation can also increase the productivity of the grazing lands themselves if water is used for producing feed directly, thus perhaps allowing crop residues to return to the soil to maintain soil fertility. Livestock are important assets and sources of cash income of the rural people, especially the rural poor. Improved feed availability increases the productivity of livestock, thus improving household income.

During the 20th century, human population tripled and water use increased six-fold, mostly for agricultural use. Agricultural productivity has also risen sharply in recent decades due to higher yielding varieties, increased fertiliser use, and major investments in water resources infrastructure. Investment in many billions of dollars in irrigation infrastructure has been the key component of the Green Revolution.

Agriculture today accounts for most of the water withdrawals,[1] and accounts for about 80% or more of water withdrawals in developing countries (Cai et al. 2001). As populations continue to grow further, the demand for agricultural water will increase and irrigation will be required to provide increasing share of total food production to meet the growing food demand (Rosegrant and Ringler 1998).

In SSA, inadequate growth in food production and increasing water scarcity pose serious challenges to future agricultural and economic development. Moreover, semi-arid and arid areas are home to about one-sixth of the world's population. Inadequate water is the principal cause of poverty in these areas. Water demand for domestic and industrial uses is also projected to grow even faster than agricultural water demand, especially in developing countries (Shiklomanov 1998; Rosegrant et al. 1999). Accordingly, water for food has been identified as a critical challenge for society in the 21st century.

However, water scarcity is not necessarily caused by inadequate rainfall, but by lack of conservation, and sustainable management and use of the available water. Even in the

1. A distinction can be drawn between water withdrawal and water consumption. Water withdrawal refers to water removed from a source, some of which may be returned to it and reused. Water consumption refers to the water withdrawn from the source and actually consumed or lost to seepage, contamination, or a 'sink' where it cannot be economically reused.

so-called dry regions, rainwater is available in abundance. For example, the International Water Management Institute (IWMI) estimates that the total renewable water resources in SSA are about 4000 km^3 per year. However, most of it evaporates or flows into saline sinks before it is put into beneficial use, mainly due to the difficulty posed by the nature of rainfall. The rain is very poorly distributed in both spatial and temporal terms. The critical challenge is, therefore, how to deal with the poor distribution of rainwater leading to short periods of too much water and flooding, and long periods of too little water. There is a need for the development, adaptation and application of innovative technologies and management strategies for more efficient conservation and use of rainwater, surface and groundwater.

The challenges arising due to increasing water scarcity can be addressed through two strategies: supply management (policies and actions to locate, develop and exploit new sources of water for irrigation, household and industrial uses) and demand management (incentives and mechanisms that promote efficient use and conservation of water).[2]

In Ethiopia, despite an estimated potential of 1–3.5 million hectares[3] of irrigable land, only about 5–10% is currently estimated to be under irrigation. Modern water development in Ethiopia started during the imperial regime in the 1950s, with large-scale irrigation schemes and hydro-electric power projects. The large-scale irrigation projects were intended to supply agricultural raw materials for the agro-processing sector and for export. These large-scale projects were nationalised in 1975 by the military regime, and handed over to the Ministry of State Farms. The focus of both the imperial and military regimes was on large-scale irrigation projects.

Unlike its predecessors, the Government of the Ethiopian Peoples' Revolutionary Democratic Front (EPRDF), since it assumed power in 1991, has given strong emphasis for small-scale irrigation development in the country. However, the history of irrigation development in Ethiopia has been characterised as one that considered irrigation development mainly as a technical or engineering issue. Policy, institutional and social factors were not accorded due consideration in the design, implementation and operation of irrigation projects. This paper intends to present and discuss important policy and institutional issues that need to be considered in research and capacity building for water resource development in Ethiopia.

Irrigation development in Ethiopia

There are various estimates of the irrigation potential in Ethiopia. These estimates range from 1.0 to 3.5 million hectares of irrigable land, of which between 160–190 thousand hectares (5–10%) is estimated to be currently irrigated. About 65 thousand hectares is estimated to be under traditional irrigation (MoWR 1997). Per capita irrigated area is also

2. Policies and actions that affect the quantity and quality of water at the entry point to the distribution system are classified as supply management, while actions that influence the use or management of water after this point are considered as demand management (UNDTC 1991; World Bank 1994)
3. The wider range of estimated irrigation potential indicates the lack of precise estimate of irrigable areas in the country.

estimated at about 35 m^2, compared with the world average of 450 m^2. About 352 thousand hectares of land is said to be irrigable using small-scale irrigation schemes.

Modern water development schemes are recent phenomena in Ethiopia. The imperial government in the 1950s took the first initiative in water resource development. Large-scale water development projects both for agricultural purposes and power generation were constructed at the end of the 1950s. These developments were concentrated in the Awash Valley as part of the agro-industrial enterprises development initiative. Water resource development at that time gradually expanded to the Rift Valley and the Wabi Shebele basin. The government's focus of water resource development was on large-scale and high technology water projects. At the beginning of the 1970s, about 100 thousand hectares of land was estimated to be under modern irrigation in Ethiopia, about 50% of which was located in the Awash Valley (Wetterhall 1972). During the imperial regime, the main objective of irrigation was to provide industrial crops to the growing agro-industries in the country, many of which were controlled by foreign interests, and to increase export earnings. Main crops grown were sugarcane, cotton, sesame, fruits and vegetables. Management and operational problems that resulted in salinity and water logging problems are said to have put thousands of irrigated land out of production in the Awash Valley in the 1980s after less than five years of cultivation (Mahmud 1997).

All large-scale irrigation schemes that were constructed during the imperial regime were nationalised by the military government in 1975, and handed over to the Ministry of State Farms. Most of the landlord based small-scale irrigation schemes were also handed over to producer co-operatives. The military government, like the imperial regime, was keen to develop large-scale water projects and its focus was on commercial farming. High technology water development schemes were managed by the nationalised agro-industrial and agricultural enterprises. However, little attention was given to small-scale and traditional irrigation schemes constructed and managed by smallholder farmers.

It was only during the second half of the 1980s, after the devastating famine of 1984/85 that the Derg regime started to show interest in small-scale water development schemes (MOA 1986; Tahal Consulting Engineers 1988). This interest was signalled by the establishment of the Irrigation Development Department (IDD) within the Ministry of Agriculture (MOA) in 1984, a department that was entrusted with the task of developing small-scale irrigation projects that would benefit smallholder farmers. However, IDD's performance was slow, only 35 small-scale projects were constructed between 1984 and 1991, of which about one-third were improved traditional irrigation schemes (MOA 1993). Moreover, small-scale irrigation development was considered as 'infrastructure development' and grouped with rural roads and similar construction teams, and largely staffed with engineering personnel.

Like the imperial regime, the military government's focus was on commercial farming and smallholder beneficiaries were excluded. Despite the long success of farmer-managed traditional[4] irrigation systems, the military regime destroyed this tradition by confiscating

4. In Ethiopia, there are four different types of small-scale irrigation systems used by farmers: diversion systems (diverting natural river flow), spate systems (systems that make use of occasional flood flows), spring systems (that use flows from springs) and storage systems (that store water behind dams), and lift systems (which extract water from rivers, irrigation canals reservoirs and wells). Diversion systems are probably the most common forms of small-scale irrigation systems in Ethiopia, although there may be regional variations.

them and handing them over to producers' co-operatives. The lessons from the experiences and failures of irrigation development during the imperial and military regimes indicate that a pluralistic approach to water development and active involvement of beneficiaries in the design and implementation of water development projects, and management of operational schemes could have benefited smallholders better and contributed to the national food production.

The focus on large-scale irrigation development and the neglect of small-scale schemes was reversed when the Ethiopian Peoples' Revolutionary Democratic Front (EPRDF) took power in 1991. The EPRDF government put the development of small-scale irrigation schemes and improvement of farmer-managed traditional schemes at the forefront of its water development policy. Moreover, with the creation of the Ministry of Water Resources (MoWR), there is now a unified public agency for water resources development.

In 1994, IDD was dissolved while the government's interest in small-scale irrigation remained very high, as manifested by the creation of the Regional Commissions for Sustainable Agriculture and Environmental Rehabilitation (Co-SAERs) in a number of regions. The primary mandate of the Co-SAERs has been to promote small-scale irrigation for the benefit of smallholders. However, like IDD the focus of the Co-SAERs also remained rather technical-oriented, with inadequate attention accorded to policy, socio-economic and institutional issues. However, there have been significant improvements in beneficiary participation compared with during the military regime.

In sum, irrigation development planning in Ethiopia has been beset by the emphasis on the agronomic, engineering and technical aspects of water projects, with little consideration to issues of management, beneficiary participation, availability of institutional support services such as credit, extension and input supply, and marketing. The experience of irrigation water development in the last five decades in Ethiopia suggest that several measures need to be taken to support farmer-managed small-scale irrigation projects in Ethiopia. These include enhancing and improving the efficiency of the traditional irrigation systems such as:

- improving the durability of headworks
- making simple, cheap and environmentally friendly irrigation technologies such as hand pumps and shallow tube wells available
- improving market access by building roads, price support and improving product quality
- developing appropriate extension and credit services, and input supply system and
- enhancing beneficiary participation in governance (establishment of working rules and responsibilities) and management (running the day-to-day operation of projects).

The impact of irrigation development during the last decade appears to be mixed. Based on a survey of 50 communities, 500 plots and more than 2000 plots in the highlands of Tigray in 1998/99, irrigation was found to increase the intensity of input use, especially labour, oxen, improved seeds and fertiliser (Pender and Berhanu 2002). Use of manure or compost was about 50% more likely on irrigated plots than on rainfed plots, controlling for other factors. By promoting increase in use of such inputs, irrigation contributes to increased crop production. The predicted average impact of irrigation, based on the predicted impacts of irrigation on use of inputs, was an 18% increase in crop production relative to rainfed field plots. However, the impact of irrigation on the productivity of land management practices (i.e. the effect of irrigation controlling for use of inputs and practices) was statistically insignificant. Thus the main impact of irrigation on crop production is through promoting increased intensity of farming, rather than through increased productivity of farming practices.

Similarly, in the Amhara highlands of Ethiopia, irrigation was associated with increased intensification through greater use of fertility-improving technologies (fertiliser and manure), and other purchased inputs (improved seed and pesticides), labour and draft power (Benin et al. 2002). However, the impact of irrigation on the productivity of farming practices, controlling for other factors was insignificant. The reason why irrigation failed to improve the productivity of farming practices in both the highlands of Amhara and Tigray deserves further and careful research on the technical, institutional, governance and managerial aspects of irrigation. Such an investigation could provide important guidance for policy and institutional intervention to enhance the impact of irrigation on productivity, income and the natural resource base.

Policy and institutional research issues

A comprehensive irrigation development strategy should take into account the technical requirements (e.g. equipment, spare parts, operation and maintenance), policy issues (e.g. incentives, pricing, cost recovery), and institutional issues (e.g. farmer participation and organisations, extension and credit services, marketing, governance and management of water resource). Sectoral policies affecting water development should be harmonised. There is a need to determine the appropriate mix and role of government and non-government agencies, the private sector, communities and individuals in the effort to develop, control and manage water resources. Institutional mechanisms need to be put in place to minimise transaction costs and resolve conflicts.

In many developing countries, the success of irrigation systems is highly affected by policy, institutional and social factors much more than technical issues (Beets 1990). Hence, in this section we present and discuss important policy and institutional issues of irrigation development that need to be considered in irrigation development strategies in Ethiopia.

Demand and supply management for irrigation water

To meet the challenges of increasing water scarcity, both more vigorous demand management accompanied by comprehensive water policy reform to make better use of existing supplies, and supply management involving the development and exploitation of new water supplies will be required (Rosegrant and Perez 1997). The level of economic development and the degree of water scarcity will determine the appropriate mix of supply and demand management. At the current level of development and degree of water scarcity, most SSA countries will likely be primarily concerned with water supply augmentation. However, demand management should not be ignored. With economic growth and development, the competition for water increases thus raising the value of water, and the benefit from and the role of demand management increases significantly.

Effective water demand management saves water in existing uses, increases the economic efficiency of water use, improves water quality, and promotes environmentally sustainable water use. With economic growth, a large share of water to meet new demand must come from water saved from existing uses through comprehensive reform of water policy. However, water reforms are challenged by the long-standing practices, and cultural and religious beliefs that have treated water as a free good, and by entrenched interests that benefit from the existing system of subsidies and administered allocation of water (Rosegrant and Perez 1997).

As water scarcity increases, the supply of impounded or diverted water becomes inelastic. As economies grow the demand for water delivery increases rapidly and the competition for water among the different uses increases. Externality problems that were not important with adequate water supply become increasingly important. All these factors raise the value of water and the benefits from efficient allocation of water, thus possibly shifting the likely balance of effort from supply management to demand management (Randal 1981).

Policy instruments potentially applicable for water demand management include (Bhatia et al. 1995):

1. enabling conditions, i.e. measures that modify the institutional and legal environment of water delivery and use, including reform of water distribution systems and water laws, assignment of water rights, and organisation and operation of water user associations
2. market-based incentives intended to directly influence the behaviour of water users through incentive systems to conserve on water use. These may include pricing reform, subsidy reduction, and development of water markets
3. non-market instruments, such as restriction quotas, license requirements, and pollution controls
4. direct intervention including public conservation programmes, maintenance and repair programmes, and infrastructure development.

Empirical evidence shows that farmers are price responsive in their use of irrigation water, by use of less water on a given crop, adoption of water-conserving irrigation technology, shifting of water application to more water efficient crops, and change in crop mix to higher-valued crops (Gardner 1983; Rosegrant et al. 1995). The choice between market, and non-market and administrative methods should be largely a function of which approach is more cost-effective. Research is needed to determine which approach has a relative advantage in specific country situations.

Large vs. small-scale irrigation

Failures of large-scale irrigation projects in Africa abound. Construction costs as high as US$ 40 thousand per hectare and estimated negative rates of return have been documented (Rosegrant and Perez 1997). The high costs and negative rates of returns have been primarily due to design and technical flaws, management failures, and political difficulties (Rosegrant and Perez 1997). Inability of ministry and agency headquarters to respond in time to field level problems, excessive centralisation of management taken away from farmers, poor training and skill levels, uncontrolled overhead costs and rent-seeking are some of the other reasons for the failure of large-scale irrigation schemes.

However, irrigation development in Africa has also documented successful large-scale schemes. For example, efficient management, relatively low-cost infrastructure, low operating costs, good technical design, availability of agronomically suitable crops and cropping systems were cited as factors for success of large-scale irrigation systems in Cameroon (Brown and Nooter 1992).

Since the 1980s, the widespread failures in large-scale irrigation systems have been used to advocate future investment strategies based on small-scale irrigation systems. However, failures and successes in both large- and small-scale systems have been observed in Africa. Scale as such seems to be less important than the extent to which control is operated by the farmers, and where systems are managed bureaucratically, the extent to which quality of management is maintained and equitable distribution of income among farmers is achieved. (Rosegrant and Perez 1997). Hence, it is not so much the size of the irrigation system that determines its success, but a host of institutional, physical and technical factors. Large-scale irrigation should be carefully assessed as a possibility for specific locations.

In general, small-scale systems may have advantages over large-scale systems. These advantages include that small-scale technology can be based on farmers existing knowledge; local technical, managerial and entrepreneurial skills can be used; migration or resettlement of labour is not usually required; planning can be more flexible; social infrastructure requirements are reduced; and external input requirements are lower (Underhill 1990). However, these advantages may not be realised if the mode of implementation is not right.

Hence, a pluralistic strategy of irrigation water development needs to be pursued in Africa. Large-scale projects need not be abandoned provided that they are carefully designed and implemented; they have no significant environmental problems; participation of beneficiaries in planning, operation and management is ensured; and they ensure benefits to the surrounding population. However, there appears to be a consensus that small-scale and user-based schemes have higher advantages, are less costly and more sustainable.

Direct vs. indirect investment strategies

Public investment strategies for the development of farmer-controlled small-scale irrigation schemes, including the improvement of traditional schemes, can be categorised as direct and indirect investment strategies (Coward 1986). In direct investment strategy, government agencies are directly involved, using their own budget and staff, in the design, construction, and operation of new or improved irrigation facilities on the traditional irrigation systems. These new or improved irrigation schemes will then be solely government-controlled or co-managed with the communities. In the indirect investment strategy, government agencies get involved through the provision to farmers of grants, loans and technical expertise, to implement irrigation development on works owned and controlled by individual users or group of users.

Experiences in South-East Asia indicate that the indirect approach may be superior, since it leaves ownership and management of the system with traditional groups or individuals, and often leads to complementary investment of local resources. Available evidence in Africa also indicates that the indirect approach may be a preferable option to assist farmer-controlled irrigation. In Nigeria, the successful *fadama* development programme had several characteristics of the indirect investment approach. The availability of small inexpensive petroleum pumps in the markets in Nigeria in the early 1980s enabled farmers to replace their traditional water lifting devices. Following the success of the small pumps, the government launched a National Fadama Development Project (NFDP).

Hence, high priority may need to be given to indirect investments for expansion of farmer-controlled small-scale projects, especially in areas where potential for rainfed agriculture is poor and risky. Initial grants or loans to establish economically sustainable technologies, for example, for purchasing a small tube well, may be reasonable given the absence or weakness of credit markets in much of Africa. Expansion of small-scale farmer-controlled irrigation would have the additional benefit of developing farmer experience not only with respect to the technological skills of operation, but also with respect to the economic, social and institutional aspects of implementation. However, research is needed to determine the strengths and weaknesses of the indirect investment approaches in the specific country situation in Africa and to identify the cost-effective way of implementing it.

Farmer vs. government-controlled irrigation schemes

There is much evidence that farmer-controlled small-scale irrigation has better performance than government-controlled small-scale systems. The substantial farmer-controlled small-scale irrigation sector that exists in many countries in Africa, often without government support, indicates that these systems are economically viable. Areas under farmer-controlled small-scale irrigation systems have grown rapidly over the past decades, and account for large and growing share of irrigated area in SSA (Rosegrant and Perez 1997).

Water users associations or co-operatives, or private individuals manage the small-scale farmer-controlled systems. Some of the factors that contributed to the relative success of farmer-controlled small-scale irrigation systems include:

- use of simple and low-cost technology such as small pumps
- active involvement of farmers in project design and implementation
- availability of supporting infrastructure to permit access to inputs and markets to sell surplus production and

- generation of high and timely cash returns to farmers (Brown and Nooter 1992).

Farmer-controlled schemes can be group or individual-owned. Individual schemes are owned and managed by individual owners. Private schemes are mainly small schemes that make use usually of pumps and tube wells and are operated by the owners. Technology is simple and management is less complicated. Some argue that private irrigation has good potential in Africa and governments need to provide the necessary policy environment for the expansion of private irrigation schemes.

In Asia, it is widely documented that private pump irrigation from ground and surface water bodies is far more productive and profitable relative to public irrigation systems (Kolavalli and Chicoine 1989; Dahwan 1990; Shah 1993). Several researchers have also shown that private small-scale pump irrigation (from ground and surface water sources) is much more productive than canal irrigation and is more financially viable and self-governing.

However, pump irrigation, the most adapted private irrigation, is suitable only in areas with sufficient ground water or along the banks of rivers or lakes. Unrestricted expansion of private irrigation will also lead to the depletion of aquifers. Therefore, the scope of private irrigation may be limited. Moreover, there are schemes that are better managed and operated communally. In this case, group ownership and management becomes essential.

When irrigation schemes are collectively owned, schemes that balance all costs and benefits for all people in a watershed and which provide secure water rights to beneficiaries are most likely to gain long-term support. However, since water is vital for livelihoods, water rights are the results of the interaction of state law, project regulations, religious laws and values, and local institutions and norms (Meinzen-Dick and Bakke 2000). Formal laws may not always coincide with peoples' own perceptions of water rights and the ways in which water has been managed at the local level, since property rights are only as strong as the institutions that back them up (Meinzen-Dick and Bakke 2000). Local institutions are important in translating water rights in actual access and use, since local institutions affect the implementation and enforcement of rules. In some case local institutions can modify formal laws. Hence, attention needs to be given to the mediating institutions that translate water rights (from whatever source) into actual access to water. Research is needed to understand the extent to which formal statutory laws regarding water rights are translated into practice and the role of mediating local institutions.

Poverty and irrigation

When resources become scarcer, the poor and vulnerable in society are hard hit and suffer most. Increased competition for water in agriculture and non-agricultural uses in developing countries reduces the access to water for the rural poor, especially rural women. Increased water scarcity also may lead to frequent conflict, loss of life and generally to the marginalisation of the poor and powerless in terms of access to water.

Irrigation development may benefit the poor by raising labour productivity, promoting the production of high-value crops, and the generation of farm and non-farm employment opportunities, especially when increased production stimulates the local economy through backward and forward linkages (i.e. water systems can be used as 'growth centres' where services, markets and employment are also stimulated). However, there does not seem to exist a consensus on the impact of irrigation on poverty alleviation, in the absence of targeted interventions aimed at benefiting the poor. The International Rice Research Institute (IRRI)-led research in six villages in Madha Pradesh, India, found that incidence, depth and severity of poverty were substantially lower in villages where there were irrigation compared with rainfed villages (Janaiah et al. 2000), while similar studies in Myanmar concluded that recent expansion of irrigation infrastructure in the 1990s has not increased household income due to farmers' inability to cope up with the economic and technical demands of the new rice-based technologies (Gracia et al. 2000). Hence, targeted measures to ensure that poor people are reached and gain from irrigation investments need to be on the agenda at the earliest stages of scheme development. For example, water allocation based on land size may reinforce the existing inequities in land distribution in the distribution of water and water-created wealth. Irrigation may induce land transactions as resource poor farmers may lease their land out. This may exacerbate income distribution further.

Some research results also indicate that plot location in relation to the irrigation scheme (head, middle and tail) may have implication for poverty alleviation. Moreover, irrigation usually induces changes in crop choice and poor farmers usually grow low value crops. Hence, targeted interventions to make inputs available to the poor are one option to enhance the impact of irrigation in poverty alleviation. Representation in the water users association (WUA) of the poor and women is one way to ensure that the interests of these people are considered in irrigation water decision-making. A pro-poor approach to irrigation development requires a good understanding of the relationship between water and poverty and the causes of poverty, so that strategic poverty reducing interventions can be identified.

Gender and irrigation

While playing a crucial role in many water and food related issues, women still tend to be underrepresented in the decision-making fora. Gender issues in irrigation water development need to be looked at three levels: farm/field level, association level, and leadership level (van Koppen et al. 2002). At the farm level, gender performance of irrigation projects need to address whether or not there are systematic gender-based differences categorically engrained to water rights, irrigated land and associated obligations. At the water users association[5] level, irrigation projects need to ensure that systematic gender-based differences in the participation in these associations do not exit. At the leadership level, irrigation schemes need to make sure that there are no systematic gender-based exclusions from leadership positions of irrigation management. It is important to note that the systematic gender bias at the field, water users association and leadership levels may not necessarily be the result of formal laws or institutions. Informal

5. Water users associations create formal and informal forums through which collective management of irrigation schemes are implemented.

institutions based on local culture and religion could be important sources of systematic gender bias. Social science research is required to identify systematic gender-based exclusions or biases in irrigation schemes, and devise appropriate strategies to ensure equitable representation and distribution of benefits.

Land use and management for better rainwater conservation

Rainfed agriculture produces the highest proportion (over 60%) of food crops in the world. Including livestock production, the contribution of rainfed agriculture to food and commodity production is very high. Moreover, rainwater is the only source of agricultural water for many rural poor.

Research results estimate that in many farming systems, more than 70% of the direct rain falling on crop fields is lost as non-productive evaporation or flows into sinks before plants use it. Hence, in rainfed agriculture wastage of rainwater is probably an important cause of low yields or complete crop failure more than absolute shortage of cumulative seasonal rainfall. For example, adoption of improved water conservation technologies in the Great Plains of the USA have contributed to about 45% increase in average wheat yields, compared with the contributions of improved varieties (30%) and fertiliser practices (5%).

The necessary technologies for overcoming loss of water in rainfed agriculture are soil and water conservation practices. The principal requirement is the improvement of infiltration, water holding capacity, and water uptake by plants. Conserving water on fields for better use by crops results in win–win benefits converting erosion-causing runoff into plant available soil water, and non-productive evaporation into productive transpiration.

Impact of land use and management for improved water conservation may have beneficial effects for both upstream and downstream users. Upstream users may benefit due to higher availability of water, which would otherwise be wasted as runoff. Downstream users would be benefiting through the reduction of floods, sedimentation and a more smooth flow of water throughout the year. Streams and springs may be better recharged if water is conserved upstream, but this needs research to be confirmed.

Appropriate strategies need to be identified for dealing with climatic variability and droughts, and identify the land use and management practices to reduce land-use related degradation of surface water. Additional research is also needed to identify policy, institutional and socio-economic factors that promote improved household and community land use practices for better conservation of rainwater on fields.

Collective action and water users associations/ organisations

Identification of factors that facilitate the establishment and effectiveness of collective action for irrigation development would help identify where collective action can easily be established and be effective, and where concerted effort is needed for the establishment and effectiveness of collective action. Key research issues regarding collective action for irrigation management include how people organise themselves with respect to water, what consistent and detectable influences of policies and other instruments can be deployed to modify stakeholder behaviour, and how experience in participatory research and extension and common property management be used to facilitate local organisations for water management. The best starting point perhaps is to learn from the success of traditional irrigation systems, especially from the institutional and legal aspect of water administration and management. Understanding the evolution, development and functioning of traditional water users associations should provide important insights as to how to organise and develop modern irrigation associations.

International experience with farmer irrigation management suggests that, for a successful community management of irrigation schemes, the economic and financial costs of sustainable self-management must be a small proportion of improved income, the transaction cost of the organisation must be low, and irrigation must be central to the improvement of livelihoods for a significant number of members. Developing local leadership skills for irrigation management also appears to be a key factor for successful collective irrigation management.

Conclusions and implications

Improved access to agricultural water supply plays critical role in the sustainable livelihoods of rural people, since it increases yields and outputs, facilitates diversification, reduces vulnerability and creates employment opportunities. In mixed crop–livestock systems, irrigation increases feed supply through increased crop residues of food–feed crops, which may reduce the pressure on grazing lands. Improved livestock productivity through better availability of feeds has the potential to increase household income.

With population growth, the demand for agricultural water increases and competitions with non-agricultural use intensifies. In SSA, inadequate growth in food production and increasing water scarcity pose serious challenges to agricultural and economic development in the 21st century, thus increasing the need for more efficient utilisation of water and the development of new supply sources. Both water demand and supply management will be increasingly required to mitigate the effects of water scarcity, although currently SSA countries may need to focus more on supply management.

In Ethiopia, despite an estimated potential of irrigable land ranging from 1–3.5 million hectares, only about 5–10% is estimated to be currently irrigated. Irrigation water development in Ethiopia during the imperial and military regimes focused on the development of large-scale irrigation schemes. The current government reversed this trend. However, the history of irrigation development has been characterised by emphasis on technical and engineering aspects, with inadequate attention accorded to policy, institutional and socio-economic factors.

The lessons from the experience of irrigation development in SSA in general, and in Ethiopia in particular, show that:

- a pluralistic approach to water development (which includes carefully selected and managed large-scale schemes, and farmer-managed small-scale projects)
- provision of supportive legal framework and secure water rights
- development of local management and leadership capacity and
- active involvement of beneficiaries in design, implementation and management of schemes could enhance the impact of irrigation on farm household income, natural resources management, and the local and national economies.

Project engineers should continuously interact with agronomists, economists and other social scientists right from the beginning to prepare a comprehensive *ex ante* evaluation of irrigation projects.

Moreover, policy and institutional interventions to enhance the impact of irrigation also need to be based on the objective of enhancing the wealth-creating potential of small-holder irrigated farming by strengthening market access, promoting high-value crops, and improving systems for providing extension and technical support to small-holder irrigation. The best place to start perhaps is to ensure access to farm inputs and produce markets. A wider menu of irrigation technologies need to be available for farmers to choose from, so that farmers would respond more flexibly to irrigation development opportunities.

Although public agencies may need to be directly involved in investing in selected large-scale projects, high priority needs to be given to indirect investment strategy through the provision to farmers of grants, loans and technical assistance for the development of small-scale farmer managed irrigation schemes. Such an indirect investment strategy empowers farmers by providing ownership and management of the system, and leads to complementary investment of local resources.

There does not seem to be a consensus on the impact of irrigation on poverty alleviation in the absence of targeted interventions aimed at ensuring that the poor are reached and gain from irrigation development. For example, allocation of water rights based on land size may exacerbate existing inequities in income distribution. Hence, when the objective is poverty alleviation, targeted measures to ensure that the poor and vulnerable benefit needs to be incorporated at the earlier stages of scheme development.

Gender issues are also important in irrigation water development, since often women get underrepresented in the decision-making fora. Gender issues in irrigation development need to be considered at three levels:

- field level, to ensure the allocation of water and land rights, and associated responsibilities do not involve systematic gender-based differences;
- water users association level, to ensure that there are no gender-based exclusions from participation; and
- leadership level, to ensure that equal opportunities exist for leadership positions.

In rainfed agriculture, lack of conservation and efficient use of rainwater is probably more important than absolute shortage of water in determining crop yields or total crop failure. Conserving water on fields through changes in land use and management results in a win–win benefits by converting runoff into plant available soil moisture, which would otherwise result in soil erosion or possible flooding, and non-productive evaporation into productive plant transpiration.

Understanding the factors that facilitate farmer organisations to manage irrigation water, and its effectiveness would help devise strategies to facilitate the development and effectiveness of local organisation for water management. The best starting point perhaps is to learn from the evolution, development, operation and success of traditional water users associations, to gain insights for the development of modern water management organisations.

Secure land rights are critical for farmers to invest in irrigation technologies and maintenance. Moreover, land allocation around irrigation schemes is an issue that deserves careful analysis, since it will have direct effect on income distribution. Perhaps, such land allocation programmes may need to be based on the determination of minimum land size for profitable farming. In cases where irrigation development displaces local people, compensation and resettlement provisions need to be part of the scheme development planning right from the early stages.

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Water harvesting in northern Ethiopia: Environmental, health and socio-economic impacts

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Abstract

In northern Ethiopia, water scarcity is a key factor in food security. In some areas, the water is so precious that the principle of 'irrigating the crop and not the land' is adopted in an attempt to curb rural exodus. In other areas, considerable effort is put to introduce innovative water harvesting and management systems. The introduction of small-scale irrigation using micro-dams has become an excellent option considering the hydro-climatological conditions of the region.

In Tigray, over the last 10 years, about 50 micro-dams were constructed; consequently, considerable improvements were observed in the livelihood of the rural poor. Water security brought food security. Some negative impacts are being observed especially on soil salinity and erosion. Malaria has become a growing concern in micro-dam areas with altitude lower than 2000 metres above sea level (masl).

In general, the positive and negative impacts of micro-dam water harvesting systems need to be well understood before further up-scaling. Research should focus on system design, farm hydrology, socio-economic constraints and systems transferability.

Introduction

Although several definitions of water harvesting (WH) have been suggested, Siegert (1994) gave the most encompassing definition as: '...an umbrella term describing a range of methods of collecting and conserving various forms of water originating from ephemeral water flows produced during rainstorms'. The aim of water harvesting is to mitigate the effects of temporal shortages of rain, so-called dry spells, to cover both household needs and productive use. This involves storage component and various forms of storage exist such as: micro-dams, farm ponds, subsurface dams, tanks etc.

Water scarcity is a critical issue for many developing countries in general and for those in the arid to semi-arid areas of the world in particular. It has long been understood that intensive water resource development can have a decisive role in the economic and social development of a country and in alleviating drought. Alleviating food security related to drought and famine through sustainable agriculture and environmental rehabilitation requires a short- and long-term planning of water resource development of an area.

In northern Ethiopia, in an effort to address the problems of recurrent drought, famine and food insecurity, attempts are being made to harvest runoff water in micro-dams for use both in households and small-scale irrigation schemes. It is recognised that the construction of micro-dams with proper irrigation and agronomic services will result in micro-climatic and environmental changes with positive impact on sustained productivity.

Notwithstanding the positive impacts on increased agricultural productivity and improved community welfare, the negative impacts of water resource development require constant assessment and monitoring on environmental changes.

Thus, the objectives of this paper are to present:

- the positive and negative impacts of water harvesting and
- the knowledge gap and research priorities in water harvesting.

The study area

General description

Tigray is the northernmost region of Ethiopia extending from 12°15’ to 14°50’N latitude and from 36°27’ to 39°59’E longitude. It is bound in the north by Eritrea, to the west by The Sudan and to the east and south by the Afar and Amhara regions of Ethiopia. It covers a little more than 80 thousand km^2, most of which are highlands between 1500 and 3900 metres above sea level (masl).

Tigray’s economy, like the other parts of the country, is based on plow cultivation for predominantly cereal production. The level of subsistence, except for periods of good rains, has declined radically during the past decade, with almost everything produced being consumed at the farm household level.

Tigray’s agriculture depends entirely on availability of rainfall; because of this, agricultural production is erratic, showing high temporal and spatial variability in yield. Agricultural production operates with very low modern external input, resulting in depletion of soil nutrients. Increasing loss of topsoil through erosion has exposed the region to serious environmental and ecological imbalances.

The agrarian system is pressed with a fast accelerating population growth and a high arable land to population density, which far exceeds the carrying capacity of the land. Recurrent drought, pest infestation and unfavourable climatic factors contribute to poor production performances. The inevitable result of these prevailing conditions has been a gradual and steady decline in soil and labour productivity.

A major means of rehabilitating and reconstructing the natural resource base is through water resource development. That water is the single most critical variable in Tigray’s agricultural production has been long recognised.

Sustainable agricultural and environmental rehabilitation programme

Having realised the need to have a comprehensive rural development programme, the regional government, in 1994, decided to establish a sustainable agricultural and environmental rehabilitation programme. Through this programme, water harvesting was seen as an option and hence was planned to construct 500 earthen micro-dams over 10 years to supply 200 thousand tonnes of grain equivalent enough to feed 930 thousand people who, without the project, would almost surely depend on food aid.

Of the estimated 1.2 million hectares of arable land, 95% is under rainfed cultivation. Since 1995, through the massive irrigation development, about 50 micro-dams (each with a capacity to hold about 50,000–2,000,000 m^3 of water), and 11 diversion plants have been constructed in drought prone areas giving an increase of 2000 ha of irrigated land only.

Additional impacts anticipated from the environmental rehabilitation programme were: degraded areas show signs of recovery, while millions of seedlings planted as a means to biological soil conservation will result in forest products. Availability of forage for livestock will improve sustainability. With storage and utilisation of seasonal surface runoff water, many prevailing social and economic problems should be alleviated; decreased women's burdensome and time-consuming responsibilities for fetching water and thus improve women and children welfare. Furthermore, the introduction of fisheries could improve the diet of the community and serve as a supplementary source of income to families.

Water harvesting and irrigation management

In Tigray, a major means of rehabilitating and reconstructing the natural resource base is through comprehensive water harvesting development. Thus, water security through runoff harvesting has been chosen as a strategy to curb the acute water shortage in the region.

Farmers in Tigray have been producing different crops under traditional irrigation management for a long time. The diversion of perennial streams using temporary structures during the dry season is the major means of irrigation. In addition, flood spreading using runoff water from higher altitudes and upper catchment areas is also practised. Horticultural crops and maize are the main crops grown under these irrigation schemes.

Materials and methods

A study to document the effects of micro-dam water harvesting on the socio-economic, environmental and health aspects was undertaken by Mekelle University and Tigray Region Health Bureau.

For the impact on health, 7000 children living in villages near to dams (less than 2 km radius) and away from dams (more than 2 km radius) were monitored for the incidences of malaria and schistosomiasis over three years (Tedros et al. 1999).

For the environmental impact assessment, salinity of soil and irrigation water was monitored over four years (Mitiku and Sorsa 2002). A survey was also undertaken through semi-structured questionnaires to analyse the perception of farmers to land degradation (as a result of catchment erosion and subsequent sedimentation in reservoirs). In addition, studies reveal that a reservoir water quality is deteriorated following biological contaminants.

For the socio-economic impact assessment, a study was undertaken using semi-structured questionnaire to see the economic returns of water harvesting in small dams used for irrigation (Mintesinot 2002).

Results and discussion

Environmental impact assessment

Most dams were constructed without prior rehabilitation of the catchments. Thus, one serious environmental problem is erosion of catchments leading to increased sedimentation, which reduces the storage capacity of the reservoirs. In some dams, the situation is so severe that periodical excavation is becoming necessary. One opportunity is that farmers are well aware of the problem and are willing to invest in sustainable land and water management interventions (Mitiku and Sorsa 2002).

Another serious environmental impact is the introduction of salinity to the irrigated schemes. With the current water management practice (furrow management without appropriate scheduling), the absence of well-designed drainage ditches and very high clay content, salinity hazard is imminent. The level of salinity in some schemes has reached a situation where serious impacts are being observed both on crops and soils.

The pattern of salt distribution was studied by taking a transect and results have shown that the salt content of irrigated fields nearer to the embankments were generally higher than fields either in the centre or at the tail end. This, according to Mitiku and Sorsa (2002), is attributed to the high seepage loss from the nearby embankments.

Although not as such wide spread incidence, there was also biological contamination observed in the reservoirs of some dams. The watercolour in the reservoirs changes from a normal blue green to deep red/brown. This change was so homogenous that a suspended powder pigment was observed. Water quality studies revealed that the incidence was a biological contamination caused by bacteria known as Myxobacteria, a Polyangiaceae genus.

The bacteria are mainly active cellulose decomposers that widely occur in soils and water. They are capable of forming fruiting bodies, which can survive for a long time under unfavourable conditions. The study has continued to identify the original sources but preliminary findings show that similar biological structures are found within livestock dung around the dams.

Health impact assessment

The impact of prolonged available surface water in newly developed irrigation areas is on water and vector-borne diseases. Areas that were periodically affected by malaria and schistosomiasis are exposed to continued year round attack. Peak transmission that coincides with seasonal onset of the big and small rains in the region will be prolonged to other months, which were relatively free of malaria. Mosquitoes and snails have an ideal environmental situation to breed.

Health studies (Tedros et al. 1999) revealed that villagers living near to dams that are built in altitudes lower than 2000 masl are faced with increased risk of malaria incidence. Incidence surveys conducted showed a seven-fold increased risk for children. Some of the documented risk factors were open caves, keeping animals in living houses and earthen roofs.

Identification of such local risk factors for malaria is important for the planning of malaria control (Tedros et al. 1999). To mitigate the risk of malaria, insecticide impregnated bed-nets were distributed to near micro-dams village under a cost-recovery scheme. Malaria incidence was then measured and the risk was reduced to less than two-fold.

Studies on the incidence of schistosomiasis revealed that the overall prevalence of infection was 39% for children and 48% for adults (Tedros et al. 1999). The effectiveness of *endod* (*phytolacca dodecandra*) in controlling snail is currently under investigation.

Socio-economic impacts

Irrigation development aims to bring about increased agricultural production and consequently to improve the economic and social well-being of the rural population. Studies on household income by irrigation (Mintesinot 2002) revealed that irrigation users, on average, have three-fold increase in income compared with those that solely depend on rainfed cultivation.

The same study indicated that irrigation compounded with rainfed cultivation ensures year-round food security, although, off-farm employment during part of the year is a common practice to obtain extra money.

Conclusion

With the growing demand for daily food and continued struggle to achieve long-term food security, there is a dire need to maximise the productivity of both land and water. Inputs to land may improve land productivity but inputs to water may not change the productive capacity of water. Improving the water security through increasing the water use efficiency (more crop per drop!) can however result in higher productivity.

The issue of water security in Tigray (northern Ethiopia) is addressed through the extensive water harvesting endeavours underway. The positive and negative impacts of this effort are, however, little understood.

Farmers living in the vicinity of micro-dams are aware of the problem of land degradation. They understand the effect of sedimentation on the reduced capacity of micro-dams to store water to be used for irrigation. Apparently, they are willing to invest in land management systems that are sustainable, productive and effective in reducing sediment load.

Health studies indicated that villagers living near micro-dams that are built in the lowlands (<2000 masl) are faced with the risk of increased incidences of malaria. Community participation in draining excess water that can be a breeding ground for mosquitoes coupled with the use of impregnated bednets has decreased the incidence of malaria. Credit schemes are important avenues to undertake this venture. The major point of departure is the benefit that is obtained from the use of the irrigation schemes. In the schemes where economic benefits are obtained the farmers are willing to pay for the extra cost of prevention of malaria (Lampietti et al. 1999)

Knowledge gaps and future avenues

Despite the vast knowledge and experiences accumulated in the field of water harvesting, there are still large gaps in research that need to be filled. Some of the reasons for the poor research in water resources could be attributed to:

- no institutional responsibility as such exists to take up research on sustainable water resource development
- limited and/or very scattered capacity (trained manpower) available to undertake interdisciplinary research
- very few institutions available to offer specialised training in water resource development.

Of the many research topics in micro-dam water harvesting, the following thematic areas are prioritised:

- hydrology at farm level
- upstream/downstream effects of water harvesting
- water productivity in agriculture
- water pricing
- co-operatives under smallholder irrigation managements
- soil–plant–water relationship.

To address the main causes for the limited attention in water resource research and capacity building:

1. there needs to be mandate sharing among the various institutions (governmental organisations and non-governmental organisations, NGO's) for research in water resources (basin-level, small-scale...)
2. higher learning institutions should play the needed role to meet the capacity building needs of water sciences.

What does Mekelle University have to offer?

There is a faculty of dryland agriculture that gives a degree level training in land resources management and environmental sciences. Through this programme, many courses are being offered in areas of water sciences. In addition, periodical short-term trainings are organised for stakeholders in areas of water harvesting, irrigation management and soil and water conservation.

Apart from this, multi-disciplinary research is being undertaken in areas of small dams: water productivity, socio-economics, and health aspects. In partnership with the International Water Management Institute (IWMI) and the Ministry of Water Resources (MoWR), a study has been launched to apply PODIUM (policy dialogue model) to develop various scenarios for future water needs (for food production, people and the environment) at both basin and national level. New studies are also being launched in areas of community water management (in collaboration with the International Livestock Research Institute (ILRI), the Ethiopian Agricultural Research Organization (EARO) and MoWR and on malaria in small dams (with IWMI). There is already a network available, but this needs to be strengthened.

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Promoting global watershed management towards rural communities: The May Zeg-zeg initiative

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Abstract

To fight land degradation, the regional government of Tigray (which is the northernmost and driest region of the Ethiopian highlands) has initiated many conservation programmes, i.e. massive introduction of stone bunds to reduce runoff, check dams in gullies and cattle exclosures on steep slopes (Gaspart et al. 1997; Kebrom et al. 1997; Bosshart 1998; Nyssen 1998; Berhanu et al. 1999; Herweg and Ludi 1999; Vagen et al. 1999; Nyssen et al. 2000a; Nyssen et al. 2000b; Nyssen et al. 2001).

In 1998, a research project on 'Desertification and anthropogenic erosion processes in a tropical mountain catchment: Tigray, Ethiopia' was initiated in the region to address fundamental research questions linked to land and water management. In the course of this project, it became clear that a given conservation technique was successful in some areas, but failed completely in others. For instance, gully check dams are successful at some sites, but fail completely in other pedo-topographic conditions. For these reasons, in 2001 an applied participatory research programme on watershed management (Zala-Daget project) has been set up in the Dogu'a Tembien District.

A broad scientific base has thus been constituted on problems of watershed management in this district; local authorities and farmers would like this knowledge to be used for watershed management in co-operation with the local Agricultural Office and administration at different levels. The farmers of the district are very active participants in soil and water conservation activities, and many of them involved in the previous and current research projects.

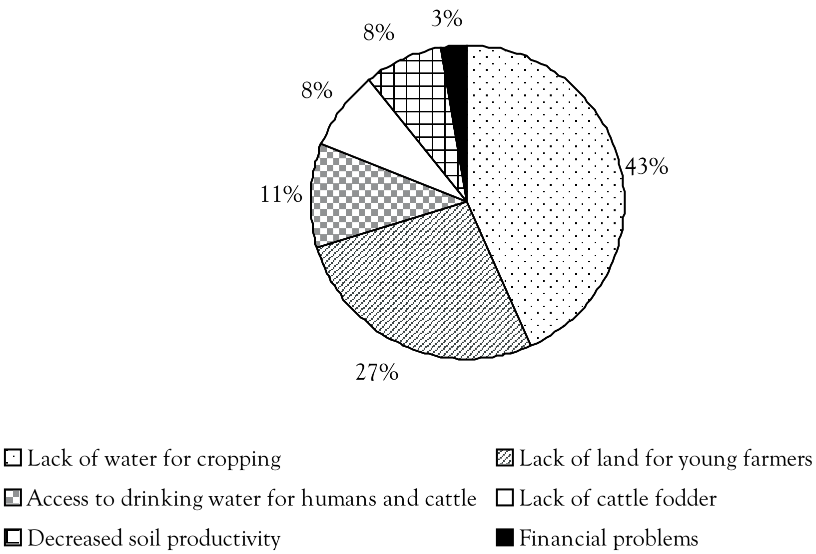
Researchers involved in the projects hope to be able to start a new project, called 'The integrated May Zeg-zeg watershed management initiative'. This project aims at

demonstrating and promoting global watershed management towards rural communities in the highlands of northern Ethiopia.

To achieve this objective two initiatives will be taken:

1. installation of a sustainably managed demonstration catchment of 400 ha and
2. elaboration of a capacity building and awareness raising programme regarding integrated watershed management.

Even if rainfall conditions in the Ethiopian highlands improved, drought and famine remain due to the erratic nature of rainfall and the low infiltration capacity of the soil (Conway 2000). A recent study shows that 54% of the farmers in the village of Hechi, in the lower part of the project catchment consider water availability as their main problem (Figure 1) (Naudts 2002). Another major issue for the farmers, fodder production, will also be directly addressed by the project, through the agroforestry component.



Source: After Naudts (2002).

Figure1. *Answers to the question 'Which is the main problem for the farmers in your village?', in Hechi (n = 37).*

Although there have been many initiatives for water conservation in Tigray (implementation of exclosures and stone bunds at a large scale, agroforestry trials), until now these techniques were never brought together and managed in a complete catchment, thus demonstrating the advantages brought by integrated watershed management. Furthermore, another innovative aspect of the project is that it includes an important, but realistic, change in land use: abandonment of free grazing system and change to no or controlled grazing.

Taking into account the broad scientific knowledge on which the May Zeg-zeg initiative is based, and the longstanding co-operation between the community and the different partners, we feel sure that this initiative will be successful with the installation of a sustainably managed demonstration catchment, which will serve for a capacity building and awareness raising programme regarding integrated watershed management.

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Small-scale irrigation development in the wetlands of South-West Ethiopia

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Abstract

The basic problem of water distribution in the world is the temporal and spatial differences that exist in the supply and demand of water. The general solution of this problem lies in adjusting water supply and demand so that the demand will always be smaller than or equal to the supply. Storage of water is one of the most useful methods for changing the amplitude and phase of the water supply. Such storage of water can be carried out only through knowledge of the water resources of the region being considered. Water resource potential is said to be abundant in Ethiopia but still difficult and expensive to exploit. A rational management and development of water resources is required to effectively and efficiently utilise water resources to achieve food self-sufficiency and food security. With this background, it is essential to develop a small-scale irrigation system. Harnessing some of the sizable rivers can produce some medium- to small-sized irrigation projects. Data were collected to show some preliminary figures about irrigated and potentially irrigable areas for some regions in West Shewa. Using a deterministic hydrologic model, the water balance of four representative rivers in West Shewa were simulated and analysed. The simulation showed that rainfed agriculture may be practised in West Shewa for seven months (March to September), and the rest of the months should be supplemented with irrigation. This implies the importance of the development of small-scale irrigation even in wet region. The small-scale irrigation development will be beneficial for this region for (a) supporting the realisation of food self-sufficiency and food security; (b) improving the living quality and standard of the people through the provision of sustainable agriculture; and (c) enhancing the contribution of irrigation in attaining national development priorities, programmes and objectives.

Introduction

The growing intensity in the utilisation of water necessitates the assessment and control of water resources. Better knowledge of the temporal and spatial variations of water supplies is a precondition for the planning, investment and regulation of systems of water distribution. The basic problem of water distribution of the world is the temporal and spatial differences in the supply and demand of water. The general solution to this problem lies in adjusting water supply and demand so that the demand will always be smaller than or equal to the supply. Storage of water is one of the most useful methods for changing the amplitude and phase of the water supply. Such storage of water can be carried out only through knowledge of the water resources of the region being considered. The quantitative statement of the balance between water gains and losses in a certain watershed during a specific period of time is known as the water budget. The water balance equation makes use of the outflow–inflow relation. A proper understanding of the role of water in agriculture requires a careful analysis of the nation's water budget.

Water resource potential is said to be abundant in Ethiopia but is still difficult and expensive to exploit. Because of the highly erratic nature of rainfall in Ethiopia, drought is a very serious social problem. The streams are difficult to dam for many reasons, among which are: inadequate storage sites, extremely high seasonal flow during the big rain period, low water retaining capacity, high sediment loads, and transportation of boulders during high flow seasons. Considering the present status of irrigation development and management in West Shewa, it is likely that irrigation has considerable potential to further increase in agricultural production and the income of people in the irrigated areas, both through construction of new projects and more efficient management of existing ones. While this view is likely to be correct, analysis of the existing situation indicates that if irrigation is to play a crucial role as an engine for further expansion of agricultural production, the management and organisation of irrigation systems, including their institutional implications, must be substantially improved.

Harnessing some of the sizable rivers can produce some medium- to small-sized irrigation projects in West Shewa. These schemes will require surface water storage, spillways and a network of main, secondary and tertiary canals. Investment costs are likely to be high. These schemes may be economical if irrigation benefits are combined with hydropower and flood control benefits. So far as technical aspects are considered, currently insufficient geological and hydrological data are available for planning and constructing large multi-purpose dams and reservoirs. Additional data will be necessary on sedimentation rates, and how these may be influenced by the construction of dams. While traditional irrigation has been practised for several decades, there is considerable need both to expand the currently irrigated area and to improve the efficiency of existing systems. There is no question that for the future economic development of the region, irrigation development and management must play an important part. It should, however, be noted that before major irrigation projects can be developed, the farmers should be well-oriented on how to use the water resources.

Decision making in irrigation development

The choice of specific irrigation and water management methods must depend on the support of all those affected by management changes. Participation of stakeholders is fundamental in the planning process of small-scale irrigation. Planning involves deciding which irrigation method and water management strategy to pursue from among a number of possible options. This decision will not only be made at the beginning of a project but throughout its lifetime in response to monitoring and evaluation of project progress and changes in the environmental system. The group of people who are responsible for implementing them should make decisions. Decision can be made using three phases, namely intelligence phase, design phase and choice phase. The intelligence phase is concerned with identifying exactly what the problem is. The design phase sets the criteria by which a decision will be made, identifies the options available and attempts to predict the outcome of each option. The choice phase comprises the selection of the best option from those available. Stakeholders can contribute to each of these phases in different ways. In the intelligence phase, consultation with stakeholders is crucial as small-scale irrigation development problems always relate in some way to water use by people. During the design phase, stakeholders can help identify the options available and will be able to provide information to help predict likely outcomes. Following the choice phase, it is important that the decisions made are endorsed by as many stakeholders as possible, otherwise the proposed plan will not receive the stakeholder support required to implement it.

Merits of small-scale irrigation

Small-scale irrigation is widespread and has a vital role to play in Ethiopia. The success of small-scale systems is due to the fact that they are self-managed and dedicated to the felt needs of local communities. Indeed, small-scale schemes are defined as schemes that are controlled and managed by the users themselves. Traditional irrigation schemes make up the most dominant form of small-scale irrigation in the region, and some of them are well managed.

The main advantages of small-scale irrigation are:

- much lower investment costs, and in a majority of cases these costs are borne by the community
- do not involve dams or storage reservoirs, hence no population displacement is involved
- less demanding in terms of management, operation and maintenance
- no land tenure or resettlement implications
- no serious adverse environmental impact
- allow a wider diffusion of irrigation benefits and
- permit farmers to learn irrigation techniques at their own pace and in their own way.

To support small-scale irrigation, efforts should be made to enhance and improve the efficiency and productivity of traditional irrigation. For example, the most persistent problem of traditional river diversion schemes in this country is the impermanence and fragility of the headworks, which are almost always made of brushwood and earth, and which are often washed away during heavy rains and have to be frequently repaired. Farmers always complain that repairing the headworks requires too much labour. Improving the durability of the headworks and other infrastructure could contribute to efficiency and productivity. Secondly, farmers should have access to simple, cheap and environmentally friendly water technologies such as hand pumps and shallow tube wells. Thirdly, improving the marketability of irrigation produce will serve as an important incentive. This may require building access roads, offering better prices, and improving product quality. These and similar measures of support will mean that non-governmental organisations (NGOs) and private enterprises will have to play a more active role. The responsibility of the state will then be to create an enabling environment for greater NGO and private sector interventions. Small, user-managed schemes work best if there is no state intervention or if such intervention is kept to a minimum. The state should focus on providing needed services such as credit and finance and on building up basic infrastructure.

Small-scale irrigation in south-western Ethiopia

Because of topographical conditions, irrigation development in southern Ethiopia is highly site-specific and accordingly generalisation may be misleading. Overall water from the large and medium size rivers that flow through the hills cannot be used, since they cut deep through the area, which means that river water levels are at too low of an elevation relative to the fields to be irrigated for effective utilisation. Consequently, irrigation in the hills is mostly dependent on smaller rainfed streams, some of which have very limited base flow, while others seem to dry up during the dry season. These streams are difficult to dam for many reasons, among which are: inadequate storage sites, extremely high seasonal flow during the big rains, low water retaining capacity, high sediment loads, and transportation of boulders during high flow seasons.

Harnessing some of the sizable rivers can produce some medium- to small-sized irrigation projects in this region, with command areas ranging between 250 and 15 thousand hectares. These schemes will require surface water storage, spillways and a network of main, secondary and tertiary canals. Investment costs are likely to be high. These schemes may be economical if irrigation benefits are combined with hydropower and flood control benefits. So far as technical aspects are considered, currently insufficient geological and hydrological data are available for planning and constructing large multi-purpose dams and reservoirs. Additional data will be necessary on sedimentation rates, and how these may be influenced by the construction of dams.

In south-western Ethiopia, the practices of obtaining water from small streams for supplementary irrigation include surface stream diversion, minor storage schemes based on farm-pond types of impoundment, pumping where energy is available either in the form of electricity or diesel, water turbines driven by the hydraulic energy of streams, or conveying water by pipes. The choice of a specific irrigation method depends on a variety of factors and constraints, overall economics of the scheme, subsidies available, accessibility of the site, quality of the soil, extent of irrigable land, and seasonal variation of available water. Very little information exists on the prevailing groundwater and the soil moisture conditions in the region. The locations of the localised pockets of groundwater, estimates of volumes of water that can be extracted on a sustainable basis, and their potential exploitation for agriculture can only be considered when more detailed geological maps of the region are available.

Small-scale irrigation in West Shewa

Irrigation is not new in West Shewa. It has been practised for several decades. What is remarkable, however, is the tremendous expansion of irrigation during the past two decades. Irrigation was highly intensified since 1984, because of the 'food self-sufficiency programme' declared by the government. In 1987, several projects were designed with the joint action of the governments of North Korea and Ethiopia with the aim of boosting the productivity of producers' co-operatives. Along with this programme several farmers were trained in irrigation water management. Unfortunately the programme terminated in 1999. It was observed that the farmers highly profited from those small-scale irrigation projects.

Considering the present status of irrigation development and management in West Shewa, it is likely that irrigation has considerable potential to further increase agricultural production and the income of the people in the irrigated areas, both through construction of new projects and more efficient management of existing ones. While this view is likely to be correct, analysis of the existing situation indicates that if irrigation is to play a crucial role as an engine for further expansion of agricultural production, the management and organisation of irrigation systems, including their institutional implications, must be substantially investigated and improved. Some research works were carried out in the areas of planting time, irrigation interval, crop water requirements, irrigation and water balance, farmers' participatory research etc. by development agents, and research and higher learning institutions. There is a great problem in getting sufficient trained manpower in relation to the number of farmers in the area. Therefore, a large number of trained manpower is required to support the farmers of the region.

On the basis of data collected from 10 *woredas* of West Shewa, some preliminary figures were shown about irrigated and potentially irrigable areas for the region (Table 1). Much of the land currently under furrow irrigation in West Shewa is in the Bako, Dibdibe, Denbeli, Guder and Ketta regions. The data collected for West Shewa identifies 1322 ha of land under furrow irrigation, which accounts for about 35% of the total irrigable land in Western Shewa (Table 1).

The Indris Small-scale Irrigation Project is located in Guder, a small town located 137 km west of Addis Ababa on the road to Nekemt. EEC/PADEP VI had funded a project on the Indris Scheme for two years (1992–94) to rehabilitate the headwork and main canal system. This project assisted the farmers in strengthening their water users association, drafting rules and regulations for managing their scheme and in developing a rudimentary schedule for distributing the irrigation water and organising maintenance. Due to a number of factors, including the activities of the Shewa PADEP Project, the farmers have dramatically increased the area cropped on the scheme during the dry season from 45 ha in 1990/91 to 170 ha in 1993/94. This increase has not been accompanied by a comparable increase in the available water supply. The German Agro-action and Abebech Gobena Orphanage and School have jointly financed another small-scale irrigation project on Indris River near a village called Mutulu with a command area of about 150 ha. The Ministry of Agriculture has planned to construct small earthen dams and ponds in the future.

Table 1. *Irrigation in West Shewa.*

Woredas	Main crops	Irrigated area (ha)	Source	Irrigable area[1] (ha)
Illu	Cabbage, tomatoes, carrot, onion	16	River	180
Dibdibe (Wenchi *woreda*)	Maize, lentil, onion, potatoes, carrot, cabbage, tomatoes, sugar cane, green pepper	367	River	33
Walmara Goro (Walmara *woreda*)	Cabbage, potatoes, carrot, cauliflower	15	River	–
Mukadima Abay	Vegetables	80	River	–
Denbeli Ketta	Cabbage, onion, maize, tomatoes	300	River	–
Bako woreda	Mango, coffee, sugar cane, bananas, tomatoes, cabbage, green pepper	386	River	1000
Jattoo Dirki (Chelia *woreda*)	Maize, sugar cane, bananas, chat	30	River	90
Aga and Illu (Adaa Berga *woreda*)	Barley, maize	20	River	27
Chilanko (Jaldduu *woreda*)	Potatoes, onion	5	River	30
Tolee *woreda* (42 farmers associations)	Vegetables	103	River spring	202
Total		1322	River	1562

1. Potential expansion.

Water budget in West Shewa

Computation of water balance and modelling the process of transformation of rainfall to streamflow need measurements of the appropriate meteorological variables. Therefore, calculation of the areal distribution of precipitation from point measurement and determination of the areal potential evapotranspiration (PET) from the necessary meteorological information were carried out. Areal rainfall was estmated from point rainfalls with the HYBSCH model (Taffa 1989, 1990b, 1991) which uses the hypsometric curve method. From these simulations, it was estimated that the average annual discharge of the rivers originating in West Shewa and flowing to the Abay river amounts to 20 billion m^3, which is equivalent to 634 m^3/s of continuous flow. While this total quantity of water is undoubtedly substantial, the river flows have significant seasonal fluctuations. An inadequate number of river gauging stations and their improper allocation make it difficult to estimate the amount of land that can be properly irrigated in West Shewa by surface water.

Results, discussion and recommendations

From the above simulations, the West Shewa watershed has a total water deficiency of 632 mm from October to April (1966–84) (Table 2). From May to June there was soil moisture recharge, that is soil comes to field capacity towards the end of June and moisture becomes available for optimum plant growth. From May to September there was a total water surplus of 696 mm, with the highest surplus at the end of July giving rise to peak streamflows at the beginning of August. From October to the end of November, stored soil moisture is utilised by plants, which means there is some amount of moisture available for plant growth, although not at optimum rate.

Table 2. *Average water balance for West Shewa (1966–84) in mm, as simulated using HYBSCH model.*

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	23	41	83	78	153	194	256	249	204	73	26	18
PET	158	116	121	148	100	74	54	51	81	132	127	172
RET	34	25	45	69	71	69	54	51	81	129	90	65
RO	0	0	0	0	9	56	165	180	123	18	1	0
Sm	2	1	1	1	26	43	47	40	38	37	3	1
cSm	–1	–1	–1	0	22	17	4	–7	–2	–2	–34	–2
Smd	135	75	38	70	–	–	–	–	–	59	101	154
Sms	–	–	–	–	53	120	202	198	123	–	–	–

Notes: (P = precipitation; PET = potential evapotranspiration; RET = real evapotranspiration; RO = surface runoff; Sm = soil moisture; cSm = change in soil moisture; Smd = P – PET, soil moisture deficit; Sms = P – PET, soil moisture surplus).

High amounts of water surplus are associated with areas of high rainfall and/or low PET. Rainfed agriculture can be practised for seven months (March to September), and the rest of the months should be supplemented with irrigation.

To help the water users association (WUA) and to manage the scarce water supply fairly and efficiently, it is essential that a more effective water management system is introduced. For this to be done, detailed information is needed not only on how much water is available but also how that water is being distributed and used. Guidelines also need to be prepared of ways in which the water management on schemes could be improved. Construction of small earthen dams and ponds shall be encouraged for the development of small-scale irrigation systems.

It is also necessary to expand farmer-managed irrigation systems (FMIS). FMIS are simple irrigation systems that are constructed and maintained by the farmers, with limited or no involvement of government agencies. Such systems mainly supply supplementary irrigation during periods of rainfall deficiency. If the government institutions provide some supervision, technical assistance, grants, and loans, it is possible to expand FMIS at relatively lower investment and operation cost since farmers could contribute labour to the construction. There is no doubt that for the future economic development of an agrarian country like Ethiopia, irrigation development and management must play an important part.

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Synthesis of research issues and capacity building in water and land resources management in Ethiopia

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Abstract

This paper presents an overview and synthesis of the key research and capacity building issues arising from the workshop presentations and papers. Three days of intensive deliberations by professionals from various research, development and governmental organisations, and of diverse disciplines, backgrounds and nationalities have clearly acknowledged that water management issues remain very crucial for poverty alleviation and rural development in Ethiopia—whose overwhelming proportion of the population depends on smallholder agricultural production, which is highly constrained by water availability (absence of perennial rivers, high spatial and temporal availability of rainfall etc.). This situation, over the years, has generated a critical need for efficient water and land management to reduce production risks and hazards, and enhance stable agricultural and livestock production. Recent decades have witnessed various efforts in the area of irrigation and supplementary irrigation (and other development initiatives), employing various water harvesting technologies, construction of micro-dams, diversions structures etc. which were largely combined with traditional yield-enhancing methods to facilitate sustainable smallholder agricultural production.

Most of these efforts did not only fall short of their desired objectives of improving smallholder production conditions but also generated a host of others such as:

- large-scale irrigation schemes (e.g. Awash Basin and elsewhere) resulted in secondary soil salinisation where large tracts of land have gone out of production
- spontaneous construction of micro-dams across the country (especially in Tigray) is associated with human and livestock health hazards that in some cases have resulted in abandonment of the dams
- production potential of extensive watersheds remain largely unexploited or inappropriately used, resulting in extensive degradation of fragile lands, and so on.

The potential for effectively integrating crops and livestock management in the context of growing water in complementary crop–livestock systems remains largely unexploited, especially from the perspective of efficient water and land utilisation. The limited success of most of the technologies in Ethiopia calls attention to a dire need for research and capacity building to understand the complex issues of water and land management, so as to enhance

national and local capacity to deal with water and land management issues to enhance food security, poverty alleviation and national economic development.

Introduction

The issue of population growth and the impending need to increase agricultural production in Ethiopia was well acknowledged at the workshop. The dual role of agriculture in providing rural livelihood and enhancing national and local level food security for the masses was also clearly articulated. Agriculture accounts for about 85% of total employment and generates 75% of exports earnings (World Bank 2000). Crops contribute about 80% of the gross value of the agricultural sector, which constitute about 40% of the gross domestic product (GDP) (FAO 2000). The relevance of agriculture (and livestock) to the economy are highlighted, which raises a critical need for examining the physical and agro-ecological framework conditions that characterise agricultural production in the country, as emphasised in many of the papers.

The country's diverse agro-climate was vividly presented to comprise the central massive highlands (up to an altitude of 4000 metres above sea level, masl) that support about 90% of the rural population, and accommodate agricultural and agro-pastoral activities, and the relatively less densely populated lowlands characterised by extensive livestock production or pastoralism. Over 70% of the country is either arid or semi-arid, characterised by low and erratic rainfall both in terms of spatial and temporal distribution. The potential for crop production in large parts of the country using traditional methods remain uncertain and often subject to crop failure and severe fluctuations in yield. This situation is further exacerbated by recurrent droughts and associated famine, which causes heavy loss of human and livestock lives especially in pastoral areas (Futterknecht 1997; Kamara 2001; MoWR 2001). The incidence of droughts is reiterated to be a natural phenomenon that cannot be entirely ruled out, but it is strongly believed that their impact on human life can be significantly reduced through efficient management of water and land resources in the country.

Water and land resources

The workshop acknowledged the abundance of natural resources in the country, but called specific attention to the under-utilised status of most of these resources—about 122 billion cubic metres of surface water is available in 12 river basins and 22 lakes, plus an appraised groundwater of about 2.6 billion cubic metres (WWDSE 2001). The potential for sufficiently tapping this water for domestic and productive purposes, however, is lessened by uneven spatial and temporal distribution, and unpredictable availability (Belaihun; Gulilat; Paulos).[1] While close to 90% of the country's water resources occur in four river basins[2] that host no more than 40% of the population, about 60% of the population living in the east and central river basins depend on less than 20% of the country's water resources

1. Throughout this synthesis, author references are to papers presented in this workshop.

(Gulilat). Though information on the distribution of the available groundwater resources in the country is limited, it is posited that the water table is relatively deep and that yields are low, making the exploitation of groundwater expensive for agricultural use (Gulilat). Despite these natural constraints and technical limitations, it is clearly acknowledged that the country's potentially utilisable water resources are largely unexploited—it is not even clearly documented which proportion of the potentially utilisable water resources the country can use within international legal provisions. Thus, this initiative in research and capacity building for water management for Ethiopia could not have been more timely (H.E. Shiferaw Jarsso, 2002, opening speech of this workshop).[3]

The uneven distribution of the productive lands was also acknowledged and highlighted (Paulos). More than 40% of the arable lands in the country occur in the highlands, containing about 95% of the regularly cropped area and two-thirds of the country's livestock population (Ewnetu et al. 1999; Paulos). With high population density of over 400 people per km^2 in some areas, most of the highland is threatened by land degradation, which threatens agricultural production and environmental sustainability.

Therefore, agricultural production in the country—both crops and livestock—depends largely, on sustainable land and water management. While land management issues may have received a great deal of attention in the past (Bruce et al. 1994), water management issues have received far less attention (Paulos). Although the country has a 50-year experience in basin level management approaches (Gulilat), attempts in the early 1970s to prepare a National Water Code that would articulate water issues was never off the ground. This issue only regained recognition after the establishment of the Ministry of Water Resources in 1995, which eventually released the National Water Resources Strategy in 1999, a document that now emphasises a comprehensive and integrated water resources management approach.

Water and land management issues in Ethiopia

Among the most pressing issues associated with land and water resources management are secondary salinisation, nutrient depletion, water pollution, de-vegetation, soils erosion and, to some extent, grazing. Soil degradation especially on fragile lands and groundwater depletion were highlighted (Mintesinot and Mitiku; Paulos; Penning de Vries et al. 2002). These processes are feared to lead to long-term (perhaps irreversible) deterioration and reduction of the potential and actual productivity of land, with adverse effects on agricultural productivity, with serious food security implications at both the national and local levels. It was also acknowledged that most of the instruments for checking these trends, especially the necessary water related policies, plans, strategies and laws, are largely in place. The current challenge, therefore, was identified to be in the area of implementation, including harmonisation of the water sector with other sectors. Existing institutions are also building on previous efforts to begin to fill in capacity gaps and pull on opportunities in linking existing research and capacity building activities (Gulilat). In this context, various

2. These include the Abay (Blue Nile), Tekeze, Baro-Akobo and Omo-Gibe basins, largely occupying the west and south-western parts of the country.
3. Minister of Water Resources, Government of Ethiopia.

issues were highlighted under different sub-sectors and specific needs for research and capacity building highlighted, with a word of caution that action be better taken today, for '... tomorrow may be too late' (Paulos).

Irrigation

The irrigation potential was presented as one of the most underutilised opportunities in the country. The country has an irrigable land of about 3.3 million hectares of which only about 5% developed to date, with about 55% of the developed area being traditional irrigation (MoWR 2001; Gulilat). At the end of the 1990s, the area under small-scale irrigation was estimated at around 64 thousand hectares while that of medium- and large-scale were appraised at 112 thousand hectares, of which 22 thousand hectares were new small-scale irrigation schemes implemented since 1992 (WWDSE 2001; Gulilat). The nation has a National Irrigation Development Strategy, which has the goal of utilising the country's natural potential (in water and land resources) to achieve food self-sufficiency at the national level, generate export earnings, and provide raw materials for industry on a sustainable basis (MoWR 2001). Specific objectives include expanding the irrigated area, improving the productivity of water in irrigated agriculture, ensuring the financial and technical sustainability of irrigated areas, and effective mitigation of water-logging and salinity. Small-scale irrigation, which is found in much of the country (Shewa, Tigray, Hararghe, Gojjam and North Omo), offers the potential for improved food security, agricultural diversity and productivity. There is considerable experience with small-scale irrigation, but the extent and potential has not been quantified and general documentation is sparse (CRS 1999).

Small-scale irrigation

Compared with other irrigation strategies used in Africa, properly implemented smallholder irrigation with appropriate technologies may have a considerable potential in improving rural livelihoods, although the viability of such systems becomes questionable when the financial responsibility rests entirely on the community in the absence of institutional support services that enhance market orientation (Kamara et al. 2002; Shah et al. 2002). Given the complex set of constraints facing smallholder producers, providing access to irrigation water by itself is not enough; smallholders also require a broad range of support services (access to inputs, credit, output markets), knowledge of farming and secure land tenure. Achieving economic viability of smallholder irrigation on a market-oriented basis requires access to support services and opportunities for producing high value crops. Thus, it was acknowledged that the issue of smallholder irrigation expansion should be viewed far beyond the narrow scope of just providing irrigation water and land, to include institutional linkages, access to markets and other support services that enhance production on a sustainable basis.

Large-scale irrigation

State run farms, which include large-scale irrigation systems, were reiterated as major components of efforts to develop the country's agricultural sector, notably in the Awash Valley. However, productivity of these top–down managed systems over the decades has been disappointing—the farms have been beset by a number of environmental, technical and socio-economic constraints. The large scale systems in the Awash basin and elsewhere suffer from water management practices that have resulted in rising ground water tables and secondary soil salinisation where large tracts of land have gone out of production (EARO 2001; Paulos). In some instances (including small-scale irrigators), farmers considered irrigation as an evil practice due to losses of crops and arable land resulting from bad irrigation practices (EARO 2001). This has also been associated with conflict and water-related diseases that have undermined the sustainability of such large-scale irrigation systems under the prevailing circumstances.

Water harvesting

Recent efforts have been largely centred around water harvesting, in some cases on a large-scale through community initiatives, but in most cases state-supported—the so called micro-dams. Water harvesting and micro-dam construction have been largely promoted to capture runoff water for multiple uses, including domestic, irrigation and livestock especially in the northern part of the country. This widespread dam construction and promotion of micro-dams is, however, slowly becoming questionable, as the negative impacts (mostly agronomic and health hazards) in some cases outweigh the benefits, leading to abandonment of the dams and associated land in some cases (Mintesinot and Mitiku; Mitiku et al. 2002). It was acknowledged that this situation is largely due to insufficient baseline studies (technical, socio-economic, agronomic) at the inception of these dams, and the consequent lack of adequate scientific knowledge on the long-term impacts of the water harvesting systems, both in terms of hydrology of the production system and socio-economic and environmental outcomes. While many are convinced that water harvesting can indeed make a difference in the country in terms of responding to the nation's food security needs, there is a consensus among experts on the huge need for scientific information on both indigenous and introduced water harvesting technologies to understand their particular characteristics and constraints, and appreciate the needs for adaptation for successful water harvesting in the country.

Wetlands/aquatic ecosystems

Wetlands are increasingly recognised as an important component of not only the environment, but the economic system as whole, with communities drawing much of the resource requirements from such systems. The relevant challenge therefore is striking a critical balance between beneficial uses of wetlands for generating livelihood for rural communities without compromising environmental values and uses. Direct use of water from wetlands affect hydrology in the basin, may cause pollution, eutrophication and sedimentation from human activities, which may place these important systems at risk. For beneficial uses of wetlands to be sustained, water and land resources management practices need to be based on principles that support these ecosystems. Even at a global level, the characterisation of the relationship between the water resources and the ecosystems is only now beginning to receive the attention it deserves (Global Dialogue on Food and Nature). In Ethiopia, where information on the characteristics of the wetlands and associated ecosystems is limited, the knowledge gap necessary to develop best management practices is large, and requires committed long-term research and capacity building.

Drainage

Inadequate natural drainage causes water logging, salinisation and, in some cases, deterioration of soil quality through erosion, leaching, destruction of soil structure or even soil losses (Mintesinot and Mitiku; Paulos; McCornick et al. 2003). These processes lead to an eventual decline in the productivity of agriculture, and may subsequently lead to abandonment. The Middle Awash Valley, for instance, and the localised problems with the small-dam developments in Tigray are two of the areas in the country where salinisation, caused by inadequate drainage, has resulted in declining productivity and subsequent loss of land. Furthermore, in the highlands, water logged soils during the rain season, were recorded to reduce the length of the growing season for rainfed agriculture (Gebrehiwot et al. 1997). At the same time, it was acknowledged that purpose-built drainage networks are expensive and difficult to justify. Localised initiatives were recognised as more feasible, including water management strategies and interventions that target problem areas, but noted to require scientific understanding of the local climate and agronomy, agro-ecology, hydrology (water table, water quality, groundwater movements), cropping systems and management practices. Developing capacity at the local level to understand these factors, and considering drainage as a component of water management and the practical interventions that could be adopted, was also recognised as necessary.

In summary, the critical issues regarding agricultural drainage in the country were highlighted to include: the paucity of information on the specific characteristics of drainage constraints; the absence of the capacity (and perhaps resources) at all administrative levels to mitigate the constraints; and the absence of knowledge on the indigenous drainage approaches. With regards to water quality, issues of particular importance were noted to exist in the Awash River and the Rift Valley rivers (Girma Tadesse 2002, personal communication). With Addis Ababa in the headwaters of the Awash valley, discharge of untreated wastewater and pollutants into the river, is a serious issue. Downstream uses in the most developed river in the country include domestic water supply and irrigation. Elevated levels of fluoride, which exist naturally in the groundwater in the Rift Valley and the Awash basin, however, make these sources unsuitable for domestic water supply (WWDSE 2001).

Livestock

The livestock sub-sector is very important in Ethiopia not only for local level food security for the growing population but also for generating foreign exchange. Despite its relatively low contribution to the GDP, livestock plays a paramount role in generating rural employment: less than 10% of the total land area of Ethiopia is cropped (FAO 1996), and extensive land use in the form of pastoral and agro-pastoral production dominates the production systems. In the highlands, livestock husbandry is combined with crops in a sedentarised system with open grazing and relatively high cropping intensities and livestock densities. The pastoral lowlands, which include Afar in the north-east, the Somali in the south-east, the Borana in the south and other minor groups, supply robust livestock to both the domestic markets and international markets, and are thus noted as important source of foreign exchange (Kamara 2001; Paulos).

Despite this relatively important role, it is noted that water for livestock and human needs in pastoral communities remain a critical problem (Paulos). Pastoralists are often compelled to trek for days in search of water at high temperatures and under stressed conditions. Water supply for nomad relies mainly on occasional water in ponds and puddles and in few instances, e.g. the Borana, traditional deep wells under very primitive conditions whose water retention potential varies with rainfall (Kamara 2001). It is therefore not uncommon to find the prevalence of water borne diseases (diarrhoea, amoebic dysentery, bilharzias etc.) among such communities, whose water sources (ponds, puddles, runoff, rarely rivers and irrigation canals) are largely polluted or unrefined for domestic use. It is also noted that providing water under pastoral circumstances is difficult, primarily because of low population densities, nomadic culture and harsh environmental characteristics. Also, in providing new water sources (boreholes, ponds and cisterns or birka) in these semi-arid areas, there is a risk of the livestock population rising above the carrying capacity of rangeland, and a potential for aggravating the impact of catastrophic events such as droughts.

Of particular importance was looking at possibilities of improving the productivity of livestock and associated opportunities for poverty reduction (Peden et al.). The potential for integrating crops and livestock in a 'cut-and-carry' and grazing system such that livestock relies on the consumption of crop residues and free fodder was highlighted as worth giving attention. In a context of growing water scarcity, such systems as are posited as having high efficiency of water use since the water for crop production would have been used with or without the animals feeding on the residues (Peden et al.). Being a by-product of crop production, the crop residue does not require additional water for providing valuable feed for livestock, while livestock provides farmers with additional value in terms of consumable and marketable outputs (meat, milk etc.) without incurring significant additional demand for water. These sort of opportunities, including the role of livestock in urban and peri-urban agriculture, where water use efficiency is increased or other outputs generated without necessarily using additional water were acknowledged as worth examining for adoption and up-scaling where appropriate (Peden et al.).

Environment

Irrigated agricultural production was acknowledged as one which will continue to be an important component in the development of Ethiopia, given the availability of water and land resources, and the direct and indirect socio-economic and economic benefits. However, as in other developing countries where irrigation consumes between 70 to 90% of available water, it is noted that there can be significant negative impacts including ecosystem deterioration in the form of water and land degradation, reduction in biological diversity, social and economic impacts, and so on. These impacts have already been observed in the relatively developed Awash valley, and are noted to appear in other basins especially in the northern parts of the country (Mintesinot and Mitiku; Mitiku et al. 2002).

Health

The increased incidence of water related diseases such as malaria, schistosomiasis and diarrhoea have been associated with the development of irrigated agriculture in the Awash Valley, small dams in Tigray and elsewhere in Ethiopia (Mintesinot and Mitiku; Mitiku et al. 2001). Diarrhoea accounts for over 46% of infant mortality in Ethiopia. To a large extent, environmental and health issues associated with irrigation and water development in Ethiopia are noted to be linked to the limited knowledge of the issues, lack of capacity and resources to investigate and mitigate the constraints and limited knowledge of indigenous practices used to protect human health or the environment (Manoncourt and Murray 1996). As in other parts of the world, it was recommended that building irrigation systems and water harvesting structures such that diseases are prevented is a more effective way of reducing health hazards, rather than curing diseases, which is sometimes impossible. In this regard, several examples and methods were highlighted, based largely on practical experiences especially in Asia (Boelee).

Water supply and sanitation

Ethiopia has a very low level of water supply coverage, with only 17 and 35% of the rural and urban population having access to safe drinking water, and similarly low levels of sanitation coverage. This issue is recommended as one that should be paramount in considering the management of the water resources of Ethiopia.

Urbanisation

Already the second most populous country in sub-Saharan Africa, the country faces increasing population growth and rural–urban migration. The population of Addis Ababa is, for instance, projected to almost double its present 2.5 million by the year 2025 (WWDSE 2001). Uncontrolled urbanisation places an increasing pressure on the land and water resources of the surrounding area, altering the natural hydrology and degrading the quality of the water, which in turn impacts the downstream users, and ecological services downstream. Moreover, the peri-urban agricultural activities in the form of vegetable production and livestock have become increasingly recognised in terms of their importance to livelihoods and food production, and possible impacts on public health and the environment. The potential for peri-urban agriculture as a significant source of income and livelihoods for the urban poor needs critical examination.

Hydropower

Estimated at 26 KWh, the per capita power generation capacity of Ethiopia is one of the lowest in the region, and is only about 15% of that of Kenya. Only around 13% of the population of Ethiopia has access to electricity (WWDSE 2001). This contrasts sharply with the hydropower generation potential of the country, estimated at about 150 TWh, which is 100 times greater than the existing capacity currently being utilised (WWDSE 2001). It is also asserted that some of the older reservoirs are gradually silting up, further diminishing the generation capabilities that are already far below expectations. This issue remains crucial and is prioritised in the National Water Resources Strategy, especially in view of the fact that Ethiopia's power generation potential, if effectively and efficiently exploited, makes it possible for the country to export power to neighbouring countries and earn foreign exchange (MoWR 2001).

Integrated water resources management

In an effort to operationalise its commitment to effective and efficient water management issues in the country, the Government of Ethiopia has developed a comprehensive National Water Strategy, based on the principles of Integrated Water Resources Management (MoWR 2001; Gulilat). Among others, the strategy emphasises strategic issues under general water resources management, and a detailed elaboration issues relating to hydropower development, water supply and sanitation, and irrigation development within the context of integrated water resources management from a basin perspective. The development of Integrated River Basin Development Master Plans has already been completed for four basins, and the Mereb, and the intention is to undertake the same for the six remaining major drainage basins, namely Wabi Shebele, Awash, Genale-Dawa, Rift Valley Region, Aysha and the Ogaden (MoWR 2001). In particular, the Awash Basin is noted as one, which presents an immediate challenge to manage the water resources in an integrated manner, given the rapid rate of urbanisation in the upper catchment with, among other things, the impact on water quality, and the relatively developed state of the water resources within the basin. In such basins, it is important to take a basin perspective, not only with regards to the water quantity, but water quality as well (McCornick et al. 2002).

Recent advances in integrated water resources management were also highlighted and discussed from a basin perspective (Sally). Among others, the relative importance of various water management strategies at the development, utilisation and allocation stages of basin development were highlighted. The significance of these phases of basin development especially in the context of a closing basin were discussed, highlighting available tools and methodologies that could be relevant for strategic management of water resources in Ethiopia's river basins (Sally). The strengths of these tools in leveraging the bargaining position of different stakeholders (including nations) in water negotiations (e.g. shared basins such as the Nile) were elaborated.

Research opportunities and capacity building requirements in water and land management

The presentations and discussions in the workshop highlighted many relevant issues of water and land resources management in Ethiopia. While noting that not all of the presented problems can be addressed at the same time, it was also recognised that some of the issues present opportunities for research and capacity building especially in the context of the existing (favourable) national policies and highly committed political will. There is already some knowledge on most of the issues raised, but most of it remains incomplete, hence the need for capacity to generate new knowledge and aid implementation. Also, much of the existing sources of information on water and land resources management in Ethiopia recognise that there is considerable relevant experience, but a paucity of information on indigenous practices, successful interventions and lessons learned.

Identified knowledge gaps

This section presents a summary of the issues, or knowledge gaps, identified during the workshop. Further details on issues discussed in the working group sessions are also presented.

- small-scale irrigation: it was recognised that there is a lack of effective strategies and tools for the implementation of small-scale, community-managed irrigation in Ethiopia. In particular, the following areas need attention:
  - strategies that enhance community participation in smallholder irrigation; strategies that enhance improvement of traditional technologies, and adaptation and scaling up of already tested modern technologies; strategies that enhance the realisation of multiple uses of water for productive purpose including livestock, and combination of activities that maximised the efficiency of water use
  - institutional issues and linkages (including tenure and property rights
  - ensuring access of smallholders to other institutional support services such as markets, credit and extension
- large-scale irrigation: effective strategies and tools for improving performance and productivity of medium- and large-scale irrigation systems to:
  - mitigate of the recurrent problem of land degradation resulting from salinisation of irrigated lands
  - alleviate of the problem of water logging of irrigated and rainfed areas and

  - address the problem of rising water tables and its consequence on soil salinisation
- research that highlights the relationship between irrigation and food security at various levels (local level/national level)
- potential and strategies for the sustainable development and utilisation of groundwater for irrigated agriculture
- enhancing the accomplishment of drought mitigation role of groundwater in pastoral areas
- livestock linkages to water in a context of increasing water productivity from a systems perspective with water as a key nutrient in livestock systems; role of water in certain metabolic aspects of livestock management
- research on water productivity in agriculture in general
- water pricing and cost recovery issues in irrigation and other sectors needs to be critically examined
- examining the potential for fisheries in many parts of the country
- closely studying the inter-linkages between water-related health and environment; a deeper understanding of causative agents and applying preventive methods rather than relying on cure, which in some cases cannot at all be achieved
- critically examining the impact of increased urbanisation (e.g. Addis Ababa) on land and water resources, and the role of urban/peri-urban agriculture in contributing to food security through
  - generating livelihood of the family, and meeting immediate food security
  - upstream–downstream issues and water quality
  - health issues and the environment (sustainability)
  - agroforestry issues not well articulated but remains a research priority.

Capacity gaps

Specific areas where further capacity is required, in addition to implementing activities related to the above gaps in knowledge, include:

- national level institution or network to co-ordinate, link, support and disseminate results of water and land resources research and capacity building
- capacity in the formation and operation of effective water users associations (WUA) in various catchments
  - effective community-based water supply and sanitation organisations
  - enhance capacity for participation in the management of trans-boundary rivers, e.g. as partners in the Nile Basin Initiative (NBI)
  - adapt technologies and practices for smallholder irrigation
- capacity in dealing with property rights issues related to land and water
- capacity to form and operate credit and marketing co-operatives
- capacity for data collection, management and dissemination
  - surveying and mapping of land title and demarcation of resource boundaries
  - hydromet services, training and education, field trial and research station services
  - monitoring of domestic water supply and quality

- capacity gaps—process
  - regional level to provide support services to small-scale community managed irrigation systems
  - linkages between research and extension/dissemination (impact of research)
  - public–private partnership for water supply (and sanitation) provision and
  - investigation and mitigation of the environmental impacts of irrigated agriculture.

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Proposed framework for collaborative research and capacity building programme on water and land management in Ethiopia

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Summary

This framework is a working document prepared by the International Water Management Institute (IWMI) in collaboration with the International Livestock Research Institute (ILRI), the Ministries of Water Resources and of Agriculture of the Government of Ethiopia, the Ethiopian Agricultural Research Organization (EARO), the Ethiopian Science and Technology Commission (ESTC), Mekelle University (MU), and the Arbaminch Water Research Institute (AWTI).

The first working draft was prepared by IWMI. It was revised based on feedback from the Ministry of Water Resources (MoWR). The current version has been revised in the light of comments made at the workshop.

Introduction

IWMI and ILRI

The International Water Management Institute (IWMI) is an international non-profit research institute. It was established in 1984 as an 'International Irrigation Management Institute', but changed its name in 1996 to reflect a broadening of its mandate. Its headquarters is in Colombo, Sri Lanka. In the year 2000, IWMI established a major Africa Regional Office located in Pretoria, South Africa. This reflects the Institute's substantial commitment to Africa.

IWMI's goals are:

- to generate new knowledge and tools on water and land use in agriculture that can have a real impact on improving the livelihoods of the world's poorest people. IWMI specialises in producing new knowledge on integrated land and water resources management and ensuring that it reaches the intended users.

- to complement the efforts of other organisations working on water/poverty issues by providing a multi-disciplinary research perspective covering hydrological, economic, agricultural, health, environmental, sociological and institutional/policy dimensions of water management. All IWMI's work is done in partnership with national, regional and international research organisations and with policy making and management entities that would use the knowledge generated.
- to promote professional development and capacity building in developing countries, which will enable these countries and IWMI's partner institutions to better manage their land and water resources.[1]
- in Africa, IWMI's specific goal is to contribute meaningfully to improving peoples' livelihoods through better access to and management of land and water for productive and other uses. This is done through interdisciplinary research in five global research themes.[2]

The International Livestock Research Institute (ILRI) is a non-profit institution governed by an international Board of Trustees created in 1995 by the merger of the International Livestock Centre for Africa (ILCA), based in Addis Ababa, Ethiopia, and the International Laboratory for Research on Animal Diseases (ILRAD), based in Nairobi, Kenya. Through the ILCA heritage, ILRI commenced research on livestock management in Ethiopia in 1974. In collaboration with the Ethiopian government, ILRI conducts research in various parts of Ethiopia.

ILRI works to improve the well-being of people in developing countries by enhancing the diverse and essential contributions livestock make to smallholder farming. Two-thirds of the world's domestic animals are kept in developing countries, and rural smallholders own more than 90% of them. Ethiopia contains more livestock than any other African country. Ruminant animals provide poor farmers with some of the resources they need most: high-quality food, animal traction and transport, manure to fertilise croplands, a daily income through dairying, and insurance against disaster. The management of these animals is highly dependent on water but also greatly affects water supply and quality that people require for many purposes.

IWMI and ILRI are among the 16 food and environmental research centres, known as the Future Harvest Centres, located around the world. Some 60 governments, private foundations, and international organisations known as the Consultative Group on International Agricultural Research (CGIAR) support these centres. As Centres supported by the CGIAR, the common mandate of IWMI and ILRI is to produce international public goods that contribute to poverty eradication.

1. Further information on IWMI's global programme can be found in its Strategy for 2000–2005, and on its web site, http://www.iwmi.org.
2. IWMI's research themes include, integrated water resources management for agriculture, sustainable smallholder water and land management systems, sustainable groundwater management, water resources institutions and policies, and water, health and the environment

Water resources and agriculture in Ethiopia

Ethiopia has abundant water resources with the annual surface runoff alone estimated to be 122 billion cubic metres (MoWR 1999). However, the spatial and temporal distribution of these resources is very uneven. This is coupled with a wide range of climatic and topographic conditions that create a diversity of agro-ecological and soil conditions across the country. Subsistence agriculture is the dominant activity of the vast majority of the Ethiopian population, providing employment for about 80% of the population and contributing over 75% of the country's exports. The main cereal crops are maize, wheat, sorghum, barley, millet and teff, with a total surface of 6.8 million hectares. Livestock is crucial for rural livelihoods in Ethiopia, with 34.5 million head of cattle and 36 million sheep and goats (FAO 2001). However, agricultural production (including livestock) remains far below expectations, with production systems that lead to considerable degradation of land resources. The generally low rainfall with very high spatial and temporal variability limit production, and makes large parts of the country vulnerable to recurrent droughts; the current drought (2002–2003) may have a devastating impact on millions of people. Technological innovation has been less than in many other countries over the past few decades. As a result of these factors, rural poverty is endemic.

To date, the water sector is at a low state of development and the developed infrastructure is performing below expectations (MoWR 1999). There is evidence that the country has sufficient water and irrigable land resources to meet the nation's domestic food needs and become a major exporter of agricultural produce. However, less than 5% of the irrigable land has been developed, and even this is said to be performing below expectation (MoWR 1999). This creates a critical need for looking at ways of exploiting the irrigation potential of the country. Most of the irrigated area consists of small-scale gravity irrigation using traditional techniques, while in the Awash Valley a few large modern farms can be found. Domestic water use also counts among the world's lowest, with only 31% of the population having access to safe water supply. This factor, combined with widespread malaria and serious malnutrition, underlies the serious health issues faced by the rural poor.

In addition to shortages of financial and human resources, Ethiopia needs to strengthen its research base as a foundation for developing its water and agriculture sectors effectively. A strong agricultural and natural resources research programme combined with appropriate extension, training and other support services, is an essential pre-requisite for expanding agricultural production. Similarly, to plan and use its water resources in an optimal way, the country needs a strong research programme in integrated water resources management. This becomes even more imperative as the country engages in a dialogue with its neighbours on the Nile Basin Initiative (NBI). Currently, in both the water and agriculture sectors there is significant capacity in some areas, but serious shortfalls in others.

In sum, for Ethiopia to address the wide variety and complexity of water and land management issues it faces, and to fully engage in the management of the Nile Basin waters, the nation must develop a strong indigenous research and water and land management capacity. The major outcome of a recent joint IWMI–ILRI mission to Ethiopia was a recognition by all parties that IWMI and partners like ILRI can make an important contribution to developing a research base, and strengthening local capacity for water and land research.[3] This paper sets out a proposed framework for collaboration with Ethiopian partners to achieve these goals.

Collaborative research and capacity building programme

The overall scope of the collaborative research and capacity building programme is water and land resources management in Ethiopia. Emphasis will be given to sustainable improvement of agricultural productivity, including livestock and fisheries; to its relationship with human health and the environment; and to water resources management.

The programme, in accordance with the Ethiopian Water Resources Management Policy (MoWR 1999), will be guided by the principles of integrated water resources management (IWRM). Research will be targeted at different scales, from the crop to field, micro-watershed and river basin levels, including trans-boundary issues.

The proposed programme will therefore have four broad objectives:

- to provide short-term support to policy makers, planners and senior managers with tools and information that they can use as they define priorities and develop and implement policies and programmes on poverty alleviation through efficient use of water and land resources. This can be achieved through workshops, training courses, study visits etc.
- to initiate conceptual and practical research on high priority issues, including at least some issues that would have results and benefits in a relatively short period, in collaboration with Ethiopian partners. This research would seek to develop solutions to problems in particular zones or under particular conditions
- to collaborate with local governments and non-governmental organisations (NGOs) to improve their impacts on poverty reduction through practical action-oriented applied research and scaling up of appropriate technologies and management systems and
- to plan and implement with Ethiopian institutions a programme of professional development and capacity building that will contribute significantly to meeting Ethiopia's medium and long term requirements in terms of land and water resources research and management.

Strategic approach to research programme

Key facets of the basic strategy for the research programme should include:

- development of technologies and approaches to water and land management that are appropriate for Ethiopia. This may include adaptation and dissemination of lessons learned elsewhere for Ethiopian conditions
- emphasis on capacity building within existing institutional entities (these are to be defined by the Ethiopian partners, but will include a broad set of institutions including

3. *Report on Mission to Ethiopia*, 25 February to 3 March 2002, by a team of five IWMI scientists and one ILRI scientist.

the Ministry of Water Resources (MoWR), Ministry of Agriculture (MOA), EARO, Ministry of Foreign Affairs, Environmental Protection Authority, various universities, NGOs etc.)
- in the Nile Basin, work within the Nile Basin Initiative (NBI) framework. It is recognised that it is Ethiopia's intent to create the necessary capacity to fully serve the nation's interest with respect to the Nile waters
- support for implementation of the national water resources management and agricultural policies
- inclusion and integration of Ethiopian scientists, policy makers and other professionals into African regional and global activities that have direct relevance to Ethiopia, including Ethiopian participation in global and regional programmes managed by IWMI and ILRI.

Comparing IWMI's and its partners' comparative advantage with the needs of Ethiopia, it is possible to envision a very large programme with many different areas of work.

Examples include:
- integrated watershed management
- river basin management
- policies and institutions for land and water management for crop production, livestock and the environment
- improved land management, including soil conservation, soil fertility maintenance, drainage and management of soil problems, rainwater harvesting etc.
- water reuse/wastewater irrigation and peri-urban agriculture
- sustainable use of wetlands
- integrated approaches to land, water and livestock management
- sustainable groundwater management
- health issues related to water, including malaria, bilharzias, nutrition, and drinking water and sanitation
- design and management of large-scale irrigation schemes and other major water infrastructure
- smallholder irrigation design, management, and viability; adaptation and use of low-cost micro-irrigation technologies
- managing tradeoffs between development of water resources for agriculture and environmental impacts such that water resources are developed to their optimal level without incurring unacceptable environmental impacts and
- drought and flood forecasting, climate variability, coping strategies and mitigation.

At this stage it is proposed to develop the future research and capacity building programme around three focal areas as follows:
- Household and farm-level integrated water and land resource management including: water harvesting, domestic water supply, agro-ecological interventions to reduce malaria, livestock husbandry practices, micro-irrigation technologies, land and fertility management; and in peri-urban areas, recycling of waste water in agriculture.
- Integrated watershed and natural resource management including: small-scale irrigation, policies and institutional arrangements at district and community levels,

livestock and vegetation management, water harvesting, irrigation and drainage scheme design and management, management of soil salinity, conservation of wetlands.
- River basin management including: policies and institutional designs at basin, regional and national level; application of decision-support tools for water management; large-scale irrigation, livestock and vegetation management; drought and flood forecasting and mitigation, climate variability and change and its implications for long term productivity.

These areas were generally endorsed by the workshop. As the programme evolves, the above areas will be prioritised and key research questions identified to address the most significant water and land management issues in Ethiopia.

Strategic approach to professional development and capacity building programme

Achieving the level of water and land management research and management capacity desired by Ethiopia will take a large investment in human resources development and institution-building over at least a decade. IWMI and its partners can make an important contribution to achieving this objective, though of course there will be other initiatives at the same time. Our comparative advantage is in post-graduate research-based education in co-operation with universities, training of trainers in the use of various tools and methodologies, policy and strategic workshops and programmes, and support for institutional reforms in both the agricultural and resources management sectors.

This component of the overall programme could therefore include the following:

In the short term

- Workshops, study tours, and short training programmes for senior policy makers, water managers, and researchers aimed at providing tools, skills, and knowledge that could be used immediately. These would be designed based on interest and demand.
- Support for MSc and PhD students' research on topics that are important to Ethiopia and within the comparative advantage of IWMI, ILRI and other CGIAR partners.
- Collaboration with NGOs, public and private institutions at district level etc. in field testing and adapting innovations that will have a direct impact on people's livelihoods through better land, livestock and water management. An example is the current co-operation on treadle pump adaptation with the Ministry of Agriculture.

In the medium to long term

- In co-operation with Ethiopian research institutions and universities, plan and implement a programme that combines research, opportunities for post-graduate studies (MSc, PhD, post-doctoral), and curriculum development. This could be implemented in a 'sandwich mode', i.e. helping Ethiopian universities to strengthen their own capacity to provide post-graduate training by further strengthening existing links and establishing new ones to universities in other parts of Africa, Asia, Europe, and North America; and co-supervising research by students.

- Assist Ethiopian technical training institutions to improve their curriculum and training skills to impart the necessary skills to technical staff in water and land management.
- Develop and implement joint research projects on the above topics in a way that provides opportunities for on-the-job training.

At the workshop, there was clearly a very high level of interest by all parties in such capacity-building activities.

Governance

Participation

To achieve its targets, the Ethiopian collaborative research programme on water and land resources requires a well-co-ordinated team of partners and participating organisations. To avoid fragmentation, research projects and activities must contribute to the overall framework. The necessary strategic planning is the proposed role of the Ethiopian National Consultative Committee for Water and Land Management Research.

The research *partners* have primary responsibility for the output of the overall programme. *Participating organisations* will collaborate on specific projects and activities, and will be responsible for the outputs from the project or activity. Participating organisations will be drawn from national and regional government agencies, national and regional research organisations (e.g. EARO, ESTC etc.), universities (e.g. Arbaminch, Addis Ababa, Mekelle etc.) and NGOs. The composition of the group of participating organisations is the responsibility of the National Consultative Committee.

Governance

The Ethiopian Science and Technology Commission (ESTC) has recently completed a study recommending the establishment of an institutional framework to support water research, somewhat like the arrangements in the agriculture and health sectors. The workshop endorsed the implementation of this institutional framework. It also endorsed the planned research department within the Ministry of Water Resources. However, it is recognised that implementation of these new institutions will take time. Therefore, the proposed Ethiopian National Consultative Committee for Water and Land Research should be established immediately to bridge the gap. The workshop also proposed that a broad Memorandum of Understanding between IWMI and the Government of Ethiopia be prepared as a framework for the collaboration.

The Ethiopian National Consultative Committee will guide the collaborative research and capacity building programme with IWMI and ILRI on water and land management. This will consist of senior representatives of major stakeholders, including the Ministries of Agriculture, Health, and Water Resources; regional government agencies; national and regional research organisations; and universities, in addition to representation from IWMI, ILRI and possibly other CGIAR centres.

The National Consultative Committee's primary functions are to:

- identify issues and requirements for research and capacity building
- guide the development and promotion of a coherent approach for the research programme
- assist in raising the necessary resources and ensure their proper management
- facilitate the synthesis and dissemination of the research results to the broader stakeholder community through institutional arrangements to be created
- monitor and assess the programme's achievements
- ensure that the programme is contributing to the larger goals of Ethiopia in the agriculture and water resources sectors.

In the short run, the Ministry of Water Resources has created the core group that organised the December 2002 workshop (this proceedings); this group with some further strengthening could lead the elaboration of the proposed long-term collaborative programme.

Timeline

The intent is to develop and implement a long-term collaboration on water and land management research in Ethiopia that has long-term substantial support from strategic donors. The December 2002 workshop has produced an agreed framework for collaboration, reflected in this proceedings, which provides a basis for designing the future programme and proposals to attract funding.

Resources and funding

The envisaged programme is ambitious and beyond the financial means of IWMI, ILRI, or indeed the Ethiopian Government by themselves. Therefore, it will be necessary for the partners to develop a strategy for attracting long term funding from interested donors. All of the partners fully recognise the need to raise funds, and will co-operate to do so. The workshop identified the need to approach many kinds of partners for support. The donors supporting the Nile Basin Initiative, among others, may also be interested in providing support to this initiative. The CGIAR Challenge Program for Water and Food, in which IWMI is the lead partner, will be another potential source of funding for research and capacity building through a competitive grant process.

Other relevant Ethiopian initiatives

The following activities were brought to our attention; more may be added at the workshop and as this collaboration matures:

- a recently completed study by the Ethiopian Science and Technology Commission (ESTC) to identify research and development issues and needs for water resources management in Ethiopia for the Ministry of Water Resources. This study has been referred to above
- the Ministry of Water Resources' on-going study to determine institutional requirements for integrated water resources management (IWRM) for Ethiopia's 12 major basins
- the Ethiopian Agricultural Research Organization has developed concept papers (EARO 2002) on smallholder irrigation, water harvesting, drainage technology, and environment and irrigation
- the Ministry of Water Resources is proposing to expand the mandate of the Ground Water Development Training Center (10 km south of Addis Ababa) to include water resources in general, and to undertake applied research.

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Summaries of working group sessions

Following the one-and-a-half-days of plenary sessions, the workshop broke into five working groups. These working groups were:

- household and farm level
- integrated watershed management
- basin/trans-boundary level management
- funding and governance
- capacity building

The groups were expected to identify key issues of research and capacity building interest to Ethiopia, explore potential research questions, identify key partnerships and determine next steps. If time allowed, the groups were to draft relevant pre-concept notes. The groups were also encouraged to provide feedback on the framework paper.

The remainder of this paper summarises the output from each of the five working groups.

Group I: Household, farm, community level issues

This group focused its discussion on the following priority areas:

Poverty alleviation

- develop and select relevant household indicators of poverty in the Ethiopia context (e.g. economic, food security, health, education, type of house)
- assess and analyse the causes of poverty especially in rural Ethiopia
- determine the level and incidence of poverty in specific communities and relate these to current water and land management strategies, and identify ways for improvement.

Water harvesting

- research and capacity building on water storage technologies for their efficiency and appropriateness (including technologies to reduce seepage and loss of stored water)
- potential and possibility of micro-irrigation with small pumps
- different technological approaches that address production in the highlands and lowlands, especially the pastoralists
- water harvesting for domestic use, and for livestock
- moisture conservation *in situ*
- catchment protection with methods such as erosion control, aforestation).

Domestic water supply

- water quantity and quality issues that are important for human consumption
- storage and treatment technologies and practices
- water use and hygiene education
- water delivery and transport systems
- assessment and protection of groundwater.

Drainage and water use efficiency

- safe drainage of vertisol soils: Prevention of water logging and excess withdrawal
- water use efficiency at farm level
- supplementary irrigation.

Uptake of technologies and agricultural crops

- participatory on-farm development and testing of new technologies (e.g. affordable drip irrigation systems)
- dissemination of existing farming technologies (e.g. tillage, irrigation, drainage, storage)
- distinction and relative importance of food crops, cash crops, fodder crops, *chat*.

Urban and peri-urban agriculture

- horticultural crops for urban demand
- potential for roof water collection

Marketing and other economic issues

- physical access to markets (roads)
- when to store, when to sell?
- post-harvest technologies (safe storage and transport)
- property rights: Land tenure, land ownership, land use rights, water rights, fragmentation of land (high pressure on land for new families)
- issues related to direct taxes on harvest and taxes on inputs, contributions (e.g. church, sports, community activities), repayment of loans and interest (payments by farmers should not be done at harvest time when the prices for produce are low)
- habits: Non-farming days (religious holidays); uneconomical use of produce (e.g. weddings, festivals); hygiene behaviour; local family planning issues; *chat* consumption.

Health issues (malaria and other diseases)

- what are the dynamics of increased malaria transmission associated with irrigation and dams?
- how does this change over time?
- who are affected?
- relation to livestock (e.g. breeding in hoof prints, diverting mosquitoes to or from people).
- bed nets (e.g. coverage, affordability).

Potential partners—Ethiopian Ministry of Health; Bureaus of Water Resources (Ethiopia); Bureaus of Health; Institute of Health Research; Universities: Addis Ababa, Alemaya, Jimma, Arbaminch, Mekelle (also medical faculties); NGOs; UNICEF; WHO; ILRI; IWMI; Private enterprises (e.g. treatment, bed nets); Bilaterals; Religious organisations; Ministry of Agriculture; Ministry of Culture; Ministry of Labour and Social Affairs; Regional Governments; Micro-finance Enterprises; Private Enterprises; Regional Research Institutes; Ethiopian Agricultural Research Organization.

Group II: Integrated watershed management

After a detailed deliberation by fourteen experts of diverse technical backgrounds and from different institutions, four key areas were identified as important focus areas for watershed management in the country, from a research and capacity building perspective. These areas included:

- water harvesting for small-scale irrigation, livestock and domestic use within a watershed
- alternative energy sources and their potential to sustain livelihood and preserve environmental needs within a watershed, including hydropower, wind, solar, animal wastes, fuel-wood etc.; domestic water supply for human activities and livestock
- livestock, agroforestry and vegetation management, including the introduction of legumes for soil nutrients replenishment, systems stabilisation through soil improvements and provision of additional livestock fodder etc.
- health and environmental issues in a watershed. Important environmental issues in a watershed of research and capacity building interest, among others, include soil erosion and land degradation, soil and water conservation, and maintenance of biodiversity within a watershed. Health issues relate more to the impact of different land and water management strategies (including management for irrigation and livestock) on human health–water related diseases etc.

The group identified various research questions, thought to be relevant for the planning research and capacity building work in water and land management in Ethiopia. The questions, grouped according to identified focus areas, are presented below, as is a draft concept note.

Focus area I: Water harvesting for small-scale irrigation (SSI), livestock and domestic use

- identification of best traditional small-scale irrigation practices and water harvesting technologies and assessment of their potential for up-scaling
- determination of runoff coefficients and rates of sedimentation from various catchments for irrigation scheme design
- water situation assessment (quality and quantity) in watersheds for various productive purposes, including surface and groundwater potential
- studies on salinity hazards in small-scale irrigation; prevention and soil reclamation
- potential for conjunctive use of surface and groundwater sustainably in watershed context
- selection of biological soil water conservation (SWC) methods in a catchment
- integrated pest management in watersheds
- potential for cost recovery in SSI, including an assessment of optimal level of cost that could be incurred by farmers sustainably, and key incentives for repayment of such costs by farmers
- ways of increasing labour productivity in smallholder production; assessment of complimentary income generating activities such as the integration of fisheries with livestock production etc.
- role of markets in supporting smallholder production and livelihoods in a watershed, e.g. access to input and output markets. Role of markets in stimulating the productivity and profitability of production on smallholder irrigation schemes and
- impact of frequent land redistribution on productivity of smallholder farmers (especially irrigation farmers), and farmers incentives for investment in soil and water conservation.

Focus area II: Livestock, agroforestry and vegetation management

- assessment of parameters and measurement of water productivity in the livestock sub-sector in the context of growing water scarcity in a watershed
- potential biological methods of improving/sustaining soil fertility and water productivity in crop–livestock systems in a context of growing scarcity.

Focus area III: Alternative energy sources in a catchment

- appropriate technology choice with regards to energy (solar, wind, water/hydropower, animal dung, fuel-wood etc.).

Focus area IV: Health and environment

- wetlands management, including potential for sustainable exploitation while preserving environmental values, uses and functions etc.
- water related diseases in small-scale irrigation (health impacts of water-harvesting technologies; micro-dams etc.)
- studies on appropriate farming practices that maintain biological diversity and resuscitate environmental quality.

Pre-concept note

Purpose

Given the research questions stipulated above, to facilitate sustainable socio-economic development through integrated natural resource management, focusing on water, within a watershed context.

Research questions

(as listed above)

Expected outputs

- capacity building: through workshops and working with communities; through student collaboration etc.
- generation of a database that will be a useful planning tool for watershed development (useful for governments, NGOs, communities etc.)
- various research outputs and packages, with recommendations for policy and development practitioners
- establishment of benchmark watershed that will be useful references for the planning and development of other watersheds.

Activities and methods

- intensive literature review
- in-depth case studies
  - designing of the study through and inception workshop
  - data collection (empirical data)
  - empirical analysis and
  - reporting and dissemination.

Impacts

- improved food production in catchments
- improved livelihood of communities and rural people living in catchments
- rehabilitation of degraded lands and
- improved capacity of communities to implement or continue projects or initiatives.

Interested partners

IWMI, ILRI, Ministry of Agriculture (Ethiopia), Ministry of Water Resources (Ethiopia), Metaferia Consultant Engineers, Environmental Protection Authority (Ethiopia), Institute for Biodiversity Research and Conservation, Addis Ababa University (Civil Engineering Department), Water Aid Ethiopia, Tigray Water Resources Development Bureau, Tigray Bureau of Agriculture and Natural Resources, Amhara Region Water Bureau; Land, Mines and Energy Resources Bureau for Southern Region; Oromiya Water Resource Bureau; Oromiya Natural Resources Bureau; Oromiya Environmental Bureau; Arbaminch Water Technology Institute.

Possible funding sources

CGIAR Challenge Program on Water and Food, IDRC, IFAD, World Bank, AfDB, FGM, GEF, IUCN, UNDP, USAID, EU, SIDA, Ethiopian Government.

Group III: Basin/trans-boundary issues

This group considered a number of issues, including various scales of analysis and categories of research and capacity building issues. The scales included the entire basin within a region or country, shared basins between regions or countries, small and large scale irrigation, and other uses, including hydropower and water supply for domestic and productive purposes.

The group then proceeded to review the Water Resources Policy, Water Resources Strategy of Ethiopia and the Framework Paper Developed by IWMI for water and land Management in the country. Various knowledge gaps and capacity building issues were identified. The major areas of research and capacity building were identified under technical, economic, institutional and legal, and social and environmental categories.

Technical issues

- river basin modelling and DSS
  - groundwater,
  - catchment, physical models

- cost effective hydrologic and hydraulic design standards and guidelines
- river morphology, sediment transport and flow/flood characterisation
- application of emerging technologies—GIS and Remote Sensing
- water quality and quantity monitoring
- information management
- groundwater
- equitable sharing
- index catchments modelling
- performance evaluation
- optimal use of land and water and other basin resources
- multi-purpose reservoirs along rivers.

Economic issues

- public–private sector partnership
- incentive mechanism for private investment
- cost recovery
- marketing problems of irrigation output—facilities at scheme and national policy level
- flexibility in design—crop and water management patterns—alternatives
- marketing and credit infrastructure flexibility
- optimum water and land use planning—links
- impact—relevance of government water policy on the national economy
- cross-sectoral issues—water and other sectors of the national economy
- sustainability of investment
- impact on income and purchasing power
- efficiency in BOT for hydropower
- DSS to evaluate impacts of technologies, management approaches, and policies for decision-makers
- share of investments for water resources development—regions
- cross-sectoral cost sharing
- water pricing and tariffs and
- economic efficiency and social equity.

Institutional and legal issues

- appropriate institutional set-up at all levels—international experience
- nature of partnerships/co-operative framework
- conflict resolution and negotiation
- water rights at different levels
- implementation of programmes—institutions
- information sharing with riparian countries

- navigational use of rivers and lakes
- enforcement of water laws—permits
- indicators for monitoring the following:
  - environmental impact
  - technical performance
  - economic performance
- wetland management strategy and
- soil salinity and other issues.

Group IV: Governance and resources

The discussions of this group were focused on institutional requirements for co-ordination and support of water resources research, identifying challenges and possible sources of funding, and identifying key partnerships. The details include:

Institutions

- endorse autonomous institution for co-ordination and support of water resources research
  - Similar to framework in agriculture and health sector
  - ESTC report offers proposal for this
  - Government should commit itself
  - Gradual development of R&D institution
  - Institution needs strategy for collaboration with international institutions
  - Possibility of IWMI role in institutional development.

Challenge

- effective co-ordination of the Ethiopian Agricultural Research Organization and the Ministry of Agriculture, Water Resources Research and Development Institute, Ministry of Water Resources, EPA etc.
  - metadata base will help bridge this gap
  - suggest: joint technical committee, with clear guidelines and terms of reference.
- importance of institutional stability
- develop water-related research and capacity building project proposals focused on government priorities—such as PRSP (food security and rural livelihoods and Agricultural Development-Led Industrialisation, ADLI).
  - water recognised as key sector
  - government commitment to research—may respond positively
  - government commitment may leverage donor funds
  - include research and capacity building components in investment projects.

Possible source of funding

- Government of Ethiopia
- private sector
- NGOs
- external support agencies—multilateral, bilateral, initiatives like NBI
- CGIAR Challenge Program on Water and Food.

Partnerships

- networking among existing water-related institutions, e.g. MoWR, universities, ESTC, EPA, MOA, EARO, professional associations, NGOs etc.
- partnerships with international institutions, such as ICID, GWP, IWMI, ILRI (and other CGIAR centres), Global Mechanism for Combating Desertification etc.

Recommendations

Ethiopian national consultative committee on land and water research, as recommended in Framework Paper reinforces technical committees of the proposed water research institute and EARO as well as universities, Geological Survey of Ethiopia, and other key national stakeholders.

Group V: Capacity building

The group focused on the identification of primary issues and development of key research questions on capacity building in water and land management. Primary issues entailed an assessment of natural resource potential, development, utilisation and associated opportunities. The primary issues, research questions and proposed research questions include:

Assessment

- water resources potential
- land resources potential
- environmental impacts

Development

- Planning
- Design

- Implementation

Utilisation

- effectiveness
- efficiency

Opportunities

- ample potential of water and land resources
- viable policy has been formulated at the government level
- sectoral/cross-sectoral strategies and action plans are being developed for implementation of policy
- increased realisation of the need for research and capacity building in water and land management
- intention to establish water research and development institute
- expansion of higher learning and technical training institutions
- growing collaboration with donor and international organisations including training institutions.

Potential research questions

- analyse minimum capacity requirements for research on land and water resources management with reference to:
  - human resource
  - financial resource
  - institutional aspects
- evaluate existing programmes with the view to strengthening the relevance and effectiveness of training in land and water resource management
- identify causes and extent of brain drain with a view to creating an enabling environment for researchers.

Proposed next steps

- the identified research questions could be addressed under the framework of the proposed water R&D institute
- the report of the study of R&D in the water sector could serve as a basis for developing research ideas and priorities.

Recommendations

- the proposed Water R&D institute should be established as soon as possible
- project proposals should be developed to address the specific research questions identified under the proposed collaboration framework.

Key partnerships

- main stakeholders in land and water resource management
  - urban and rural communities
  - national and regional research institutions
  - government institutions (e.g. AAWAS, EEPCO, NMSA, GSE, ministries of water resources, agriculture, infrastructure, capacity building, rural development), Regional Water Bureau)
  - higher learning and technical institutions (e.g. AWTI, AAU, AU, MU, JU, BU, DU)
  - industry (private and public)
  - non-governmental organisations—local and international (e.g. Water Aid, Water Action, SNV)
  - international research organisations (e.g. ILRI, IWMI)
  - donor agencies (e.g. GTZ, SIDA, Dutch Government, CIDA, USAID, JICA)
  - consulting firms (e.g. WWDSE, MCE, Aquatech Consult, Continental Tropics)

Closing remarks

H.E. Gebremedhin Belay
Vice Minister of Agriculture, Federal Democratic Republic of Ethiopia

Honourable Guests
Dear Participants
Ladies and Gentlemen

I am pleased to congratulate you on behalf of the Ministry of Agriculture and on my own for the successful deliberation you had on the workshop 'Integrated water and land management research and capacity building priorities for Ethiopia'.

Ethiopia is endowed with a variety of natural resources and wide ecological diversity. Indeed, the country's available natural resources and the water and land use on the sufficiently potential arable land are not developed to ensure the proper and sustainable exploitation of the resources for improving the livelihood of the nation and its peoples. Environmental degradation is aggravated and the intensity of soil erosion has been increasing from time to time mainly due to high population growth on existing arable land, which requires more settlement area, farming plot, grazing land, and energy mainly from the natural forest.

The settlement pattern is not in balance with the land carrying capacity and other resources. Population density widely varies from region to region and from one agro-ecological zone to another.

In most of the lowland areas, there are relatively wide areas of arable land. In fact, these areas may not require fertilisation for the first few years when put under cultivation. However, until very recent years, there was lack of clear and properly articulated settlement policy and strategy. This problem is compounded due to the low level of infrastructure development, variable weather conditions, high incidences of diseases etc. These factors have hampered the mobility and settlement of the people in these areas.

The Government of Ethiopia in its current rural development policy and strategy has properly articulated the need for undertaking voluntary settlement and infrastructure development where there is a possibility for investment and settlement.

Nevertheless, this is not something that the Ethiopian Government alone could carry out with its limited resources. In this regard, resources from external agencies and specialised institutions are highly expected.

Ladies and Gentlemen

Because of total dependency on rain fed agriculture, the occurrence of drought is always a challenge for Ethiopia. Its effect extended from economic destruction to loss of life. This particular year, the failure of crop alone is estimated to affect or threaten the lives of 14–15 million people, who have no reserve to feed themselves; as a result, the burden fell on the shoulder of the nation and donor communities. You can imagine the crises in the absence of timely intervention.

Actually, the impact of drought is not limited only to the livelihood of the society but also affects the biodiversity, which must get due attention. Why? Because the existence of biodiversity is important for the sustainable productivities of land.

Ladies and Gentlemen

In your three days deliberation, you have discussed a number of issues in relation to integrated water and land management. I have been informed that the issues are actually very important to address the agenda of poverty although basic research will still be needed. Immediate research results for solving problems of local dimension and capacity building at all levels in this respect are extremely important. Therefore, it appears that adaptive research, which can bring immediate benefits to the community, should be given top priority.

Ladies and Gentlemen

Before I conclude my statement, let me assure you that your recommendations will be taken as important considerations by the Ministry of Agriculture and other stakeholders in making further interventions.

Once more, I would like to thank the International Water management Institute (IWMI), the International Livestock Research Institute (ILRI), the Global Mechanism (GM) of the United Nations Convention to Combat Desertification (UNCCD), the International Development Research Centre (IDRC) and United Nations Economic Commission for Africa (UNECA) for financial assistance for the workshop. I would also like to extend my thanks to all of you who have made the plan a reality.

Finally, wishing happy journey to foreign and regional participants, I now declare the workshop is officially adjourned.

I thank you.

Programme

Workshop on integrated water and land management research and capacity building priorities for Ethiopia 2–4 December 2002

Time	Subject	Presenter
2 December 2002		
8:30 am	Registration	
Plenary session A: Opening		
9:00 am	Welcome address	Ato Gulilat Berhane
9:10 am	Workshop goals and expected outputs	Dr Doug Merrey
9:30 am	Opening remarks	Dr Don Peden
	Opening statement	H.E. Ato Shiferaw Jarsso
10:10	Coffee break	
Plenary session B		
Moderator: Ato Mesfin Tegegne, Vice Minister of Water Resources		
10:30 am	Keynote address in the area of land and water resources	Dr Admassu Gebeyhu (Consultant)
10:50 am	Present and future of water resources development in Ethiopia	Ato Gulilat Berhane (MoWR)
11:10 am	Present and future trends of natural resources management: Land and water in agriculture	Ato Belayhun Hailu (MOA)
11:30 am	Present and future of natural resource management research: Strategy, gaps/issues on research and capacity needs	Dr Demle Teketaye (EARO)
11:50 am	Discussions	
12:30–1:30 pm	Lunch	
Moderator: Comm. Mulugeta Ameha		
1:30 pm	Global and African programme of IWMI: Relevance to Ethiopia	Dr Doug Merrey (IWMI SA)
1:45 pm	Water harvesting in northern Ethiopia: Environmental, health and socio-economic impacts	Drs Mintesinot Behailu and Mitiku Haile (MU)

Time	Subject	Presenter
2:00 pm	Policies and institutions to enhance the impact of irrigation development on productivity, income, natural resource management and welfare in the highlands of Ethiopia	Drs Birhanu G/Medhin and Don Peden (ILRI)
2:15 pm	Water harvesting and land management in semi/and dry land	AU
2:30 pm	Agriculture, irrigation and drainage research in the past and in the future.	Dr Paulos Dubale (EARO)
2:45 pm	Discussion	
3:30–3:45 pm	Coffee break	
Moderator: Dr Peter McCornick		
3:45 pm	Advances in research in integrated water resources management in agriculture	Dr Hilmy Sally (IWMI)
4:00 pm	Challenges and opportunities in capacity building for water resources development and research in Ethiopia: The AWTI contribution and experience	Dr Sileshi Bekele (AWTI)
4:15 pm	Small-scale irrigation development and water balance in western Ethiopia	Dr Taffa Tulu (Ambo College of Agriculture)
4:30 pm	Integrated watershed management	(ILRI/IWMI)
4:45 pm	Promoting global watershed management towards rural communities: The May Zeg-zeg Initiative	Jan Nyssen, Mitiku Haile, Katrien Descheemaeker, Jozef Deckers, Jean Poesen, Jan Moeyersons and Trufat Hailemariam (MU)
5:00 pm	Discussion	
6:00 pm	Reception and Dinner – ILRI Campus	

3 December 2002

Plenary session C

Moderator: Ato Teshome Workie

8:30 am	An overview of the Ethiopian Rainwater Harvesting Association (ERHA)	Sis. Meselech Seyoum (ERHA)
8:40 am	Comparative advantages and research interest area of the Department of Civil Engineering	Dr Yilma Sileshi (AAU)

Time	Subject	Presenter
8:50 am	Rural water supply	Ato Getachew Abdi (MoWR)
9:00 am	Discussion	
Livestock, water, environment and health		
Plenary session D		
Moderator: Dr Azage Tegegne—ILRI Debre Zeit		
9:20 am	Livestock and water in Ethiopia	Drs Don Peden and Zinash Sileshi (ILRI/EARO)
9:30 am	Advances in livestock and water research and capacity development	Dr Don Peden (ILRI)
9:40 am	Managing water for livestock and fisheries development	Dr Sileshi Ashine (MOA)
9:50 am	Community health, water supply and sanitation	Ato Muchi Kidanu (MOH)
10:00 am	Discussion	
10:30–10:40 am	Coffee break	
10:40 am	Water, health and the environment in irrigated agriculture	Dr Eline Boelee (IWMI HQ)
10:50 am	Water and the environment in Ethiopia	Ato Mateos Mekiso (EPA)
Plenary session E: Research and capacity building in water and land management		
Moderator: Dr Abdul Kamara		
11:00 am	Research issues and capacity building in water and land institutions	IWMI/Ato Abebe Mekuriaw (ESTC)
11:50 am	Introduction to the draft 'Framework for collaborative research on water and land management in Ethiopia'	Dr Doug Merrey (IWMI SA)
12:10 pm	Discussion	
12:30–1:30 pm	Lunch	
1:30–1:40 pm	Briefing about the breakout session	
1:40–3:30 pm	Breakout session I	
	Determine and prioritise key issues and needs in research and capacity. Identify key partnerships and mechanisms for addressing issues. Begin drafting concept notes.	
3:30–3:50	Coffee break	
3:50–5:00	Breakout session II	
	Continue activities from breakout session I	

Time	Subject	Presenter
	Enhance and develop concept notes	
5:10 pm	Close for the day	

4 December 2002

8:30 am	Summary of previous day, and agenda for today	
8:40–10:00 am	Breakout session III	
	Continue activities from breakout session II	
	Prepare for presentation to plenary	
10:00–10:30 am	Coffee break	
10:30–12:30	Plenary session E	
10:30 am	Reporting from breakout sessions	
	Presentation and discussion of breakout session results	
	Primary issues	
	Recommendations on framework	
	Key partnerships	
	Draft concept notes	
12:15 pm	Closing	Vice Minister of Agriculture, Government of Ethiopia
12:30–1:30 pm	Lunch	

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