Land and water resources assessment in the Ethiopian Central Rift Valley

Project: ecosystems for water, food and economic development in the Ethiopian Central Rift Valley

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ABSTRACT

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This report describes results of the project 'Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley'. Aim of the project is to strengthen the local authorities, development organizations and the private sector in the field of sustainable land and water use, and sound environmental planning and management with the aim to contribute to the sustainable development of the CRV. In this report the relation between land and water resources and the impacts of land developments on the water resources and the environment are elaborated.

Keywords: policy support, competing claims, land management, water management, IWRM, land classification, closed basin.

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Contents

Preface

This report describes and summarizes results of research carried out within the project 'Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley'. This project is sponsored by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) and contributes to LNV's policy theme 'Water for Food and Ecosystems'. Aim of this policy is to support governments in identifying management practices, to share practical lessons learned and to identify the necessary enabling environments that lead to sustainable water use at the river-basin level and the harmonization of food production and ecosystem management with a view to implementing already internationally agreed commitments.

The project 'Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley' started in May 2006 with an inception mission (Hengsdijk & Jansen, 2006b). Aim of the project is to support the policy debate on the sustainable use and management of water and land resources in the Central Rift Valley of Ethiopia. First step of the project was to develop a sound knowledge base on the Central Rift Valley enabling well-informed decision-making. This report takes stock of current resource use and management in the Central Rift Valley.

The research has been elaborated in close cooperation with the 'Central Rift Valley Working Group´, a group of stakeholders professionally involved in the sustainable development of the Central Rift Valley. We thank them for their input and discussions during the research process. We also thank Geert Westenbrink, Agricultural Council at the Royal Netherlands Embassy and Janny Poley, Regional First Secretary of the Royal Netherlands Embassy in Addis Ababa for their critical and supportive remarks, discussions and facilitation during project missions.

Executive Summary

The Central Rift Valley (CRV) is situated in the administrative regions Oromiya and the Southern Nations Nationalities and Peoples Region (SNNPR), and covers an area of approximately 10000 km^2. It is one of the environmentally very vulnerable areas in Ethiopia. Being a closed basin, relatively small interventions in land and water resources can have far reaching consequences for ecosystems goods and services, and potentially undermine the sustainable use of the area

The total population of the CRV is approximately 1.5 million with an average population density of 1.5 p ha^{-1}. The total livestock population is in the order of 850000 Tropical Livestock Units. The situation in the CRV is a typical example of competing claims for land and water resources. There is an urgent need for improved resource use, with land and water management that takes the carrying capacity of the CRV ecosystem into account. The challenge is to manage the different resource claims to achieve sustainable development (pathways) for the CRV.

The goal of the project "Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley" is to strengthen local authorities, development organizations and the private sector in the field of sustainable land and water use, and sound environmental planning and management with the aim to contribute to the sustainable development of the CRV.

Stakeholders

The CRV Working Group was initiated as multi-stakeholder platform and major counterpart and platform for dialogue. This Working Group has no formal status yet. It presently consists of civil organizations, representatives of ministries and water-related institutes, the tourist sector and academia. The goal of the CRV Working Group is to 'promote a basin wide integrated water resources management approach so as to make certain that adequate supplies of water of good quality are maintained for the people in the area, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature'.

Water resources

The CRV encompasses a chain of three large lakes (Ziway, Langano and Abyata) and streams that are spatially and temporally strongly interlinked. The Meki and Ketar Rivers are situated in the upstream portions of the catchment. They discharge their water into Lake Ziway. From Lake Ziway water is discharged into the Bulbula River, which flows to Lake Abyata, being the terminal lake.

Lake Shala is situated in an adjacent catchment, however is part of the National Park, together with Lake Abyata and the surrounding woodlands. The lakes have been submitted by the Ethiopian Government to the Ramsar Convention on wetlands in order to be recognized as an international Ramsar site.

The total discharge from the Meki and Ketar River is, on average, 675 to 695 million m^3 per year. The average level of Lake Ziway has decreased by approximately 0.5 meter since 2002. At the same time the discharge by the Bulbula River has decreased from more than 200 million m^3 per year in average years to less than 50 million m^3 in 2003 and 2004. The reduced inflow into Lake Abyata has caused a reduction of the size of this lake to less than 60% of its original size[1].

Land resources developments
The decreased discharge into the Bulbula River corresponds with the development (in the order) of 7500-10000 ha irrigated land. This increased irrigated area is in line with the results of the land survey and satellite image interpretations. Most of the new developments are concentrated in the very downstream portions of the Meki and Ketar catchments and around Lake Ziway. We estimate associated water abstraction of this irrigated land at about 150 million m^3 per year.

The domestic water use and the water use for livestock (respectively 7 and 8 million m^3 per year) are relatively small. The same is valid for the soda ash factory (approximately 1 million m^3 per year). The current water use by the rose farms is in the order of 2 million m^3 per year. It is, therefore, concluded that the development of irrigated agriculture, especially for open field vegetable and fruit production systems, have a large impact on the water resources system and are the predominant cause of the observed reductions in water levels and river discharges.

Impacts
The impacts of the decreased (average) water level of Lake Ziway are:

- Impact on fisheries and lake-related ecosystems (not quantified);
- Reduced outflow to the Bulbula River:
    - negatively affecting water users along the Bulbula River (domestic water users, livestock and irrigated farms);
    - reducing the inflow into Lake Abyata, causing the shrinkage of this lake and the associated environmental degradation, particularly the loss of aquatic bird life;
    - reduction of the flushing of Lake Ziway, causing increased salinity and pollution levels in Lake Ziway.

A serious future threat is that the further decrease of the water level may turn Lake Ziway into a terminal lake. This will cause that Lake Ziway, being the largest fresh water resource in the CRV, eventually becomes saline (similar to Lake Abyata). Given the relatively shallow depth critical salinity levels could already be reached within 5-10 years. The salinization of Lake Ziway will obviously have major repercussions for the recent floriculture developments and the local population, who depend on the lake water for their domestic water supply and their livestock watering.

[1] i.e. the size in 1999 and previous years (1986, 1973).

Floriculture and smallholders
The present water use by the closed systems (floriculture) is minor. If the existing plans are realized the water consumption will increase to 20 million m^3 per year, which is still a small percentage of the total abstraction by irrigated agriculture. The main environmental risks are associated with the use of pesticides and herbicides and the fate of their residues in the soil and water.

From a tentative economic assessment it was concluded that the resource use indicators of flower production systems, especially water and land productivity, are much higher than those of other irrigated production systems. The performance indicators for smallholder irrigated production systems vary largely, as the results are very much determined by (variable) product prices. Various sources have nevertheless indicated that the current economic performance of irrigated smallholder production systems can be improved considerably. Considering their impact on water resources focus should be more on improving the environmental and economic performance of current systems than the further development of these systems.

Rain-fed agriculture
Although water consumption by rain-fed agriculture is an order of magnitude greater than irrigated agriculture, the impact of rain-fed agriculture is much smaller, because the variability of rainfall is directly reflected in the variability of the actual evapotranspiration. This means that years with low rainfall cause low actual evapotranspiration, which principally affects the farmers through reduced harvests. For irrigated agriculture dry years result in higher water consumption.

Because of the relatively limited surface water resources (despite of the presence of big lakes), in combination with the nature of closed basins (where the water resources are interlinked both spatially and temporally), the use of surface water resources can have large impacts, even for relatively small irrigated areas.

Climate change
Over a period of 37 years, the maximum daily temperature has increased with 1.5°C. As a result the potential evapotranspiration will have increased in the order of 3-4 %. This will have caused increased water stress to the rain-fed agriculture (in the same order), while the evaporation from the lakes will also have increased (order of magnitude of 40 million m^3 per year).

The further increase of temperatures can, therefore, significantly impact on the availability of water resources and on the water stress that is already experienced in rain-fed agriculture and ecosystems.

There is no hard evidence of a long-term rainfall trend in the CRV. A more detailed assessment is required to draw more decisive conclusions with respect to the impact of climate changes in relation to the natural erraticness of rainfall.

Recommendations

- Integrated land and water development and management involving all stakeholders is imperative to ensure the sustainable development of the CRV. The existing CRV working group should be further equipped to take the lead in this process;
- The further development of smallholder irrigated production systems should be discouraged given the large impact that they have on the water resources and the environment. Instead, emphasis should be on improving the environmental and economic performance of current irrigated smallholders. In addition, more research is needed to investigate the possibilities to improve the performance of rain-fed agriculture and other livelihood strategies as income alternatives to the predominant poor population;
- The (potential) impacts of residues from the horticulture and floriculture systems on the surface water resources, particularly Lake Ziway, should be investigated;
- A more detailed water quality assessment should be conducted, focused on the risk of salinization of Lake Ziway;
- A more detailed study should be conducted to assess and anticipate the impacts of climate changes on the CRV in more detail.

1 Introduction

1.1 Background

The Central Rift Valley (CRV) of Ethiopia consists of a chain of lakes, streams and wetlands with unique hydrological and ecological characteristics. The wide diversity of landscapes and ecosystems comprise extensive biodiversity-rich wetlands. At the same time the CRV is one of the environmentally very vulnerable areas in Ethiopia. Being a closed basin, relatively small interventions in land and water resources can have far reaching consequences for ecosystems goods and services, and potentially undermine the sustainable use of the area (Ayenew, 2004; Legesse et al., 2004).

The CRV is also one of those regions in Sub-Saharan Africa where poverty and degradation of natural resources are firmly intertwined: On the one hand severe poverty forces people to deplete natural resources in their struggle for survival, on the other hand degraded natural resources together with unfavourable, highly variable climatic conditions aggravate poverty, particularly for the predominant subsistence rain-fed farmers.

Due to the rapidly growing population and the lack of proper land (fertility) management, conversion of natural vegetation into agricultural land is increasing. Trees are cut for construction wood and the production of charcoal, which is an important source of income for the local poor. The abundant livestock population accelerates the loss of vegetation cover through the overgrazing of rangelands.

The increase in degraded land is a clear symptom of the 'hunger' for land. The relatively limited natural resources in combination with the high population pressure have resulted in a "spiral of non-sustainability", and in strong competing claims for land, water, biomass and nature. There is a clear decrease of the water resources. Lake levels have lowered and wetlands have deteriorated.

The competition for land and water amplified after the 1990s, when Ethiopia adopted the Agricultural Development Led Industrialization policy as the main and overarching national development program. This market-based policy strategy envisages the creation of favourable investment conditions for the intensification of agriculture. One of the effects of this policy is the increase of the area under irrigated horticulture and floriculture for export, especially in the Central Rift Valley.

The situation in the CRV is a typical example of competing claims for land and water resources. The challenge is to manage the different claims to achieve sustainable development (pathways) for the CRV.

1.2 Problem statement

There is an urgent need for improved resource use, with land and water management that takes into account the carrying capacity of the CRV ecosystem. Local policy makers, however, seem to have serious difficulties in coping with the negative impacts of the ongoing land and water developments on the livelihood of communities and ecosystems. Resource conflicts will aggravate due to lack of adequate information on resource use by different stakeholders, the carrying capacity of the available natural resources and insight in resource management options to deal with the competition for resources.

One of the prerequisites of sustainable development is sound information and knowledge on the natural resources, with regard to:

- their current use and management;
- their potential for development;
- the impacts of any interventions on the livelihoods op the people and the environment.

On the basis of such a knowledge base options for improved resource use and management can be identified and assessed.

Local policy-makers, institutions, community based organizations and other stakeholders need to be involved in land and water issues. Sound knowledge thus helps to facilitate the policy dialogues for negotiations, policy development and priority setting. Systems knowledge also helps to set the right priorities for further research.

A well-founded knowledge base will help to distinguish myths and perceptions from facts, which will contribute to consensus building among the different stakeholders, and promote the wise use and management of scarce natural resources.

1.3 Objectives

The goal of the project "Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley" is to strengthen local authorities, development organizations and private sector in the field of sustainable land and water use, and sound environmental planning and management with the aim to contribute to the sustainable development of the CRV.

The purpose of this report is to provide scientifically based information to support and facilitate a policy dialogue in the CRV aimed at identification of resource use and management options associated with the rapid increase in the use of water by agriculture and industry. An integrated analysis of the multi-facetted issues at stake helps to conceptualize problems and facilitate the identification of policies and options required to improve current management of water and land resources in the CRV.

1.4 Activities

Preceding activities
The current report follows a desk-study that was carried out in 2006, which provided an outline of the main land and water issues and identified the priorities for a research agenda (Hengsdijk and Jansen, 2006a). Thereafter, an inception mission was organized to further conceptualize and analyze the problems. On the basis of this inception mission a more comprehensive, multi-disciplinary research plan was drafted and implemented (Hengsdijk and Jansen, 2006b).

Collection of data and information
Sustainable rural development requires a multi-disciplinary approach; it needs the inputs from various disciplines and sources. In this study both primary and secondary data and information were collected, from a wide variety of sources (see also the References), the most significant being:

- A rapid appraisal of agricultural development and water use in the CRV based on formal and informal interviews. During various field visits, interviews with relevant stakeholders were held to supplement information from literature. Specific information on agriculture and associated water use in the CRV were collected (Scholten, 2007).
- As a part of the development of a Code of Practice for the floriculture sector 35 flower farms in Ethiopia were surveyed. This survey provided a.o. information on management and input use in the floriculture sector (Danse et al. 2007; Van den Bosch and Valkman, 2007).
- The University of Addis Ababa, especially the Department of Geology and Geophysics has published various international peer-reviewed journal articles on the hydrology in the CRV (Vallet-Coulomb et al., 2001; Legesse et al., 2004; Ayenew, 2004; Alemayehu et al., 2006; Legesse and Ayenew, 2006).
- Climate data were obtained from the National Meteorological Services Agency (NMSA) of Ethiopia. They included daily rainfall data of 20 selected meteorological stations in and around the CRV for the period 1996-2005. In addition daily data on sunshine duration, wind speed, minimum and maximum temperature, and relative humidity were collected for Ziway meteorological station. Long-term monthly rainfall and temperature data were obtained for some selected meteorological stations in the CRV.
- Long-term hydrological data, such as water levels of the major lakes and discharge from rivers were obtained form the Ministry of Water Resources. In addition, existing (master plan) studies have been used in the analysis (JICA & OIDA, 2004; Makin, 1976).
- To analyze changes in land use in the CRV satellite images from 1973, 1986, 1999 and 2006 were obtained. In 1973, 1986 and 1999 Landsat MSS images (available at the Addis Ababa University) were used, while for 2006 ASTER images were acquired. On the basis of these images the land use was classified. For 2006 some ground checks were also organized.

1.5 Project organization

The project "Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley" was conducted by researchers from four DLO institutes, namely Plant Research International (coordination), Alterra, Wageningen International and the Agricultural Economics Institute. The contribution of researchers with different backgrounds allowed to analyze the interrelated and complex issues in the CRV from different disciplines.

The Environmental Science Faculty of the Addis Ababa University was the scientific counterpart organization in Ethiopia. It provided local knowledge on the hydrology of the CRV. Associated researchers of the Science Faculty were mainly involved in the land resources assessment (Chapter 4). In addition, the Science Faculty provided support to Dutch students performing research within the project as part of their internship.

1.6 Related initiatives and projects

The project 'Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley' links to several other research and development initiatives. The 'Horn of Africa Regional Environment Network' (HoAREN) is an initiative of the Addis Ababa University in close cooperation with the Dutch regional environmental program in the Horn of Africa, sponsored by the Netherlands Embassy in Ethiopia. The HoAREN network aims at improving environmental governance in the Horn of Africa through collaboration, information exchange and networking.

The network consists of selected civil society organizations, universities and research institutions in Sudan, Ethiopia, Djibouti, Somalia, Eritrea and Kenya, who are dealing with environmental governance issues. The focus is on three major (integrated) environmental management topics, namely:

- management of lakes and wetlands;
- management of parks and buffer zones;
- management of erosion prone highlands and dry lowlands.

Together with Lake Naivasha in the Kenyan Rift Valley and the Sudd Swamps in Southern Sudan, the CRV is one of the case studies within the management of lakes and dry lowlands. The main aim of comparing these three cases within HoAREN is to exchange knowledge and experience regarding the improvement of management of lakes and wetlands that face more or less similar challenges.

In addition, the project has links with two other Policy Supporting projects funded by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV). The project collaborates closely with the project 'Support to the Dutch Horticulture Partnership' in taking stock of current management and production of flowers in Ethiopia (WUR, 2007a). In addition, the project is one of the case studies within LNV's multi-lateral wetland project aimed at the development of guidelines for wetland management (WUR, 2007b).

1.7 Structure of report

The study was aimed at supporting the Ethiopian governments and other entities involved in water planning, development and management. The report, therefore, starts with a summary of the most important stakeholders, interested and affected parties (Chapter 2). The physical setting of the area is presented in Chapter 3. In comparison with previous reports (Hengsdijk et al, 2006a and 2006b) more emphasis is given to the climate.

A detailed assessment of the land resources is given in Chapter 4. In this chapter both the present and historical land uses are presented, and trends in the different land developments are elaborated, especially trends in irrigated agriculture. The major economic aspects of the various farming systems based on irrigation are assessed in Chapter 5.

The assessment of water resources assessment is presented in Chapter 6. The various water uses in the area are quantified in Chapter 7.

In Chapter 8 the relation between land and water resources is elaborated and impacts of land developments on the water resources is further quantified. Conclusions and recommendations follow in Chapter 9.

2 Stakeholders, interested and affected parties

2.1 Stakeholder interaction

Traditionally, science generates new knowledge that is disseminated along well-accepted channels to the public, for example, through peer-reviewed articles. Knowledge transfer to the different stakeholders and society at large is usually a one-way road and interaction between the different receivers of knowledge is limited (Figure 1a).

This project is aimed at establishing and supporting a dialogue with stakeholders. Here, science is the major means to share information with and among stakeholders and to facilitate a discussion on ecosystems, water, food and economic development in the CRV. The exchange of newly generated knowledge with different stakeholders through the 'Central Rift Valley' Working Group (Section 2.2) has resulted in feedback on research results, new research questions and interaction among the different stakeholders, which is required to realize a dialogue on policies and priorities, and action-oriented research (Figure 1b).

The dialogue is a means to address interrelated and complex policy issues which can only be resolved in participative setting through argumentation, negotiation and persuasion based on sound knowledge, which is a prerequisite in such policy analyses and formulation processes.

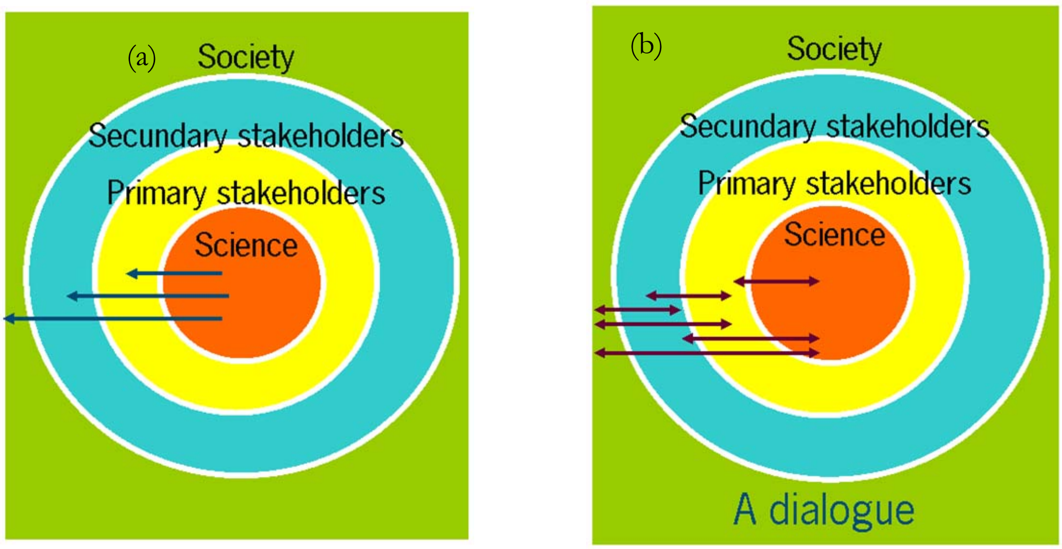

Figure 1. Traditional dissemination of research results (a) and the approach in this project resulting in a dialogue with and among different stakeholders (b).

2.2 Central Rift Valley Working Group

The central counterpart and platform for dialogue was the Central Rift Valley (CRV) Working Group. In April 2006, the Ethiopian Country Water Partnership (ECWP) initiated the multi-stakeholder platform CRV Working Group to specifically address the interrelated problems in the CRV in a public debate. This Working Group was formed as a voluntary group of institutions and organizations, all professionally involved in the CRV and consisted of civil organizations, representatives of ministries and water-related institutes, the tourist sector and academia. The goal of the CRV Working Group is to 'promote a basin wide integrated water resources management approach so as to make certain that adequate supplies of water of good quality are maintained for the people in the area, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature'.

Although the Working Group has no official mandate or authority in the CRV, it provides a first-of-its-kind platform of different stakeholders for policy dialogue on complex and interrelated issues in the CRV. Participants of the Working Group, individually or organized, can initiate new activities as part of their own specific mandate, based on shared knowledge and information. Sharing of information and networking on the basis of which new and well-coordinated activities may be initiated are important secondary goals of the Working Group.

Through presentations at meetings of the Working Group, policy notes and email exchange information and research results were disseminated. In addition, a project web-site comprised all published and presented research information. During various missions bi-lateral meetings with stakeholders were used to discuss results in detail, to generate new research issues, and to identify new project activities. New action-oriented research initiatives of civil organizations were reviewed and provided with advice for improving impact.

2.3 Human and livestock population

The so-called *woredas* represent the lowest administrative units in the CRV. Figure 2 presents the study area with the location the various woredas (see also Section 3.1).

Human population
As there is no registration at woreda level, the population size can only be estimated on the basis of a combination of various sources (IBC, 2005; Scholten, 2007). Table 1 presents the estimated population in the ten major woredas in the CRV.

Arsi Negele is the most populated woreda, while Mareko has the smallest population. The total population of the CRV is approximately 1.5 million with an average population density of 1.5 p ha^{-1}. The population density varies from 1 p ha^{-1} in Ziway Dugda to 6.6 p ha^{-1} in Meskana. The northwestern portion of the CRV (woredas situated in the Southern Nations Nationalities and Peoples region) is the most populated area.

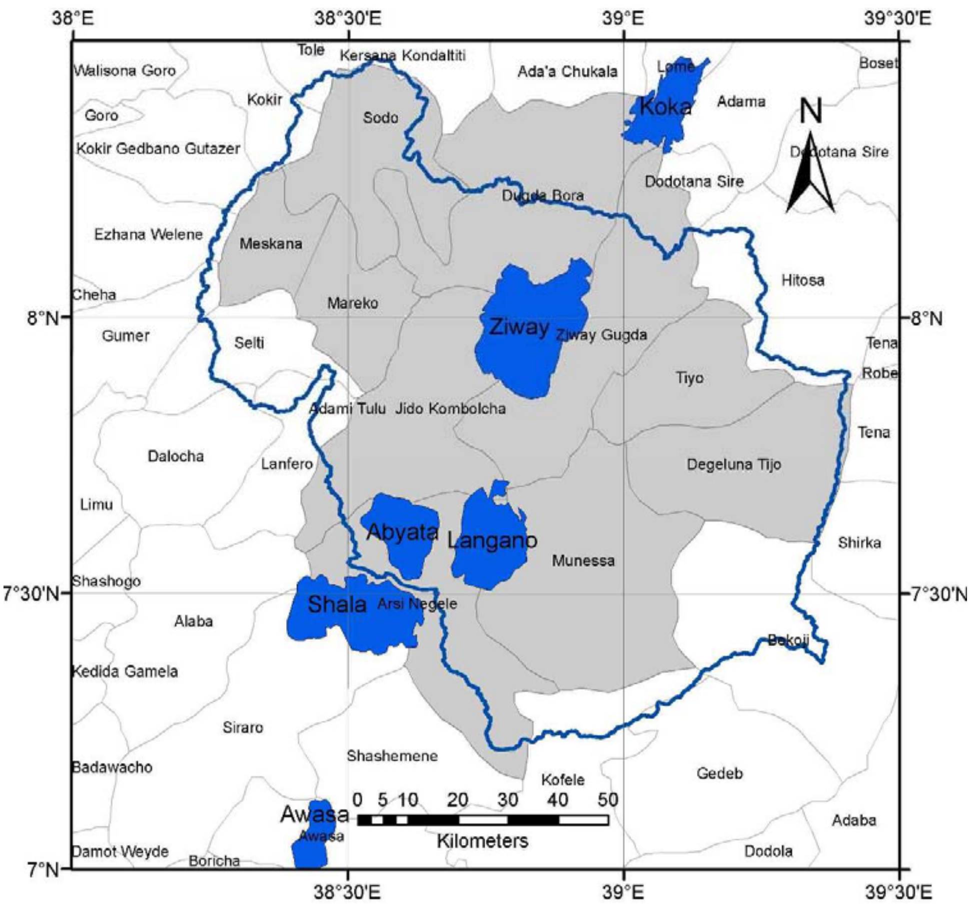

Figure 2. Woredas in the Central Rift Valley (in grey the woredas that were surveyed).

Livestock

Animal husbandry is an important livelihood strategy in the conventional mixed farming systems in the CRV. Animals serve as traction power, but also as savings objects for periods with insufficient food. The number of animals also provides the owner socio-cultural status.

Not only animals from mixed farming systems graze the area, but also nomadic pastoralists periodically graze their herds in the CRV, although their number seems to decrease as a result of more conflicts with arable farmers. The presence of animals in the CRV is highly dependent on the availability of food (seasonality). The livestock population and density shown in Table 1 should, therefore, be interpreted with caution (Scholten, 2007).

Despite of the uncertainty in the size of the livestock population, the area clearly shows signs of overgrazing. The degraded bare land and the predominance of less palatable plant species including the recently discovered invasive weed Parthenium, are indicators of overgrazing (http://www.cbit.uq.edu.au/parthenium/parthenium.html).

Table 1. Estimated human and livestock population (mid 2006) and densities in 10 woredas of the Central Rift Valley (na= not available).

Woreda	Area (ha)	Human population	Human population density (p ha^{-1})	Livestock population (TLU)[2]	Livestock density (TLU ha^{-1})
Sodo	83017	169469	2.0	60573	0.7
Meskana	36615	240373	6.6	na	na
Mareko	50422	63756	1.3	21713	0.4
Dugda Bora	151423	189410	1.3	104317	0.7
Adami Tulu Jido Kombolcha	125049	150471	1.2	na	na
Tiyo	63336	94557	1.5	85972	1.4
Degeluna Tijo	97233	114765	1.2	143693	1.5
Ziway Dugda	126729	120508	1.0	138207	1.1
Munessa	152061	180012	1.2	154615	1.0
Arsi Negele	134000	199347	1.5	246286	1.8
Total	1019884	1522668	1.5	857333	0.8

2.4 Abyata-Shala Lakes National Park

The Abyata-Shala Lakes National Park is one of Ethiopia's National Parks, being located in the East Showa zone comprising three lakes: Abyata, Shala and Chitu (Figure 2). The park used to be well known for its unique ecological characteristics.

The national park is well-known for its large number of wetland birds, over 400 species have been recorded. The park is situated in one of the narrowest portions of the Great Rift Valley, and a major flyway for both Palearctic and African migrants, particularly raptors, flamingos and other waterbirds.

The fringes of the lake are an important feeding and resting ground for waders and ducks. The alkalinity of the lake water fluctuates with the inflow of fresh water and is conducive for algae growth attracting small arthropods which serves as food for shore birds.

The Bulbula River is the main tributary river to Lake Abyata. The river discharges fresh water from Lake Ziway. The level and discharge of the Bulbula River determine the riverine forests, the alkalinity of the lake and the fish populations. The more fish in the lake, the more fish eating birds can be observed.

Lake Shala has a relatively steep shoreline and is much deeper and more alkaline. Due to its high alkalinity the production of biomass of organisms in the primary food

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2 TLU = Tropical Livestock Unit. This is a standard unit used to compare different animal species. Conversion factors are: Cattle= 0.7 TLU; sheep/goat=0.1 TLU; horse=0.8 TLU; donkey=0.65 TLU; mule=0.7 TLU; pig=0.2 TLU; chicken=0.01 TLU (Ghirotti, 1993).

chain is low. Therefore the lake cannot support large populations of animals higher up in the food chain. The avifauna is nevertheless very diverse and the islands in Lake Shala used to be important breeding sites for cormorants, storks and pelicans.

An important potential source for the development of tourism is the hot springs on the eastern side of Lake Shala. These springs vary in size and temperature. The water flow increases towards the end of the rainy season and the salinity of the springs vary accordingly.

The Abyata–Shala Park supports one of the largest African colonies of Pelecanus onocrotalus: the birds breed on an island in Lake Shala and feed their young ones with fish caught in Lake Abyata. The pelicans along with other fish-eating birds leave and return to the lakes, depending on the fish stocks.

The national park suffers from the lack of financial resources and management capacity. Larger animals are eliminated from the park, leaving only some smaller species. The Acacia savannah, previously dominant in the park, has been replaced by fields of sorghum and maize, despite of the low fertility of the soils. The riverine vegetation has been reduced as a result of the reduced inflow from the Bulbula River, while the grasslands along the shores of the lake Abyata are heavily overgrazed.

Furthermore the park suffers from severe encroachment of settlers, deforestation for charcoal, cultivation and grazing. Currently the ecosystem of the park is seriously degrading and the park is losing its attractiveness for tourists. Several studies have been conducted on the development of tourism but no up to date information is available to assess the development potential.

3 Physical setting

3.1 Location and topography

The Central Rift Valley (CRV) in Ethiopia is situated between, approximately, 38°15'E and 39°25'E, and 7°10'S to 8°30'S, at 150 km south of Addis Ababa. The area is situated in the administrative regions Oromiya and the Southern Nations Nationalities and Peoples Region (SNNPR). Figure 3 presents the general location map.

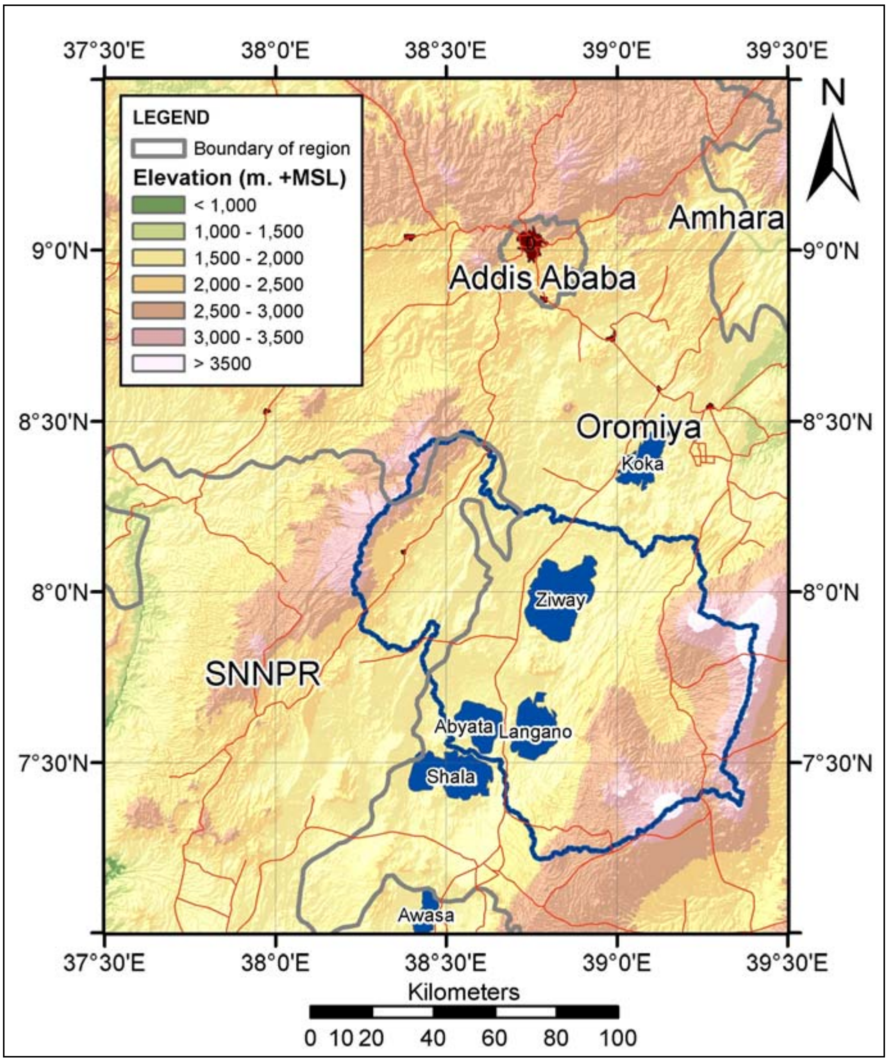

Figure 3. General location map

The CRV is bounded to the east and west by highlands, with altitudes of more than 3000 m +MSL (above mean sea level) and a peak of 4245 m +MSL (Mount Kaka, east of the lakes).

The study area can be delineated by the hydrological boundaries (the blue line in Figure 3) or the boundaries of the major woredas (used for the regional statistical information; see Figure 2).

The CRV encompasses various administrative areas (*woredas*), of which the most important ones are: Sodo, Meskana, Mareko, Dugda Bora, Ziway Dugda, Adami Tulu Jido Kombolcha, Arsi Negele, Munessa, Tiyo and Degeluna Tijo. The three first-mentioned woredas are part of the Southern Nations Nationalities and Peoples Region (SNNPR), while the other woredas are situated in Oromiya (Table 2 and Figure 2).

Table 2. Woredas in the CRV.

Region	Woreda	Area (ha)
SNNPR	Sodo	83017
	Meskana	36615
	Mareko	50422
Oromiya	Dugda Bora	151423
	Adami Tulu Jido Kombolcha	125049
	Tiyo	63336
	Degeluna Tijo	97233
	Ziway Dugda	126729
	Munessa	152061
	Arsi Negele	134000
	Total	1019884

The area encompasses three large lakes, Ziway, Langano and Abyata. Lake Shala is situated in an adjacent catchment, however is part of the National Park. The national park consists of the two saline lakes, Lake Abyata and Lake Shala, and the surrounding woodlands. The lakes have been submitted by the Ethiopian Government to the Ramsar Convention on wetlands in order to be recognized as an international Ramsar site.

The rivers and lakes in the CRV are situated at an altitude above 1500 m +MSL (Figure 3).

3.2 Climate

The climate in the CRV varies markedly with altitude. Pronounced gradients of rainfall and temperature exist between the high plateaus, in the eastern and western portions of the CRV, and the valley in the central portion of the CRV.
The area is characterized by warm, wet summers (with most of the rainfall occurring from July to September) and dry, cold and windy winters.

Figure 4 presents the average annual rainfall in the period from 1996 to 2005. The highest average annual rainfall was measured in the western part (Chelektu; 1251 mm), while the lowest rainfall was recorded in Bulbula (649 mm) in the center of the CRV (see also Table 3).

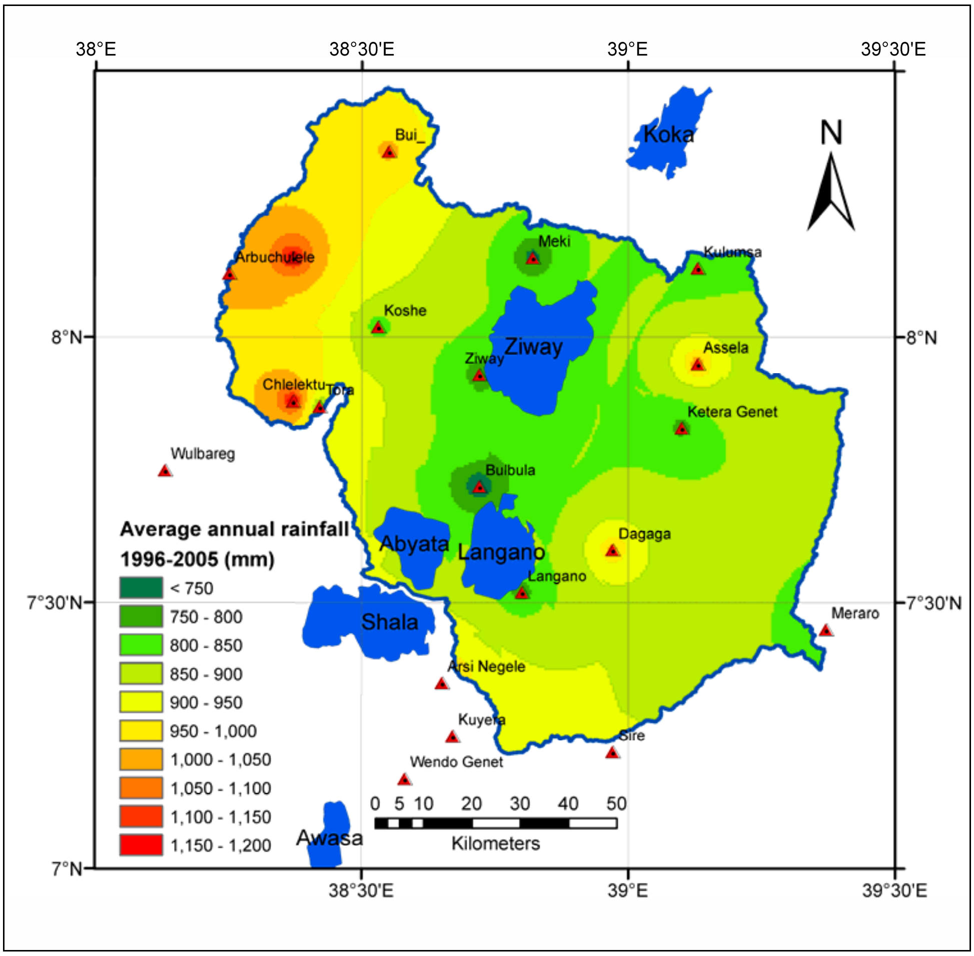

Figure 4. Meteorological stations in and around the Central Rift Valley and isohyets of average rainfall (interpolation without further processing).

The variation in the annual rainfall (1996-2005) varies between 13 and 26% for the 20 meteorological stations in and around the CRV. The distribution of the rainfall within the year is highly erratic. Figure 5 presents the rainfall distribution for the meteorological station Ziway (having an average annual rainfall of 734 mm). In some years the accumulated rainfall till July (start of the rainy season) totaled 200 mm, while in other extreme years it was as high as 500 mm. These large differences together with the relatively short rainy season indicate that rain-fed agriculture is very susceptible to water shortages.

Table 3. Average annual rainfall (1996-2005) of 20 meteorological stations in and near the Central Rift Valley.

Station Name	Latitude	Longitude	Elevation (m. +MSL)	Rainfall (mm)	Coefficient of Variation (%)
Arbu Chulule	8°07’	38°15’	2480	1038	16
Arsi Negele	7°21’	38°39’	1800	1196	25
Assela	7°57’	39°08’	2350	1078	17
Buee	8°21’	38°33’	2020	1039	25
Bulbula	7°43’	38°43’	1700	649	20
Butajira	8°09’	38°22’	2000	1233	23
Chelelektu	7°53’	38°22’	1675	1251	15
Dagaga	7°36’	38°58’	2787	1042	14
Katar Genet	7°50’	39°06’	2400	754	21
Koshe	8°01’	38°32’	1860	788	19
Kulumsa	8°08’	39°08’	2200	816	9
Kuyera	7°15’	38°40’	2870	873	16
Langano	7°31’	38°48’	2700	784	20
Meki	8°09’	38°49’	1400	731	13
Meraro	7°27’	39°22’	2940	790	10
Sire	7°13’	38°58’	2390	952	19
Tora	7°52’	38°25’	1600	853	26
Wendo Genet	7°10’	38°35’	1880	1140	15
Wulbareg	7°45’	38°08’	1800	1275	15
Ziway	7°56’	38°43’	1640	734	20

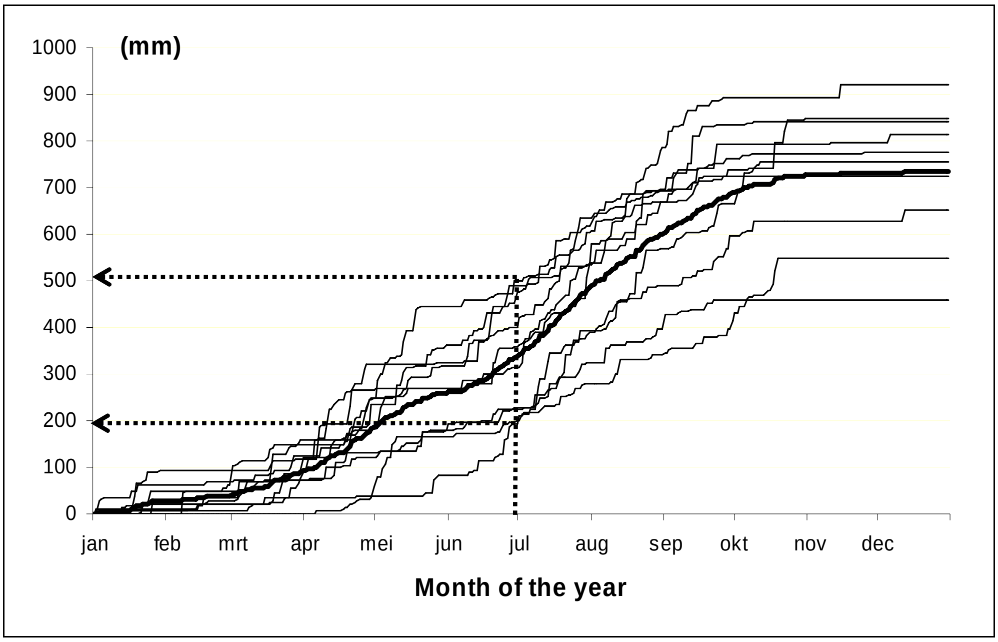

Figure 5. Accumulated rainfall in Ziway for the period 1996-2005(the thin lines represent the individual years, the thick line is the average accumulated rainfall in this period. Dotted lines indicate differences in accumulated rainfall at the beginning of July between the two most extreme years).

The temperature is relatively constant throughout the year. In Ziway the daily maximum temperature ranges from 24.2 to 30.5 °C and the daily minimum temperature between 10.4 and 16.8 °C (Figure 6 a). The minimum and maximum temperatures will drop towards the east and west of the CRV, being dependant of the elevation.

The CRV is relatively sunny with an average of 8.6 sunshine hours per day in Ziway. However, there is a distinct decrease in sunshine hours during the wet period (Figure 6 b).

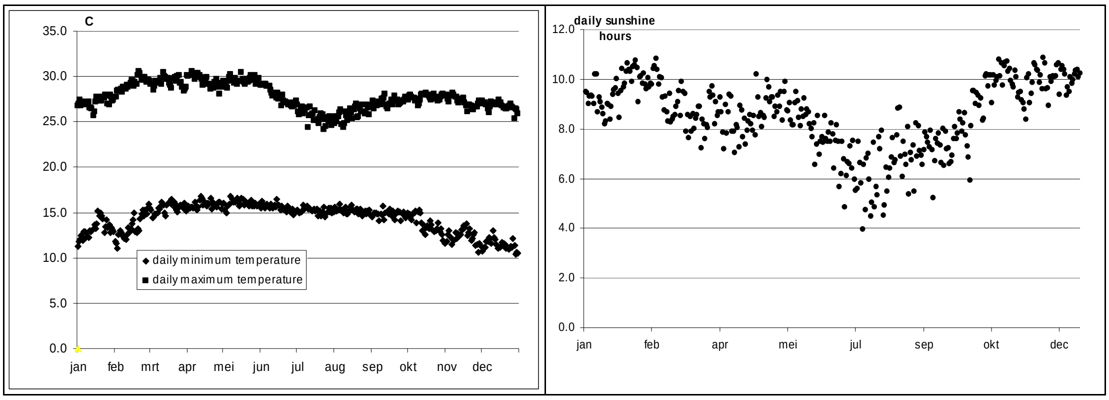

Figure 6. (a) Average daily minimum and maximum temperature; (b) average daily sunshine hours in Ziway (1996-2005).

To check the quality of the digitization of climate data, daily rainfall data of station Ziway has been checked with an independently digitized rainfall data set (Abraham, 2006). Comparison of both data sets showed that differences in total annual rainfall (1996-2003) were on average less than 1%. Only for 2002 and 2003 these differences were larger, our rainfall data were 7% higher and 4% lower, respectively, than the data of Abraham (2006). This comparison is an indication of the quality of data digitization without being able to conclude which data source is more accurate.

The reference evapotranspiration (based on Penman-Monteith) of the land cover varies between approximately 1250 and 1450 mm per year (Table 4 and Figure 7). The inter-annual variation of the reference evapotranspiration is much less than the inter-annual variation in rainfall.

Table 4. Average annual reference evapotranspiration in and near the Central Rift Valley (FAO).

Station	Average annual reference evapotranspiration (mm)
Assela	1238
Kulumsa	1278
Butajra Police Station	1351
Kuyera	1341
Langano	1460
Wendo Genet	1427
Ziway	1433

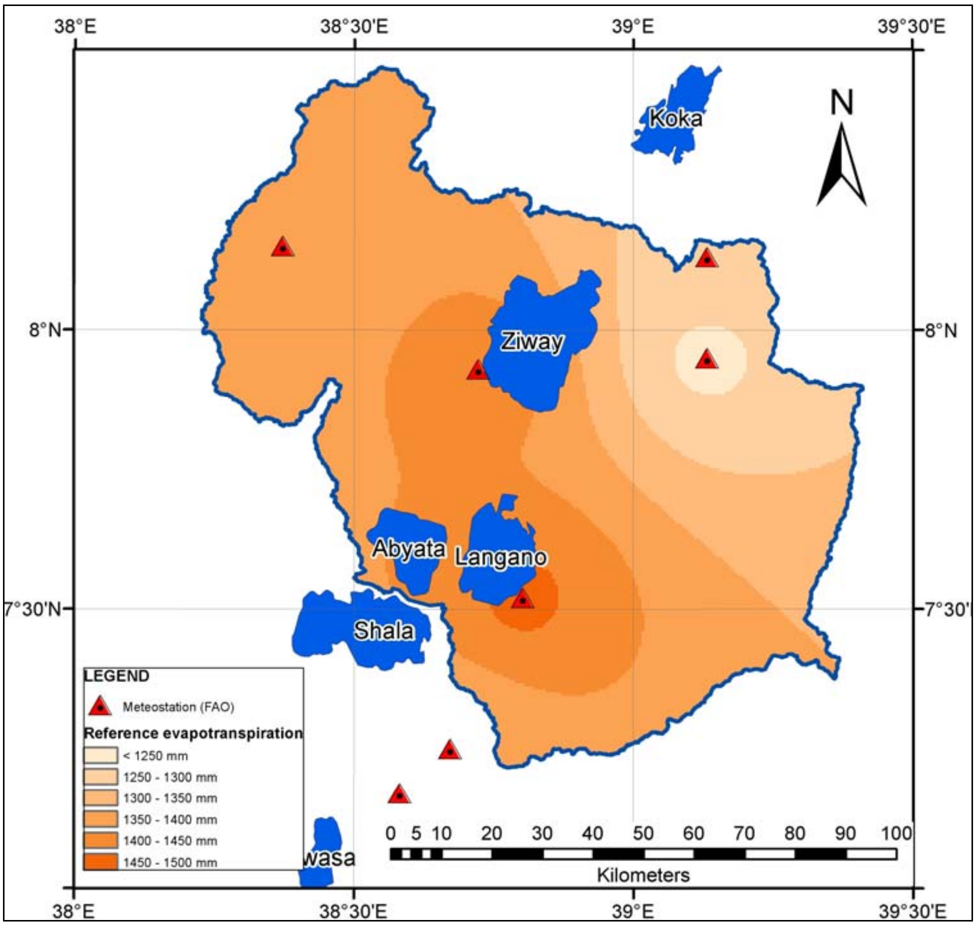

Figure 7. Average reference evapotranspiration in the Central Rift Valley (source: FAO; interpolation without further processing).

3.3 Soils

In the CRV two soils are predominant. In the central portion of the CRV *"tropepts"* are found. These soils are characterized by moderately dark A horizons with modest additions of organic matter. The B horizons have brown or reddish colors, the C horizons are slightly pale. These soils are generally found in (tropical) regions with moderate or high rainfall.

In the eastern and western portion *"udalfs"* are found. These soils are also typical for a humid climate, often formed under a hardwood forest cover. They consist of brown soils formed in an udic[3] moisture regime and in a mesic or warmer temperature regime.

[3] Pertaining to a soil moisture regime where the soil is not dry for as long as 90 cumulative days (USDA, 1975).

3.4 Catchment, subcatchments and surface water

The various lakes in the CRV are interlinked and situated in a closed basin. Within this closed catchment area various sub-catchments can be distinguished. The catchment and subcatchments were delineated with the aid of a digital elevation model[4] (DEM) having a spatial resolution of 90 x 90 metres. The SWAT ArcView extension for the BASINS package (Arnold et al., 1998) was used to calculate the catchment and subcatchment boundaries and to calculate the surface drainage pattern. The delineation of the catchment and subcatchment is presented in Figure 8.

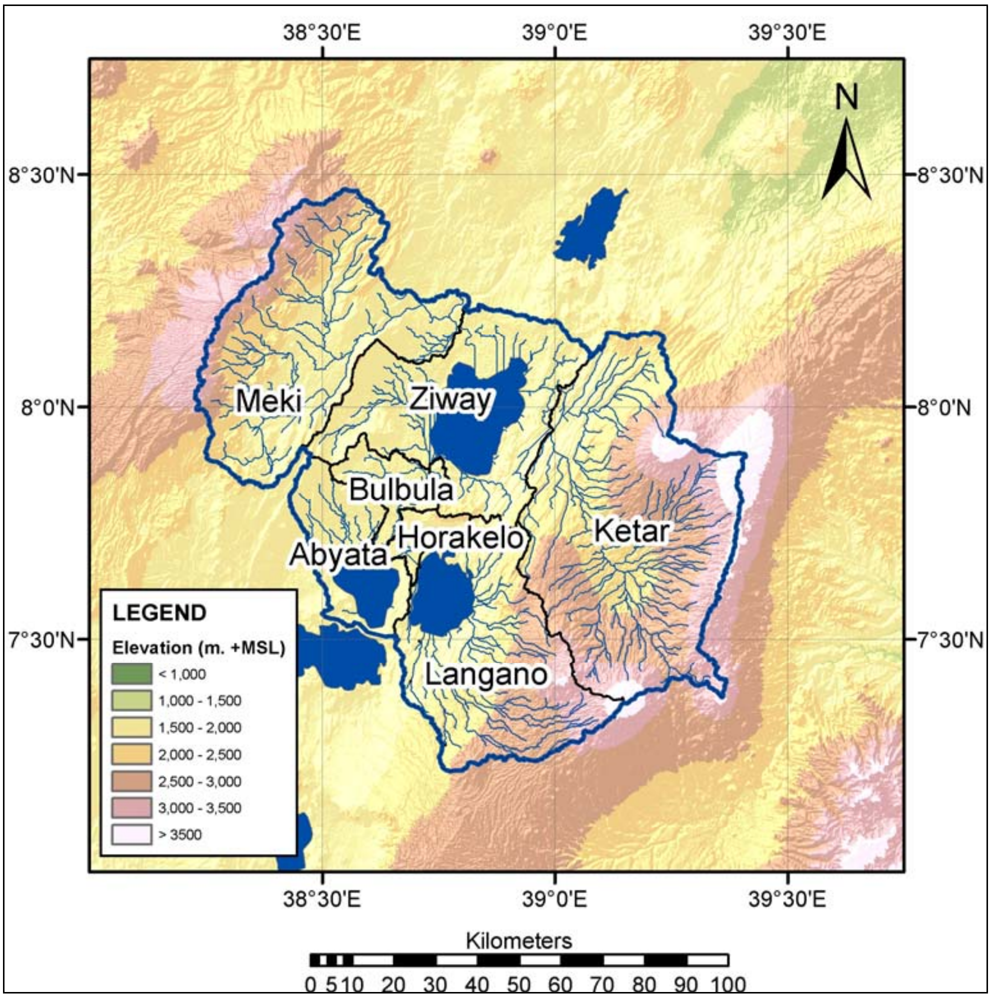

Figure 8. Delineation of catchments and subcatchments

From Figure 8 it can be concluded that the study area consists of 7 subcatchments. The catchment of Lake Ziway incorporates the area around Lake Ziway, which directly drains to Lake Ziway, and the catchments of the Meki and Ketar River. Similarly the catchment of the Bulbula River incorporates the area that directly drains to the Bulbula River plus the entire catchment of Lake Ziway. The Horakelo catchment also incorporates the entire catchment of Lake Lagano. Finally, the

[4] Also referred to as "digital terrain model".

catchment of Lake Abyata includes the area that directly drains to the lake plus the entire catchments of the Bulbula and Horakelo Rivers. Lake Abyata is the terminal lake.

Table 5 presents the areas of the individual subcatchments and their total area including all upstream catchments. The total surface area of the study area is approximately 10330 km^2. The catchment of Lake Ziway incorporates the area around Lake Ziway and the catchments of the Meki and Ketar Rivers, which represent 70% of the total catchment (Table 5).

Table 5. Characteristics of subcatchments

Subcatchment	Area	Gross area (including upstream catchments)	
	km^2	km^2	
Meki	2225	2225	
Ketar	3177	3177	
Ziway	1848	7249	(70%)
Langano	1890	1890	
Horakelo	174	2064	
Bulbula	325	7574	(73%)
Abyata	693	10330	(100%)
Total	10330	10330	

4 Land resources assessment

4.1 General outline

In general, and certainly in the CRV, land and water resources are strongly interrelated. Any change in the land use will have an impact on the hydrological system of the catchment and on the available water resources. For this reason much effort was put in the assessment of the land resources and in the quantification of historical trends in the land use.

The current land use and historical trends were assessed by the interpretation of satellite imagines. Satellite images were acquired for the dry seasons in 1973, 1986, 1999 and 2006. For the land use classification in 1977, 1986 and 1999 LANDSAT MSS images were used. The classification of 2006 was done on the basis of 9 (mosaiced) ASTER images. In 2006 also some ground checks were executed to verify the (2006) classification results.

Section 4.2 presents a summary of current (2006) land use in the CRV. The changes in land use since 1973 are presented in Section 4.3. In this section also the spatial trends in land use are addressed. Given the importance of rain-fed and irrigated agriculture and their impacts on land and water resources, more details on the various farming systems are presented in Section 4.4 and 4.5, respectively. As the big lakes are of special interest in the CRV, the trends in the surface areas of Lake Ziway, Lake Langano and Lake Abyata are presented in Section 4.6.

4.2 Land use in 2006

For the land classification originally 12 different types of land use were distinguished. After this classification some of the not very distinct (and for this study irrelevant) land use classes were lumped, resulting in 9 classes. On the basis of ground checks, large farms could be distinguished within the intensively cultivated areas and the wet areas, which resulted in two additional classes, referred to as "large scale farming" and "irrigated farms", respectively[5].

Figure 9 presents the resulting map with current land use (2006). The land use classes and the areas for each of these classes are also presented in

The relatively large irrigated farms are situated around Lake Ziway. To the east and southeast of Lake Ziway some land of old state farms has been redistributed among private farmers (intensively cultivated areas delineated with a black line). The degraded area around Lake Abyata is also clearly visible.

[5] The "large scale farming" often concerns redistributed lands from large former state farms. These lands are presently not irrigated.

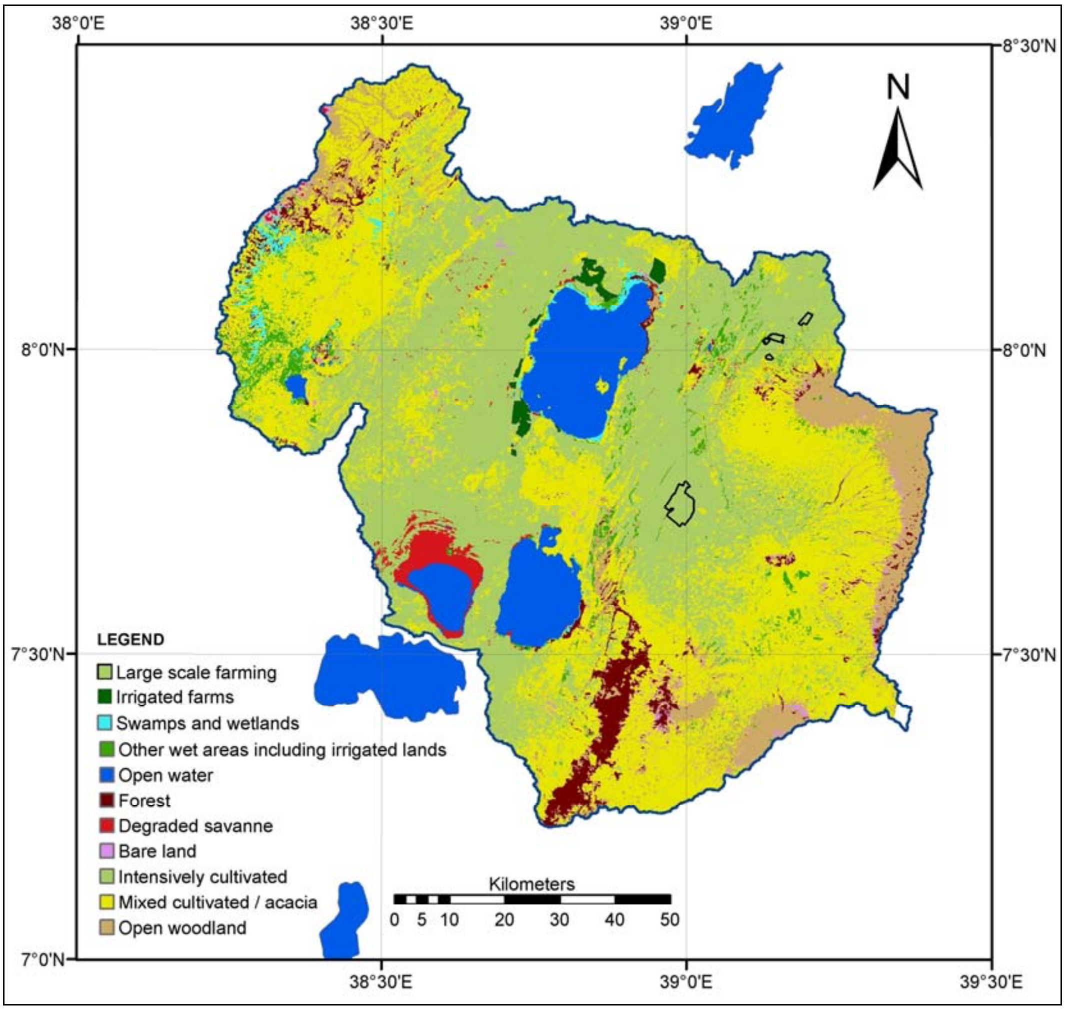

Figure 9. Land use 2006 (classification from ASTER images)

Throughout the catchment a large number of relatively small plots were classified as "wet areas including scattered irrigated agriculture". Unfortunately it was not possible to discriminate between the small irrigated plots and adjacent wet areas. It is known that in recent years many small farmers have acquired pumps for (small-scale) irrigation. Additional field checks are required for a more detailed quantification (see also Section 4.3).

Table 6. Land use 2006 (entire catchment)

Land use	Area (ha)	%
Large irrigated farm	5094	0.5
Swamp and wetlands	9380	0.9
Other wet areas including irrigated lands	25254	2.4
Open water	75208	7.3
Forest	31584	3.1
Degraded savanna	13495	1.3
Bare land	11732	1.1
Intensively cultivated	393464	38.1
Mixed cultivated / acacia	386491	37.4
Open woodland	80358	7.8
Total	1032060[6]	100.0

The survey by Scholten (2007) showed that the irrigated area by small-holder farming is in the order of 7300 ha. In this report the total irrigated area is estimated at 7500-10000 ha, on the basis of the information from the survey together with the data in Table 6[7].

The predominant land uses are mixed cultivated /acacia lands and intensively (rain-fed) cultivated lands. It is noted that the classification can show some ambiguities, as the images were not taken on the same day.

4.3 Historical land use trends

To assess historical changes in the land use satellite images from 1973, 1986 and 1999 were also interpreted, using the same classification as in 2006. Figure 10, Figure 11 and Figure 12 present the land classification for these years, respectively.

[6] A very small portion of the area (9 km^2), situated in the eastern mountains, was not covered by the ASTER images.
[7] Being the irrigation by smallholders and irrigation by large farms.

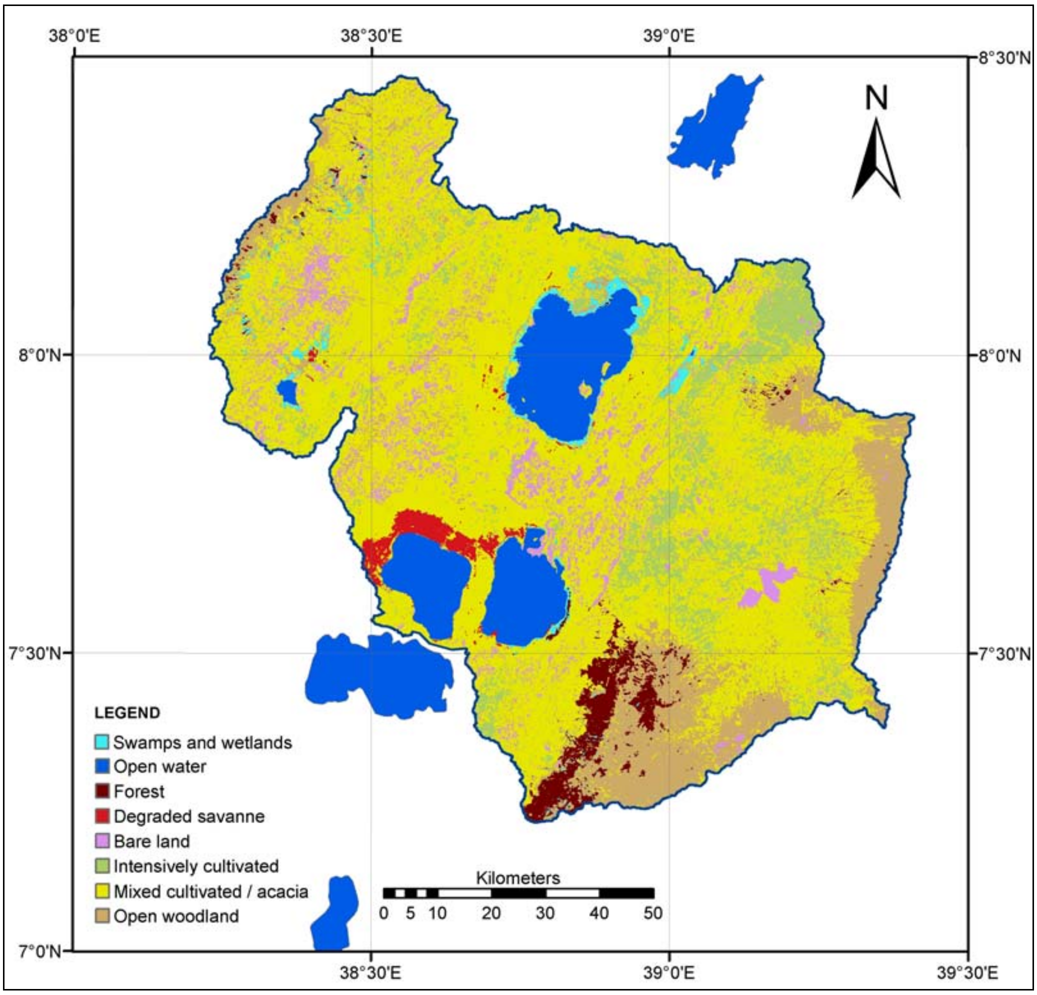

Figure 10. Land use 1973 (classification from LANDSAT MSS image)

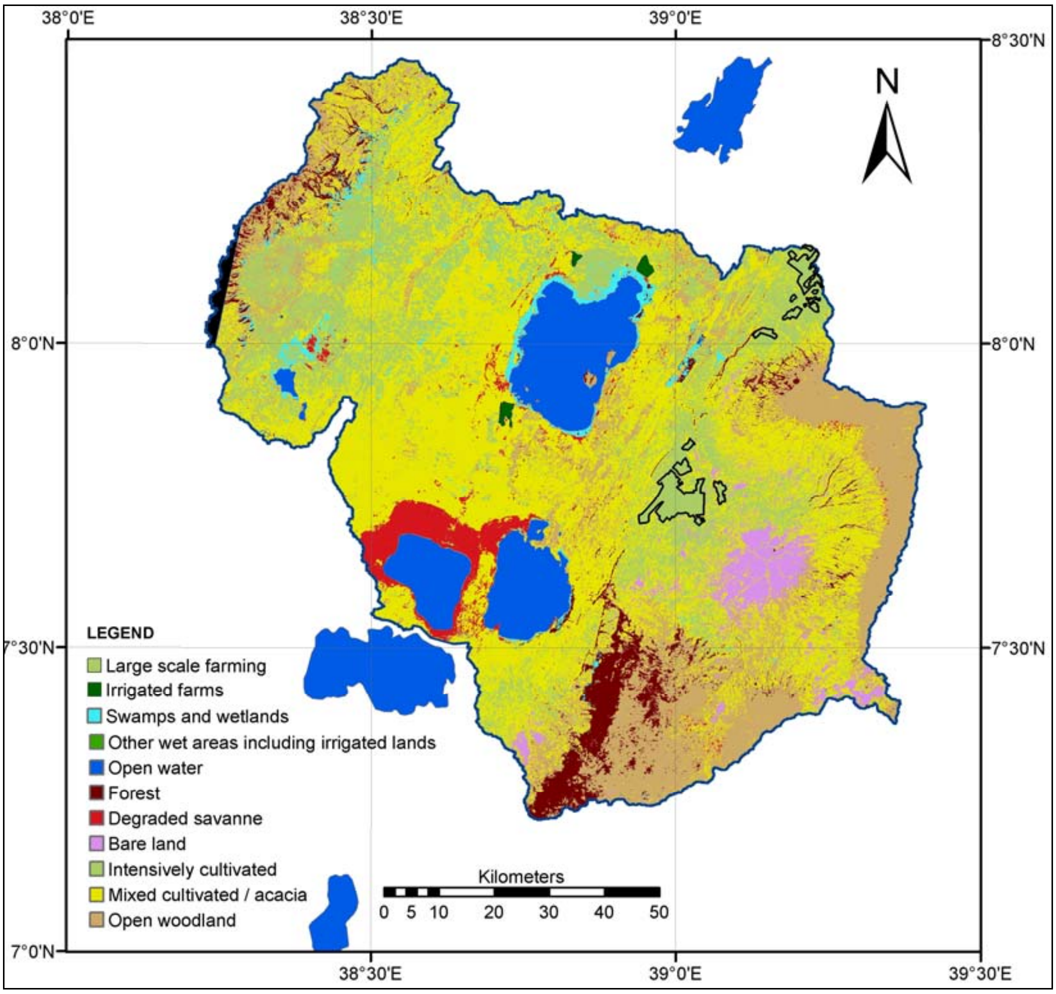

Figure 11. Land use 1986 (classification from LANDSAT MSS image)[8]

[8] A very small portion of the area, situated in the eastern mountains, was not covered by the LANDSAT image of 1986 (indicated as a black surface).

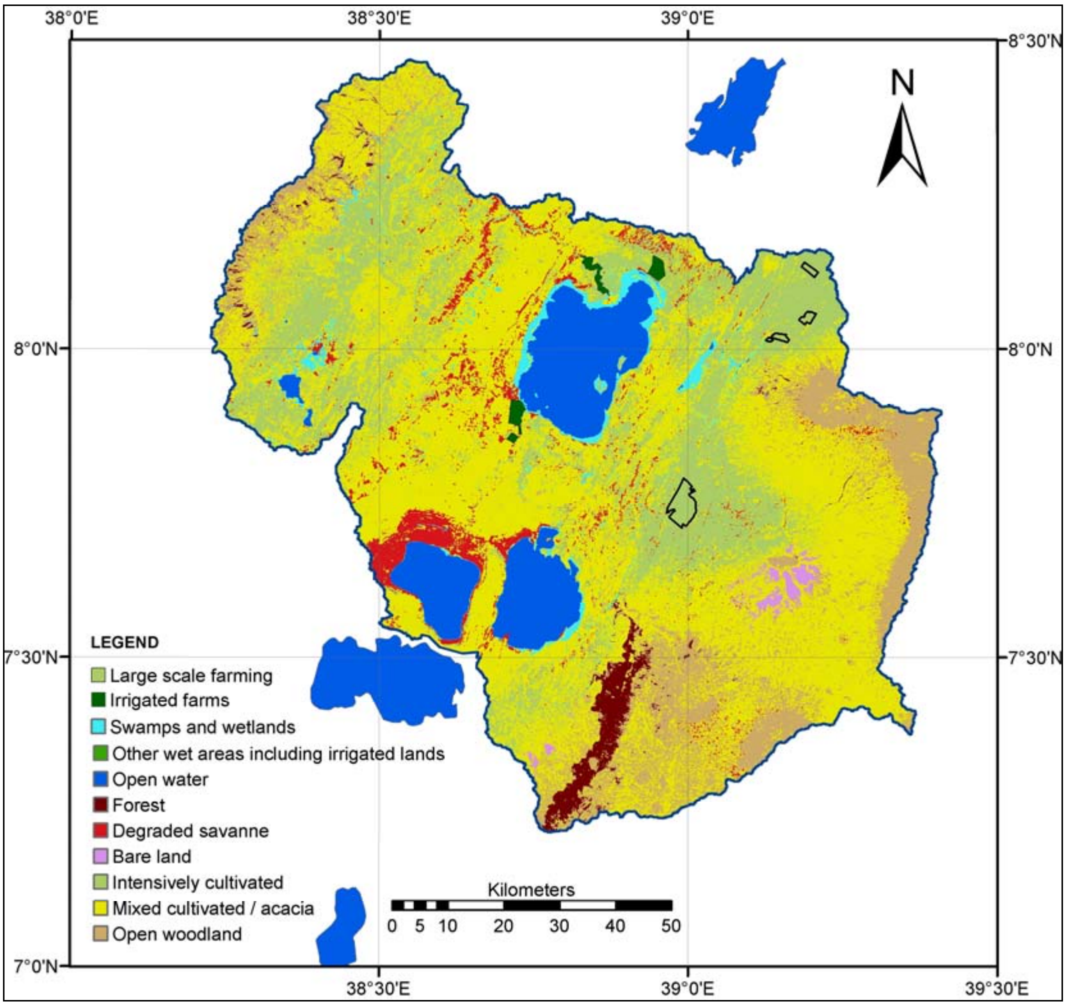

Figure 12. Land use 1999 (classification from LANDSAT MSS image)

For the present study the irrigated areas and intensively cultivated lands are particularly relevant, as their changes will probably have the largest impact on the water resources in the catchment. In addition to temporal trends also spatial trends were analysed. The changes in land use were determined for each of the 7 sub-catchments (Section 3.4), as well as for the total catchments of Lake Ziway and Lake Abyata.

As previously stated, it was not in all cases possible to distinguish between the small irrigated plots and the other wet areas. A large area of irrigated agriculture could, however, be identified. Since 1973 this area has increased, especially in the catchment of Lake Ziway (Figure 13), to more than 5000 ha.

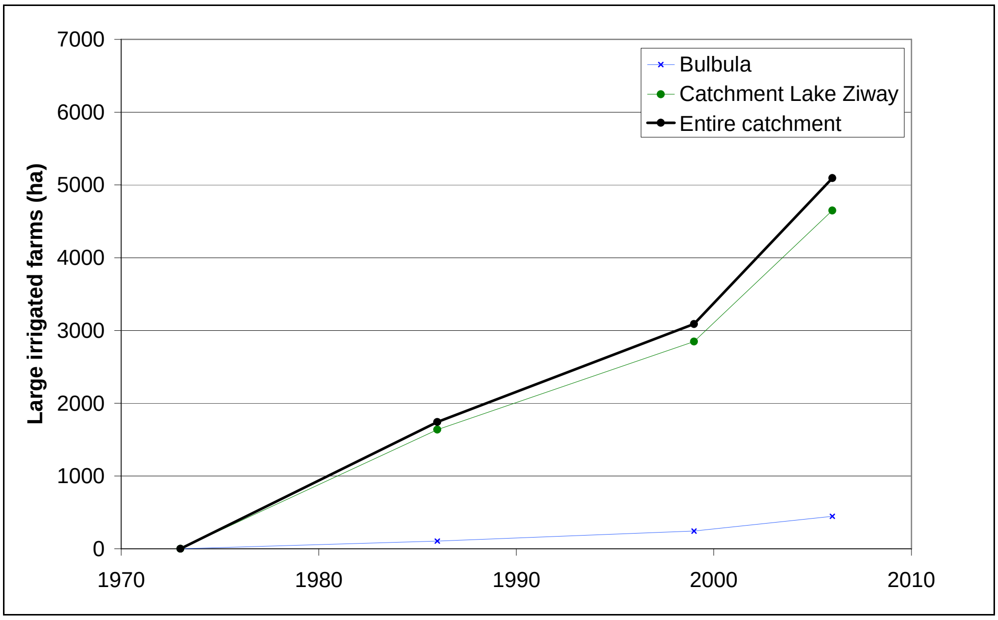

Figure 13. Area trend for large irrigated farms since 1973[9]

The development of many scattered small-scale irrigation could not be well quantified on the basis of satellite images, but an indication can be obtained by looking upon all relatively wet areas. The total area of relatively wet land seems to have increased, especially in the Meki catchment, and mainly after 1999 (Figure 14). Data from Agricultural Development Offices showed that the present area with small-scale irrigated agriculture is in the order of 7300 ha, most of this area being situated in the catchment of Lake Ziway (which includes the Meki catchment) (Scholten, 2007).

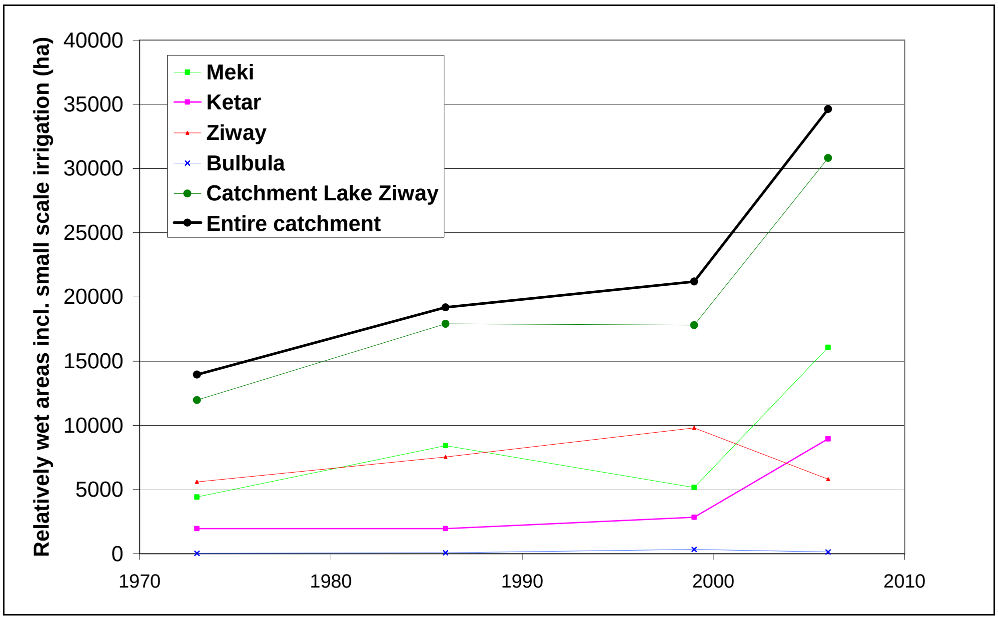

Figure 14. Area trend of relatively wet areas since 1973

[9] A large state farm of 1000-1500 ha was situated near the discharge point of Lake Ziway. Based on the topography the farm was in the catchment of Lake Ziway. However, the irrigation water was pumped from the very upstream section of the Bulbula River.

Finally it was observed that the intensively cultivated areas have also increased since 1973, especially in the catchment of Lake Ziway (Figure 15). The total area of intensively cultivated land as derived from the satellite images was in line with the results of field surveys and data from the Agricultural Development Offices (393464 ha versus 321797 ha)[10].

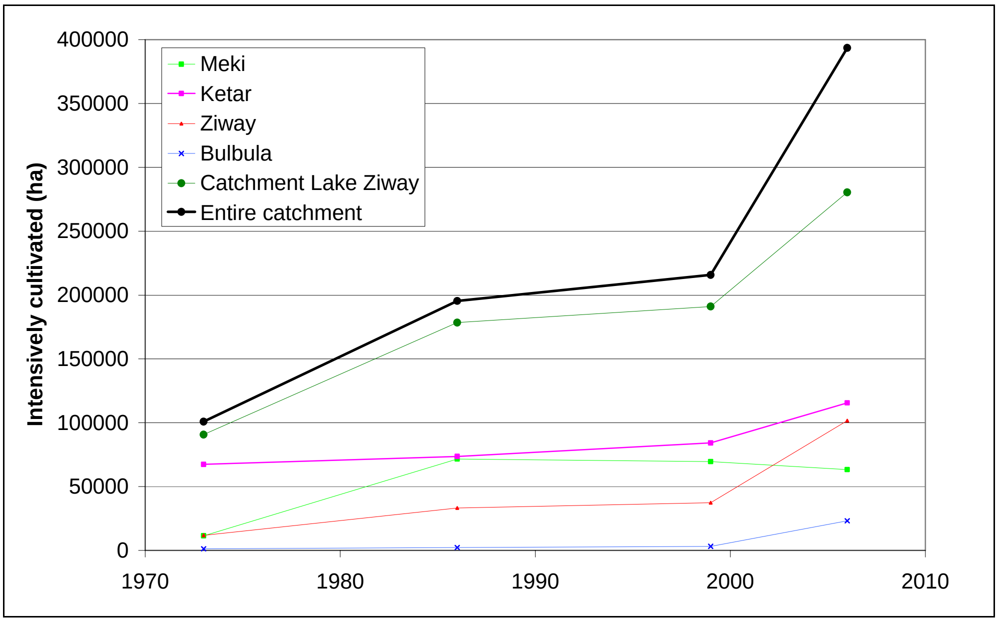

Figure 15. Area trend of intensively cultivated lands since 1973

4.4 Rain-fed farming systems

The predominant farming system in the CRV is the small mixed rain-fed production system consisting of grain crops and livestock. The major grain crops are wheat, maize, barley and teff (in decreasing order). The predominant livestock is cattle, sheep and goat (in decreasing order).

No specific data have been collected with respect to the rain-fed farming systems but NACID (2006) gives a characterization of these farming systems in three *woredas,* Siraro, Arsi Negele and Adimitulu Jido Kimbolecha. These woredas are situated in the vicinity of the Shala/Abyata National Park (Figure 2). The described farming systems are representative for poor farmers in the lowlands of the CRV. Most striking are the very low crop yields, varying between 230 and 400 kg ha^{-1} for maize and from 69 to 150 kg ha^{-1} for teff. A large percentage of these farming systems does not achieve food security and depends on food relief. The performance of farming systems in the CRV mainly varies in relation with the altitude (rainfall) and soil type.

[10] Note that there will be a discrepancy, as the hydrological boundaries do not coincide with administrative boundaries (see also Section 3.1).

4.5 Irrigated farming systems

In addition to the rain-fed production systems four types of irrigated production systems can be classified on the basis of ownership, farm size and production type (Hengsdijk and Jansen, 2006b):

- Closed vegetable and flower production systems
- Open field vegetable and fruit production systems on state farms.
- Open field vegetable and fruit production systems on private farms.
- Open-field smallholder vegetable and fruit production systems

Closed vegetable and flower production systems

Presently only one closed production system is operational in the CRV. The investor (Sher-Ethiopia) has constructed a greenhouse complex and leases greenhouse units to individual enterprises producing flowers or horticulture products for export. The first phase of the complex aims at 360 ha of greenhouses, while currently (end of 2006) about 100 ha are in production. Another 300 ha is obtained from the neighboring state farm to expand in the future. Finally, a planned area of 1000 ha of greenhouses will be developed.

Open field vegetable and fruit production systems on state farms

At present one irrigated state farm is still operational, namely the Ziway Development Farm. The farm is located along the upstream part of Bulbula River, south of the greenhouse complex. In the past this state farm irrigated over 1000 ha of land. Mid 2006 the irrigated area was about 680 ha.

The cultivated crops are mainly beans, tomatoes, onions and maize for seed production. A smaller area was grown with fruits, such as grapes, papaya and avocado. The size of the state farm is expected to further decrease in the future, because of the expansion of closed production systems on its former land.

Open field vegetable and fruit production systems on private farms

Since the economical reforms, several private farms have been established in the CRV. An example is the Ethio-Flora farm, located along the Bulbula River south of the state farm Ziway Development. This private farm consists of 70 ha irrigated lands. Predominant crops are maize (for hybrid seed production), green beans, papaya and banana. The farm also has a livestock unit, which uses, among others, maize residues as feedstuff.

Open-field smallholder vegetable and fruit production systems

The open-field smallholder vegetable and fruit production systems differ from the previous category with respect to the irrigated area. They are much smaller, often less than 0.5 ha. These systems predominate in the CRV, both in terms of number and irrigated area. The smallholders are often united in so-called Peasant Associations and they run irrigation schemes collaboratively.

The main crops in these systems are tomatoes and onions. These irrigated systems may combine with rain-fed cropping and/or livestock husbandry. The predominant irrigation method is furrow irrigation, where water is applied in a small trench between the crop rows.

The irrigation water is mainly extracted from the Meki, Ketar and Bulbula Rivers, Lake Ziway and from shallow wells near Lake Ziway. As the temperatures are relatively constant over the year (Section 3.2), the crops can be grown during the entire year provided that irrigation water is available. As a consequence, there is no clear growing season for this farming system in the CRV (Scholten, 2007).

4.6 Surface water

From the satellite images the changes in size of Lake Ziway, Lake Langano and Lake Abyata could also be determined. Between 1973 and 2006 the size of Lake Ziway and Lake Langano have not been subject to significant changes (less than 2% fluctuation between the various images).

However, in 2006 Lake Abyata had reduced to approximately 60% of its size in the nineteen eighties and nineteen nineties (Table 7). In 1973 (when there was no irrigation yet) the area of the lake was 20% more than in 1986.

Table 7. Changes of the size of Lake Abyata

Year	**Size of Lake Abyata (km^2)**
1973	194
1986	162
1999	163
2006	95

5 Economic assessment of irrigated agriculture

5.1 General outline

Water-demanding activities in the CRV should be assessed from an economic point of view to gain insight in the economic performance of different activities. This will support the identification of needs and possibilities for improvements in resource use. Important economic indicators in this respect are the monetary value derived from applied irrigation water (irrigation water productivity), land productivity, and labor productivity. These indicators are addressed in, respectively, Section 5.2, 5.3 and 5.4. A synthesis is given in Section 5.5.

Based on the classification of irrigated farming systems (Section 4.5), these systems are subdivided in floriculture, irrigated open-field vegetable production (by the state Farm) and smallholders.

It is noted that the economic assessment is preliminary, as the amount of water applied in irrigated agriculture could not be quantified accurately (Chapter 7). In addition, economic indicators are affected by fluctuations in yields, product prices and crop management, resulting in different resource use efficiencies. Therefore, the presented resource use efficiencies are indicative and are used to show differences in the order of magnitude. Where possible the consequences of different product prices for water and land productivity are also presented.

5.2 Irrigation water productivity

Irrigation water productivity is defined as the net income received by farmers per unit of irrigation water applied, expressed in Birr per m^3 of water. The net income is the marketable product (yield) multiplied with its price minus the variable production costs such as machinery, hired labor, fertilizers, biocides and seeds. These costs vary according to crop and production system. Costs of family labor in smallholder production systems is not accounted for.

It is assumed that the annual crops, which are shown in Table 8, are entirely grown in the dry season with an average water use efficiency of 30% (Table 18). The various factors that determine the irrigation water requirements are presented in Section 7.5. On the basis of information on price fluctuations for a number of crops in the CRV (Scholten, 2007) the implications of the minimum and maximum product prices on the value of irrigation water were analyzed.

Table 8. Irrigation water productivity for various irrigated crops in the Central Rift Valley.

	Yield (kg ha^{-1})	Price (Birr kg^{-1})	Costs (Birr ha^{-1})	Water applied (m^3 ha^{-1})	Value of water (Birr m^{-3})
Roses	2.5 * 10^6 [1)]	1.4 - 1.5 [2)]	3.16 * 10^6	20000	17 - 29.5
Grapes (state farm)	7000	3.65	34006	22000	-0.4
Tomatoes (state farm)	37800	0.72 - 2.20 [3)]	17389	17100	0.6 - 3.8
Maize for hybrid seed (state farm)	6000	2.55	8229	11800	0.6
Tomatoes (smallholder)	26000	1.00 - 2.20 [4)]	21863 [5)]	17100	0.2 - 2.1

[1)] Million stems
[2)] Birr per stem
[3)] Minimum price received by the state farm, and maximum price highest price observed in survey (Scholten, 2007).
[4)] Minimum and maximum price as derived from survey (Scholten, 2007).
[5)] Costs based on Alemu (2004)

Table 8 shows that flower production clearly generates the highest economic value per unit of irrigation water applied. Despite of the high costs, net income derived from roses is very high. At the same time the water use is relatively low compared to other crops, because of the use of drip irrigation.

The value of irrigation water may become negative as in the case of grapes due to the low yields and low product prices in relation to high production costs.

The possibly large impact of different product prices on the irrigation water productivity is shown for tomato production. The State Farm received a much lower price (0.72 Birr kg^{-1}) than the highest price (2.2 Birr kg^{-1}) that some vegetable smallholders received in the CRV (Scholten, 2007). The irrigation water productivity can then increase more than six times if farmers are able to bargain a higher price for their tomatoes.

5.3 Land productivity

Land productivity is defined as the net income received by farmers per unit of land. Based on the data shown in Table 8 the land productivity or net returns to land can be calculated (Table 9).

Table 9. Land productivity for different irrigated crops in the Central Rift Valley (see footnotes Table 8).

Crop	**Land productivity (Birr ha^{-1})**
Roses	590000
Grapes (state farm)	-8456
Tomatoes (state farm)	9827 - 65771
Maize for hybrid seed (state farm)	7071
Tomatoes (smallholder)	4137 - 35337
Onions (smallholder) [1)]	-10472 - 37528

[1)] Costs based on Alemu (2004), with average onion yield (16000 kg ha^{-1}) and product price range (0.5 - 3.5 Birr kg^{-1}) based on Scholten (2007).

Table 9 shows that, in general, land productivity of flowers is at least a factor 10 higher than open-field vegetables.

Land productivity of irrigated vegetables varies widely, from negative to profitable values, as a result of the large dependency of the product price. In reality, land productivity will also be affected by differences in yields and costs among producers. For example, average tomato yields vary between 4.4 t ha^{-1} in Arsi Negele to 28 t ha^{-1} in Ziway Gugda (Scholten, 2007).

5.4 Labour productivity

Based on the net returns determined in the previous section and the labour requirements associated with the different agricultural activities the labour productivity can be calculated as the ratio between both. This indicator gives information on the economic returns per unit of labour (i.e. per person).

Labour requirements can vary largely according to the type of technology used and crop management. For some crops, such as tomatoes, the total labour requirements are mostly related to yield level, as harvesting is very labour-demanding. The data from the state farm were not used for this assessment, since the use of seasonal labour force made it difficult to estimate the labour input in the various crops that are grown at the farm.

The labour requirements for flower production are extremely high. The survey under flower producers showed that these labour requirements ranged from 20 to 70 persons per ha per day (Danse et al., 2007). However, it is not clear if this number includes administrative and service personnel, temporary construction workers, guards, etc. It was assumed that the labour requirements for flower production be in the order of 30 p ha^{-1}. Moreover, 200 workable days per year were assumed to convert seasonal labour inputs of smallholder production into annual labour requirements.

Table 10. Labour productivity for different irrigated crops in the CRV (See footnotes Table 9).

Crop	Labour requirements (p ha^{-1})	Labour productivity (Birr p^{-1})
Flowers	30	19666
Tomatoes (smallholder)	4 [1])	1034 - 8834
Onions (smallholder)	0.4 [1])	< 87274

[1]) Based on PRISM (2004)

As a consequence of the high labour requirements in flower production the difference in labour productivity between flower production and smallholders is less than the differences in water and land productivity.

The labour productivity in onions production is very high, which can be explained by the low absolute labour requirements (PRISM, 2004).

5.5 Synthesis of economic assessment

It is noted that resource use efficiencies, as elaborated in the preceding sections, are difficult to calculate accurately in the absence of consistent and systematically collected data sets. In addition the unknown variation across years and farms further complicates the interpretation of available data.

The preliminary results serve to highlight the main underlying issues and help to draw generally valid conclusions:

- Resource use indicators of flower production systems, especially water and land productivity, are much higher than those of other irrigated production systems. The average labour productivity in flower production systems may be lower than in vegetable production by smallholders, which is possibly due to under-estimated labour requirements for vegetable production.
- The large variability in the resource use indicators based on product price only suggests scope for improved performance of irrigated smallholder production. In addition to better marketing strategies resulting in better product prices, better crop management resulting in higher yields of high quality could improve the performance.
- In addition to the previous conclusions, other sources (a.o. Alemu, 2004) suggest that the current economic performance of various smallholder irrigated production systems is poor and may even result in economic losses. This is possibly associated with the indigent status and poor maintenance of various irrigation schemes in the CRV (Scholten, 2007; PRISM, 2004). Poor water management skills and expertise (PRISM, 2004) and high costs of water extraction (Alemu, 2004) have further contributed to this situation.

6 Water resources assessment

6.1 General outline

To relate (changes in) the land resources with (changes in) the water resources a more detailed assessment of the water resources was conducted. This assessment was aimed at quantifying the most determining components of the hydrological system and analysing spatial and temporal trends.

In Section 6.2 a general overview is given of the hydrological system and the most relevant components are identified. In the following sections each of these components is further assessed. This chapter is concluded with some remarks on the (impacts of) temporal variability of water resources (Section 6.8).

6.2 Components of the hydrological system

The CRV is a closed basin, hence there is no inflow and outflow of surface water. There is also no evidence of (significant) groundwater inflow or outflow. As a result all water resources in the area eventually originate from rainfall.

Above land the rainfall is intercepted by the vegetation, temporarily ponds in surface depressions, or infiltrates into the soil, from where it can directly evaporate or be utilized by crops (evapotranspiration). If the rainfall exceeds the infiltration capacity of the soil, surface runoff can occur. In the case of relatively large infiltration rates, a portion of the rainfall can recharge the groundwater (Figure 16).

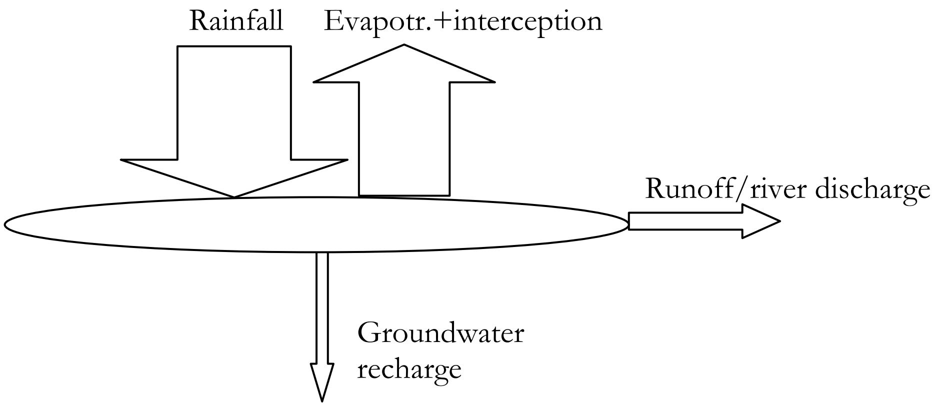

Figure 16. Simplified water cycle above the land surface

The groundwater recharge can eventually discharge into the lakes, discharge into the rivers as baseflow, be temporarily stored (in aquifers), or be utilized.

Above open water the evaporation rates exceed the rainfall. The level of the lakes is, therefore, maintained by a net inflow of surface water and groundwater.

At (closed) catchment level the total rainfall minus the interception equals the total evapotranspiration (in an equilibrium situation). Above land temporal variations in rainfall cause temporal variations in the other water components (Figure 16), which are partly attenuated by water stored in the (sub)soil. Above water these fluctuations are (mostly) compensated by changes in water storage in the lakes, thus causing a (natural) fluctuation of the lake levels.

The principal impact of changes in land use is that the spatial distribution of the evapotranspiration (and interception) in the catchment changes. If irrigated agriculture is developed the evapotranspiration in these areas will increase, which implies that elsewhere in the catchment the evapotranspiration has to decrease[11].

From the above it is obvious that the rainfall and evapotranspiration are important components in the water balance. They will be assessed in more detail in Section 6.3 and 6.4, respectively.

The present irrigation developments are mostly based on surface water. In Section 6.5 the surface water resources are characterised and quantified. The focus is on the catchment of Lake Ziway, as most irrigation developments occur in this subcatchment (see Section 4.3).

In Section 6.6 only a tentative assessment of the groundwater resources is given. The current land developments do not yet utilize large quantities of groundwater, however the role of groundwater may become more important in the future.

The rainfall has a rather erratic character (Section 3.2). The implications of the temporal variability of rainfall is further described in Section 6.8.

6.3 Rainfall

To calculate the volume of rainfall in the catchment, the daily rainfall data from 20 meteorological stations were collected from the National Meteorological Services Agency. The data comprise the period from 1996 to 2005. For practical reasons not all the meteorological stations with data in the study area were selected for this assessment. If a more detailed assessment is required in future, the obtained information can be supplemented and updated.

[11] This can occur in many ways, for example:

- The natural vegetation may decrease or change (to species that consume less water).
- The natural lakes will partly deplete and reduce in size so that they evaporate less (this is actually experienced in Lake Abyata).
- Man-made measures can be implemented to reduce the ponding of water after storm events and to enhance groundwater recharge.

A list of the selected meteorological stations is presented in Table 11. Their locations are also shown in Figure 17.

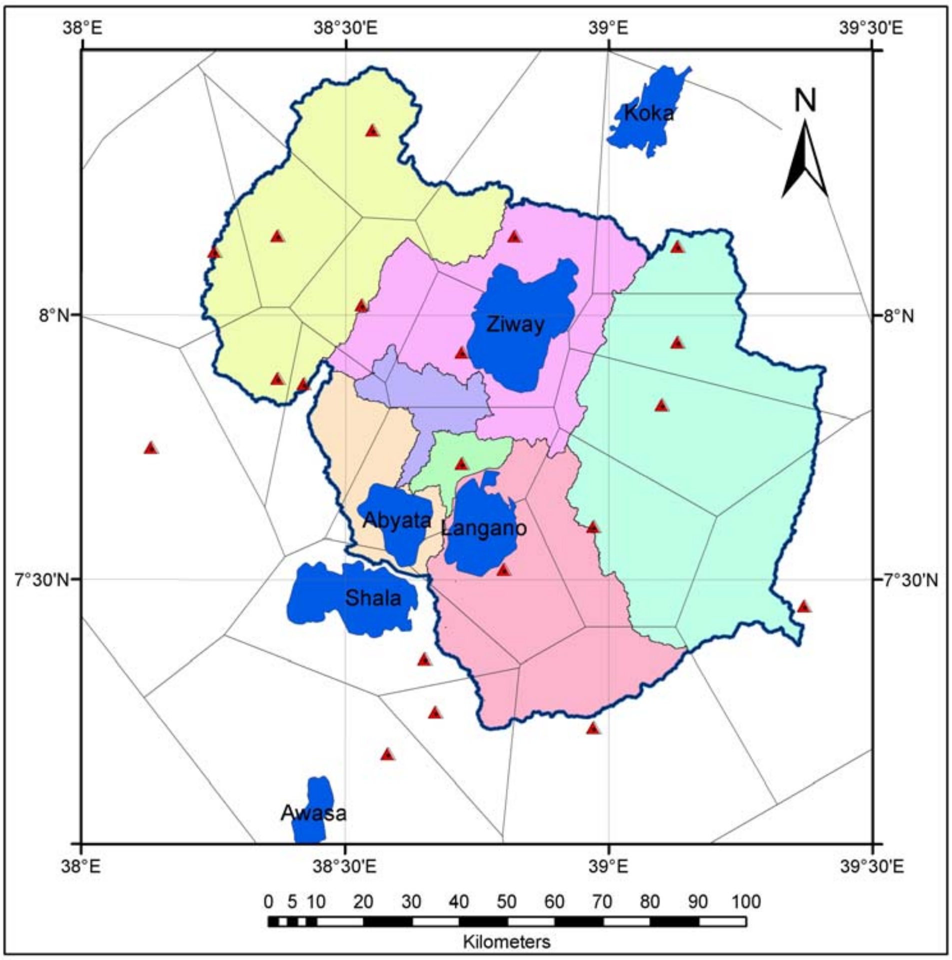

Figure 17. Selected rainfall stations and Thiessen polygons[12]

[12] Note that the Thiessen polygons of two stations are entirely outside the study area.

Table 11. Selected meteorological stations for rainfall data.

Station Name	Latitude	Longitude	Altitude (m. +MSL)
Arbuchulele	8°07’	38°15’	2480
Arsi Negele	7°21’	38°39’	1800
Assela	7°57’	39°08’	2350
Bui	8°21’	38°33’	2020
Bulbula	7°43’	38°43’	1700
Butajra	8°09’	38°22’	2000
Chlelektu	7°53’	38°22’	1675
Dagaga	7°36’	38°58’	
Ketera Genet	7°50’	39°06’	2400
Koshe	8°01’	38°32’	1860
Kulumsa	8°08’	39°08’	2200
Kuyera	7°15’	38°40’	2870
Langano	7°31’	38°48’	1700
Meki	8°09’	38°49’	1400
Meraro	7°27’	39°22’	2940
Sire	7°13’	38°58’	2390
Tora	7°52’	38°25’	1600
Wendo Genet	7°10’	38°35’	1880
Wulbareg	7°45’	38°08’	1800
Ziway	7°56’	38°43’	1640

The volume of rainfall that falls in the subcatchments was calculated with Thiessen polygons (see Figure 17). As the density of meteorological stations is reasonable this method was considered accurate enough, despite of the occurring topographic gradients.

For each sub-catchment the annual volume of rainfall was calculated (Table 12). Missing data in the rainfall records were estimated with data from nearby stations[13]. The average annual volume of rainfall in the period 1996-2005 in the study area amounted to 9.1 billion m^3.

[13] It would have been more correct (scientifically) to redraw the Thiessen polygons for each period with incomplete data. However, this procedure is very laborious, while the expected increase of accuracy would be limited (most probably within the error margin). An indication of the error introduced was obtained by comparing the calculated average volume of rainfall with the average volume of rainfall in the years with complete data. This difference is only approximately 2%.

Table 12. Annual volumes of rainfall on the subcatchments

Subcatchment	Rainfall (million m³)										
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Ave-rage
Meki	2804	2206	2415	2060	2053	2569	2011	2227	1787	2792	2293
Ketar	3049	2920	3077	2728	2952	2997	2377	2700	2693	2815	2831
Ziway	1677	1574	1486	1233	1342	1496	1012	1441	1265	1548	1407
Langano	2151	1666	1796	1828	1665	1712	1333	1707	1452	1605	1692
Horakelo	150	79	120	131	125	122	77	116	78	130	113
Bulbula	299	231	248	210	228	241	157	236	211	274	234
Abyata	697	471	568	516	558	541	383	463	446	598	524
Total	10826	9147	9710	8707	8924	9678	7349	8890	7933	9761	9093

During the past ten years a decreasing trend of the volume of rainfall was observed. Figure 18 shows that this downward trend is observed in the entire study area and also in the catchment of Lake Ziway. The volume of rainfall in the catchment has decreased by approximately 15 %. In the catchment of Lake Ziway (representing 70% of the total catchment) the volume of rainfall has decreased by approximately 11%. The period of 10 years is, however, too short to draw decisive conclusions on long-term trends.

The impact of the rainfall variability and rainfall trends is presented in Section 6.8.

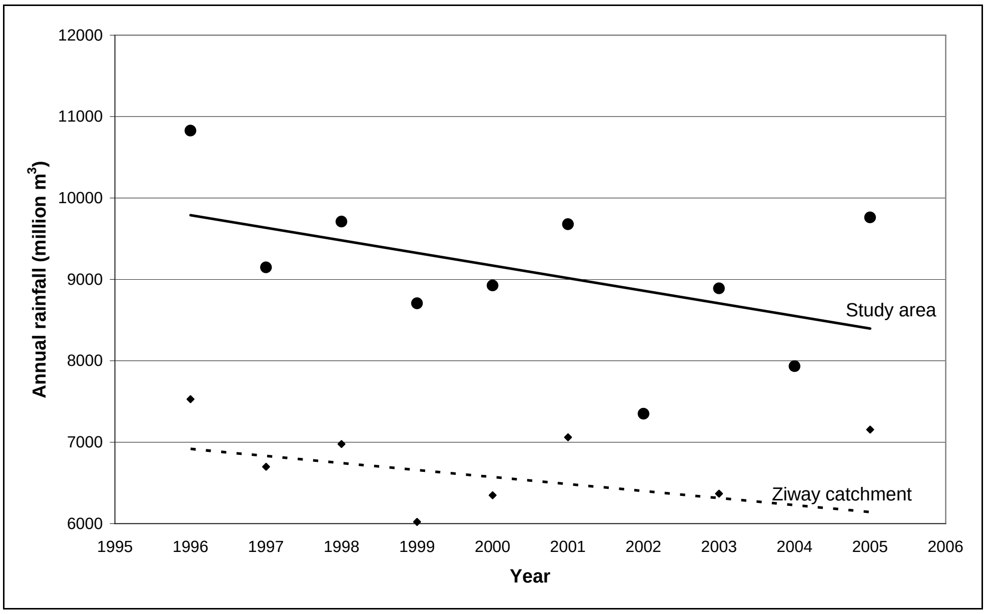

Figure 18. Annual volume of rainfall in study area and (entire) catchment of Lake Ziway

6.4 Evapotranspiration

Most of the rainfall that falls on the study area is evaporated. The *actual evapotranspiration* is difficult to quantify directly, as it depends on the crop characteristics, the atmospheric conditions and the actual availability of water in the rootzone.

In an equilibrium situation the actual evapotranspiration (in the entire catchment) equals the rainfall minus the interception. In this section an assessment is made of the evapotranspiration on land and above open water, because the evapotranspiration above land is much more dependent on the rainfall than the evaporation of open water. The actual evapotranspiration was calculated on the basis of the reference evapotranspiration.

The *"reference evapotranspiration"* represents the theoretical quantity of water that can be evaporated by a specified crop (reference crop), depending on the prevailing climatologic conditions. The reference evapotranspiration thus assumes no limit of water availability.

The reference evapotranspiration in the study area was determined with the long-term average data of 6 meteorological stations and their Thiessen polygons (Figure 19). As both the spatial and temporal variability of the reference evapotranspiration are much less than the variability in the rainfall the data from these six stations are expected to give a reasonable result.

The calculated reference evapotranspiration in the study area is approximately 14 billion m^3, which thus largely exceeds the rainfall. In the valley the reference evapotranspiration exceeds the rainfall in each month of the year. In the high rainfall zones (mountains), the rainfall exceeds the reference evapotranspiration in the months from June to September[14].

[14] An implication is, that there is scarcity of water resources, i.e. it will theoretically not be possible to develop the land in the entire catchment such that the crops or other vegetation all have optimum growing conditions (unless additional water is made available).

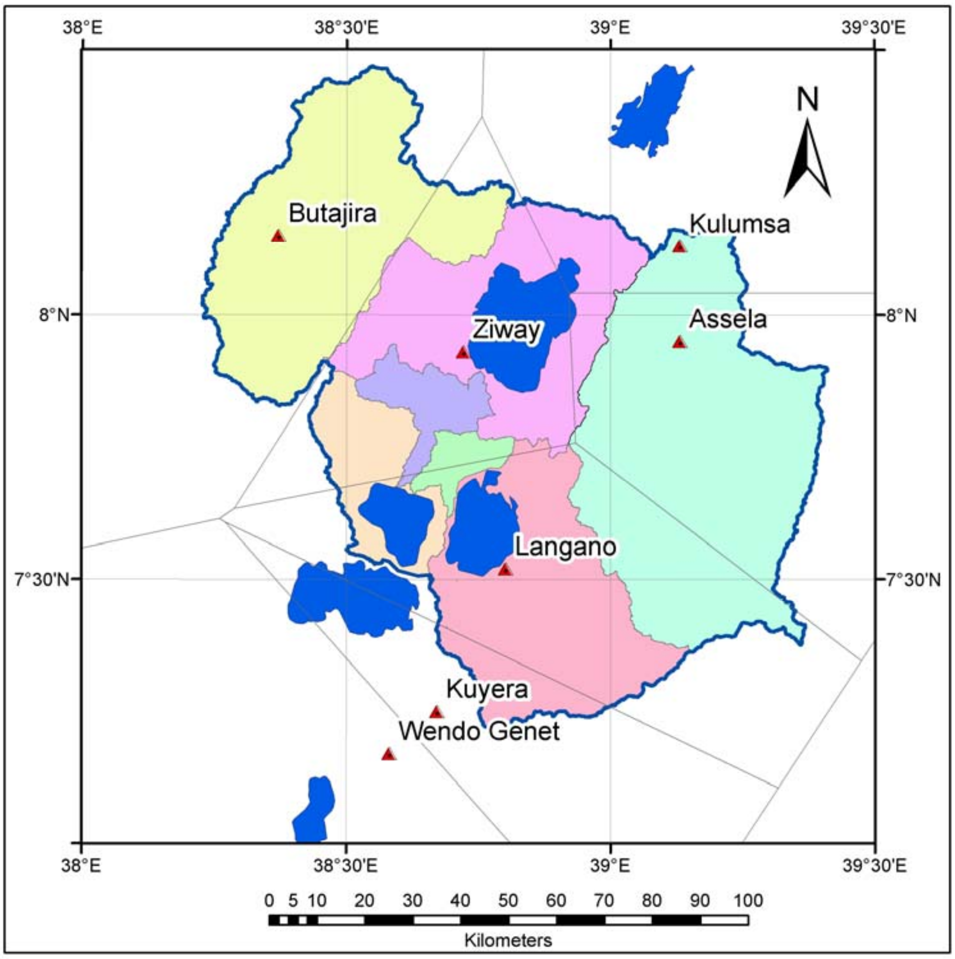

Figure 19. Meteorological stations with (reference) evapotranspiration data (FAO)

The order of magnitude of the actual evapotranspiration was calculated on a monthly basis (see Box 1), assuming that:

1. the actual evapotranspiration equals the rainfall minus the interception and runoff[15] in the months in which the reference evapotranspiration exceeds the rainfall minus the interception and runoff. Hence no groundwater recharge is assumed in these conditions.
2. In the other months the actual evapotranspiration was assumed to equal the reference evapotranspiration[16].
3. For the lakes during the entire year the actual evapotranspiration was assumed to be equal to the open water evapotranspiration (since there are no limits in water availability)[17].

[15] The rainfall minus the interception and runoff (also referred to as "effective rainfall") was computed according to the USDA Soil Conservation Service Method. Note that no irrigation is considered.
[16] An inaccuracy was introduced here, as the potential evapotranspiration of individual crops can differ (generally not more than 10-20%) from the reference evapotranspiration.
[17] The open water evaporation was calculated as 1.05 * reference evapotranspiration (see FAO, 1998).

Box 1. Actual evapotranspiration:

$$ET_a = P - I - Q \qquad (\text{if } ET_0 > P\text{-}I\text{-}Q)$$
$$ET_a = ET_0 \qquad (\text{if } ET_0 < P\text{-}I\text{-}Q)$$

ET_0 = *Reference evapotranspiration*
ET_a = *Actual evapotranspiration*
P = *Rainfall*
I = *Interception*
Q = *Surface runoff*

According to this assessment the annual actual evapotranspiration in the study area is in the order of 6 - 6.5 billion m^3 above land, and 1.5 - 2 billion m^3 at the lakes and the permanent wet areas.

It is noted that this volume represents the situation, where rainfall is the only water source. Obviously the actual evapotranspiration will increase if the rainfall is supplemented with irrigation water (as this will improve the water availability; see also footnote). The present contribution of irrigated agriculture to the total evapotranspiration in the catchment is minor (less than 1%). However, due to the specific characteristics of closed basins, irrigated lands can still have significant impacts on the hydrology (see also Section 6.8 and Chapter 8).

The evaporation from the major lakes was estimated at 1.2 billion m^3 (Table 13), being less than 20% of the total evapotranspiration losses in the study area. Most of the actual evapotranspiration, therefore, comes from the natural vegetation and from rain-fed agriculture.

Table 13. Estimated evaporation from the lakes.

Lake	Area (km^2)	Annual evaporation (million m^3)
Ziway	415	619
Langano	226	346
Abyata	161 [18]	247

6.5 Surface water

Daily data on the surface water discharge were collected from the Hydrology Department of the Ministry of Water Resources. The data comprise the period from 1990 to 2005. A list of the hydrometrical stations in the study area is presented in Table 14. Their locations are also shown in Figure 20.

[18] Based on the (historical) maps presented in this report (natural situation). Due to the reduction of the lake the present evaporation from Lake Abyata has decreased to, approximately, 145 million m^3 per year, i.e. a decrease of approximately 100 million m^3 per year. This water is evapotranspirated elsewhere in the catchment (e.g. through irrigation; see also Section 6.2).

Table 14. Hydrometrical stations

Station number	Station name	Longitude	Latitude	Data
081001	Lake Ziway Nr. Ziway	38°45'	7°54'	Water levels
081002	Lake Abyata Nr. Aroressa	38°42'	7°31'	Water levels
081007	Upper Timala Nr. Digelu	39°15'	7°45'	Discharges
081010	Ashebeka Nr Sagure	39°09'	7°41'	Discharges
081011	Katar Nr Fite	39°03'	7°47'	Discharges
081018	Meki @ Meki Village	38°50'	8°09'	Discharges
081019	Katar Nr Abura	39°03'	8°04'	Discharges
081023	Lake Langano Nr. Hotel	38°31'	7°32'	Water levels
081025	Chiufa Nr. Arata	39°04'	7°59'	Discharges

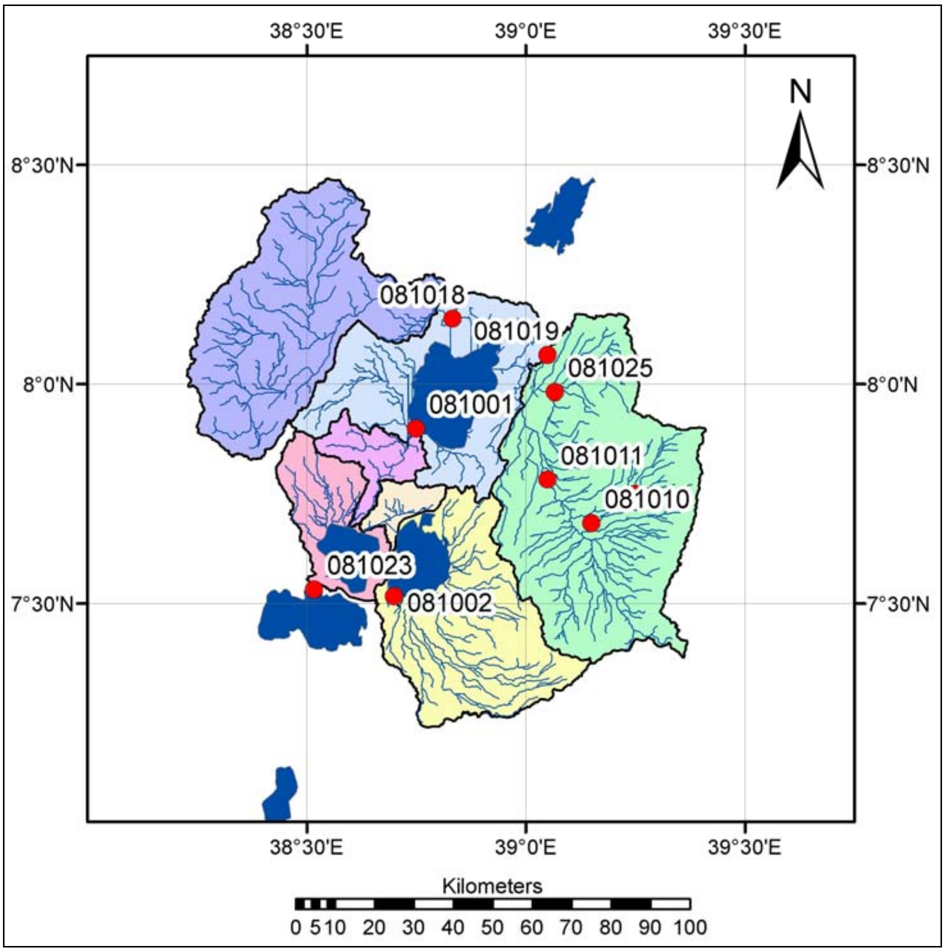

Figure 20. Locations of hydrometrical stations

River discharge data were only available for the sub-catchments of the Meki and Ketar Rivers. Table 15 presents the annual outflow[19] of the Meki and Ketar River at the most downstream monitoring location. The annual discharges show a large temporal variability. The average inflow into Lake Ziway was calculated as 675-695

[19] In the case of missing data of not more than 10 consecutive days, the daily discharges were estimated by interpolation. Years with data gaps of more than 10 days were not considered for the annual calculations.

million m^3 per year, which is in line with a previous study by [Ayenew, 2004], who calculated an annual inflow of 657 m^3 (based on data from 1970-1996)[20].

Table 15. Annual outflow of Meki and Ketar catchments

Year	Outflow Meki River (081018)	Outflow Ketar River (081019)	Inflow into Lake Ziway
		million m^3	
1990	330	n/a	n/a
1991	271	335	606
1992	n/a	466	n/a
1993	450	461	911
1994	n/a	441	n/a
1995	n/a	410	n/a
1996	n/a	421	n/a
1997	188	208	396
1998	499	508	1008
1999	235	364	599
2000	119	365	485
2001	193	521	714
2002	n/a	n/a	n/a
2003	363	329	693
2004	341	322	664
Average	299	396	675-695

6.6 Groundwater

For the present study the relevance of the groundwater system is principally associated with the sustainable groundwater abstraction (safe yield) in the area and with the interaction between the groundwater and the lakes. The sustainable groundwater abstraction largely depends on the groundwater recharge. The quantification of groundwater recharge is, however, complicated requiring extensive investigations, for which the existing data are not sufficient. In addition, the groundwater system in the CRV is rather complex (Hengsdijk and Jansen, 2006). As there is no evidence that the aquifer is presently being overpumped, only a tentative assessment of the groundwater system was made.

[Ayenew, 1998] estimated that the annual groundwater recharge varied from nil in the central portions of the valley, to 7,5-9 % of the rainfall in the (high rainfall) highlands.

Given the nature of the area and the rainfall and evapotranspiration characteristics it is expected that the groundwater recharge is negligible in the subcatchments of Horakelo, Bulbula and Abyata. Also in the subctachment of Langano the

[20] It is however noted that the 675-695 m3/year does not include the direct inflow into Lake Ziway (through gullies and minor channels; see the drainage pattern in Figure 20).

groundwater recharge is expected to be very small compared to the other water balance terms.

In the catchments of the Meki and Ketar River the average groundwater recharge is expected to range from 5 to 10 % of the rainfall, thus representing a volume of approximately 300 to 600 million m^3 per year. In the period 1970-1977 the baseflow (originating from groundwater) of the Meki and Ketar Rivers was calculated as 372 million m^3 (Chernet, 1982), these rivers then having a total annual flow of 786 m^3, hence 100 million m^3 more than presently (see Section 6.5). Various references report a decrease in the baseflow of the rivers.

In addition to emerging as baseflow, groundwater is abstracted by wells, scattered through the area, or flows towards Lake Ziway.

6.7 Interception

The interception in the catchment of Lake Ziway is approximately 700 million m^3 per year[21]. Deforestation and ground clearing will decrease the interception and thus result in more surface runoff.

6.8 Temporal variability of water resources

From Section 6.3 it was concluded that the rainfall in the CRV can show a large variability between successive years. This temporal variability is not only important for the assessment of available water resources from year to year, but also for the hydrological system analysis. As the CRV is a closed catchment, the water resources are not only spatially interlinked, but also strongly interlinked in time.

Surface water resources- rivers
The impact of the temporal variability of rainfall on the rivers was investigated for the period from 1996 to 2005. The relation between the annual rainfall and annual river discharges is shown in Table 16 and Table 17. These tables show that there is no direct relation between the annual rainfall and the percentage of the rainfall that is discharged by the rivers. For example, in the relatively dry year 2004 the discharge by the Meki River was more than in the relatively wet year 2001.

[21] Based on the recorded river discharges and the calculations of the "effective rainfall".

Table 16. Relation between annual rainfall and annual river discharge Meki River

Year	Rainfall in Meki catchment	Outflow Meki River (081018)	River discharge
	million m^3		(% of rainfall)
1997	2235	188	8.4
1998	2415	499	20.7
1999	2060	235	11.4
2000	2053	119	5.8
2001	2569	193	7.5
2002	2011	n/a	n/a
2003	2227	363	16.3
2004	1787	341	19.1
Average		12.7 %	

Table 17. Relation between annual rainfall and annual river discharge Ketar River

Year	Rainfall in Ketar catchment	Outflow Ketar River (081019)	River discharge
	million m^3		(% of rainfall)
1996	3049	421	13.8
1997	2920	208	7.1
1998	3077	508	16.5
1999	2728	364	13.3
2000	2952	365	12.4
2001	2997	521	17.4
2002	2377	n/a	n/a
2003	2700	329	12.2
2004	2693	322	12.0
Average		13.1 %	

On average the river discharge is approximately 13 % of the rainfall.

The inter-annual variability of river discharge is much greater than the variability of the rainfall (Figure 21 and Figure 22). Obviously the river discharge is largely determined by the rainfall pattern during the year. Figure 23 shows that the discharge characteristics are to a large extent determined by the occurrences of relatively heavy rain showers, rather than the absolute amount of rain.

This implies, for example, that climate studies should very much focus on the changes in rainfall patterns and not only on changes in rainfall quantities.

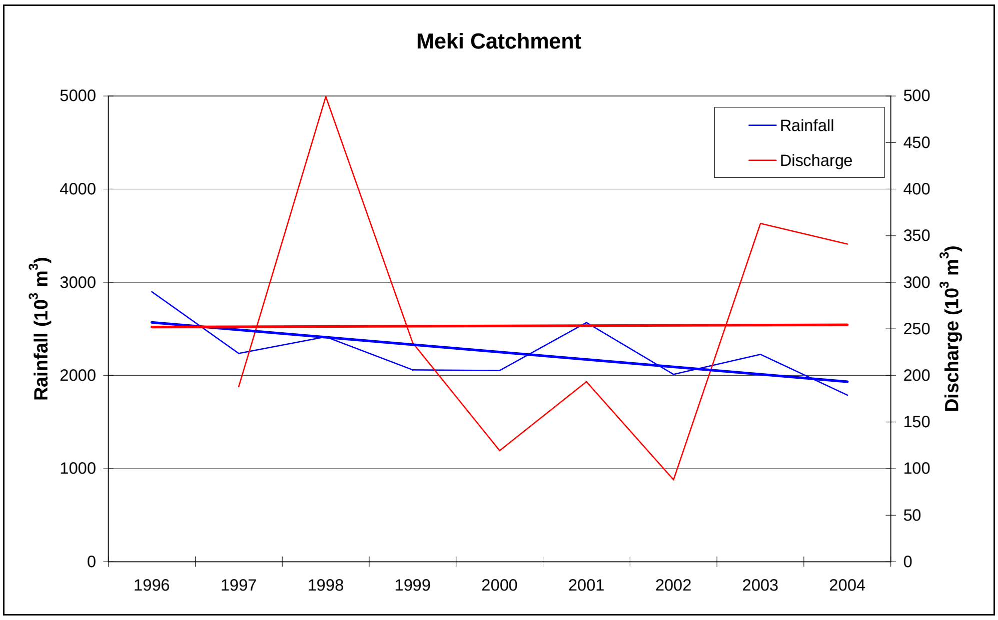

Figure 21. Annual variability of rainfall and discharge in Meki catchment

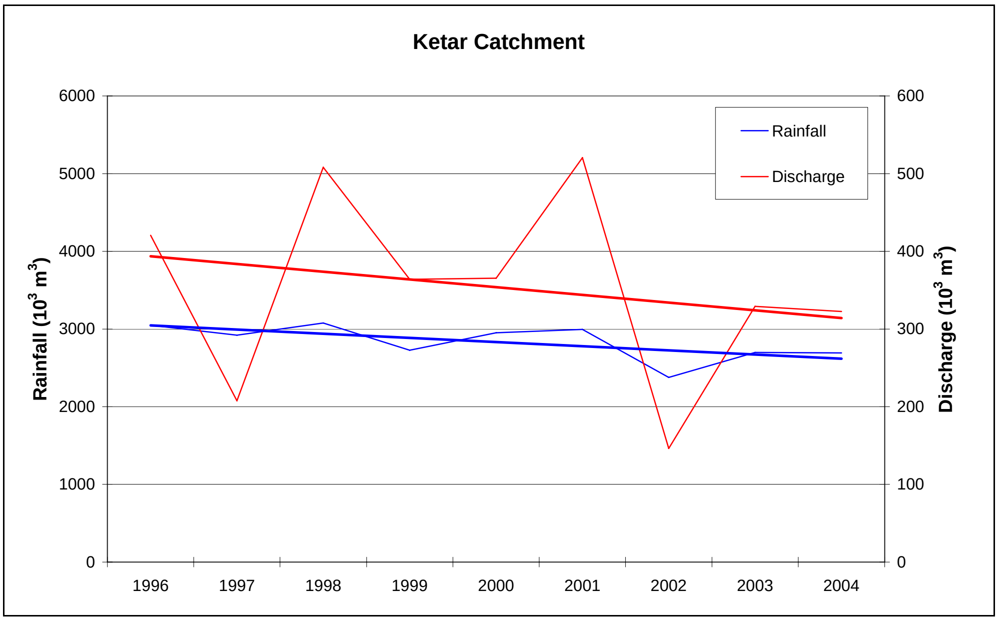

Figure 22. Annual variability of rainfall and discharge in Ketar catchment

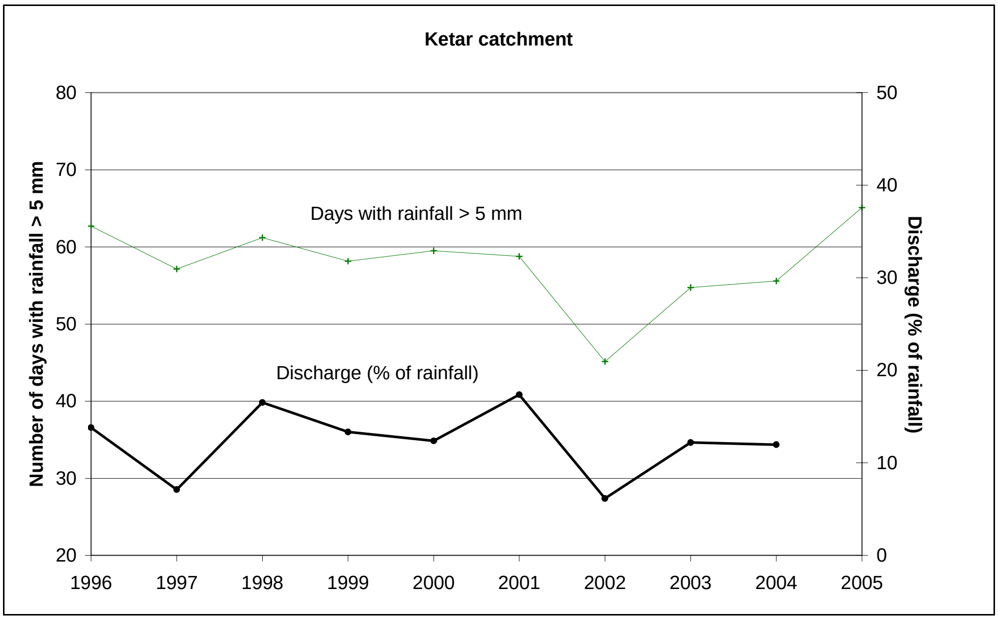

Figure 23. Relation between discharge characteristics and rainfall pattern (Ketar catchment).

In the Ketar catchment both the rainfall and river discharges show a decreasing trend in the past 10 years, in the Meki catchment the downward rainfall trend is not reflected in the river discharges. This confirms the largely erratic character of the river discharges. Obviously the land resources determine to a much larger extent the fate of the rainfall and thus have a great buffering effect on river discharges.

Evapotranspiration

The evaporation rate on open water is only slightly dependent of the rainfall. This implies that the average lake levels will decrease in dry years and increase in wet years.

From the assessment in Section 6.4 it can be concluded that (on land) 30-40% of the annual evapotranspiration occurs in the wet period, from June to September. In the remaining months the actual evapotranspiration will largely follow the rainfall. The variability in evapotranspiration is therefore strongly related with the variability in rainfall.

This means that the variability in the rainfall is principally affecting the rain-fed agriculture and natural vegetation (through reduced evapotranspiration). The impact on surface water resources is smaller and also less direct.

The impact of the temporal variability of the rainfall on the groundwater resources has not been investigated[22].

[22] The groundwater recharge will also be subject to temporal variability, but as the groundwater resources represent a vast storage reservoir (with large residence times of water) temporal fluctuations are largely attenuated.

7 Water abstractions

7.1 General outline

The assessment of the water abstractions refers to direct abstractions from surface water and groundwater resources, and does not account for water uses that depend on rainfall (rain-fed crop production for the local human and livestock population, and ecosystems). These water uses are addressed in Section 6.4.

The following water users were identified in the CRV: domestic water users (Section 7.2), livestock (section 7.3), closed irrigated production systems (Section 7.4), open-field irrigated production systems (Section 7.5) and the soda-ash plant along the shore of Lake Abyata (Section 7.6).

The water use by the various users is not being measured. The data presented are, therefore, estimates and mainly aim to show the major differences in water use among stakeholders. An overview of these differences is presented in Section 7.7.

7.2 Domestic water use

The minimum daily water requirement for survival during normal activity in temperate climates is 2 to 5 l d^{-1} per person (Gleick, 1996). The average domestic water use in Ethiopia is 13.3 l d^{-1} per person, being very low compared with other countries in the world. As there is no detailed information available on the domestic water use in the CRV, the average national water use is assumed. This means that a population of about 1.5 Million (see Table 1) in the CRV consumes about 7.3 million m^3 of water on annual basis.

7.3 Livestock water use

The water intake by animals varies largely and depends on many factors, such as the prevailing climatic conditions, the activity level of the animals, the amount and type of feed consumed, lactation, and the salinity of water. In this assessment it is assumed that the livestock in the CRV consumes 15 l d^{-1} per TLU in the wet season (4 months) and 30 l d^{-1} per TLU in the dry season (Van der Meer, pers. com.).

This corresponds with an average daily intake of approximately 25 l d^{-1} per TLU, which is in agreement with the typical use of livestock (Peden et al., 2006). Based on a livestock population of 0.85 million TLU (Table 1), the total annual water consumption by the livestock sector is estimated at 7.7 million m^3.

7.4 Closed irrigated production systems

The water use of closed irrigated production systems refers to the production of roses. In collaboration with the project Dutch-Ethiopian Horticulture partnership a survey among (mainly greenhouse) flower producers in Ethiopia was carried out during the Fall of 2006 (Danse et al., 2007). Based on data from 22 farms that cultivate roses under drip irrigation the average water use for irrigation was estimated at approximately 18000 m^3 ha^{-1} per year.

The minimum water use in the survey was 11500 m^3 ha^{-1} per year and the maximum water use 30300 m^3 ha^{-1} per year. All closed production systems used drip irrigation systems. The observed variation in water use is the result of various factors, such as differences in climate zone, the availability of recirculation systems or rainfall basins, the use of substrates or soil cultivation, crop management, etc.

The rose farm in the CRV uses approximately 10% more water than the average of the surveyed farms. This water use does not yet include the water for processing and other on-farm activities (cleaning, etc.), as the farms could not provide reliable estimates for these quantities. At the closed production systems in the CRV part of this water is drained and discharged to Lake Ziway. Also the rainfall on the greenhouse canopies is being discharged to Lake Ziway, being estimated at approximately 6000 m^3 ha^{-1} $year^{-1}$.

On the basis of these data the gross annual water use for the production of roses is estimated at 20000 m^3 ha^{-1}. The net water use will be somewhat lower, because of the drainage water. Various experts estimate that the actual evapotranspiration of roses under the conditions at Ziway vary between 10000 and 13000 m^3 ha^{-1} per year. Therefore, water use efficiency in the greenhouses (roses) is about 50 to 65%.

Total gross water use by closed irrigated production systems is in the order of 2 million m^3 per year by the end of 2006 (based on 100 ha). If this area increases to 1000 ha, the annual water consumption will increase to an amount in the order of 15-20 million m^3.

7.5 Open-field irrigated production systems

The open-field irrigation in private, state as well as smallholder production systems are mostly based on furrow irrigation (Section 4.5).

The crop water requirements are calculated on the basis of the reference evapotranspiration and crop coefficients, using the CROPWAT model (Clarke, 1998). The calculated crop water requirements refer to the potential evapotranspiration, which represent an optimum situation. The actual required water is more, depending on the (overall) irrigation efficiencies.

In the CRV the irrigation efficiencies are unknown, but they, typically, vary between 30 and 50% in traditional irrigation schemes (FAO, 1997). In smallholder vegetable production in the Meki-Ziway area the irrigation water use efficiency was estimated at less than 30% (PRISM, 2004). For different crops and growth periods the irrigation water requirements for a medium textured soil were estimated for two irrigation water use efficiencies, namely 20 and 40%.

Table 18 illustrates how the crop type and the growing season and duration determine the crop water requirements for the climatic conditions represented by the meteorological station of Ziway. On the basis of the rainfall data, the irrigation water requirements for various open-field irrigation production systems can be calculated.

Table 18. Estimation of irrigation water requirement in open field crops using the CropWat model (see text).

Crop	Growing season	Duration	Crop water requirement	Effective rainfall (Ziway)	Irrigation water requirement (m^{-3} ha^{-1})	
		(d)	(mm)	(mm)	Efficiency of 20%	Efficiency of 40 %
Tomato	Jan. 1 - May 25	145	665	210	22800	11400
Dry bean	Jun 1 - Sept 19	110	450	325	7032	3516
Dry bean	Nov 1 - Feb 19	110	426	33	19673	9789
Dry bean	Jan 1 - Apr 21	110	449	129	15977	7983
Grapes	Jan 1 - Dec 31	365	1228	611	30904	15452
Maize	Jul 15 - Oct 23	100	370	251	5950	2975
Maize	Jan 1 - Apr 11	100	424	109	15724	7862

It is noted that the factors that determine the irrigation water requirements vary throughout the CRV. It is therefore difficult to accurately determine these quantities. In the CRV normally two crops per year are grown on irrigated lands, however there is no well-defined growing season for each of the cultivated crops (Scholten, 2007). On the basis of the above information the average annual irrigation water use can be estimated at 20.000 m^3 ha^{-1} for open-field irrigated production systems.

(Scholten, 2007) estimated the average irrigation water use at 10.000 m^3 ha^{-1} per growing season on the basis of the number of irrigations, inundation depth, and inundated area. This value is in line with the information from Table 18.

Based on a total irrigated area of 7500-10,000 ha (see Section 4.2) the total water use by open-field irrigated production systems is estimated at 150-200 million m^3 per year. It is noted that not all this water is used. As the irrigation efficiencies are in the order of 30% part of this water will recharge the groundwater (and can, therefore, be reused), another part may indeed be lost through evaporation. The amount of excess irrigation water and conveyance losses that eventually recharge the groundwater is unknown.

7.6 Soda ash plant

Since 1990 a soda-ash factory is operational along the shore of Lake Abyata. This factory produces soda-ash (Na_2CO_3) from sodium bicarbonate ($NaHCO_3$) dissolved in lake water. The lake water is evaporated in large evaporation ponds, leaving sodium bicarbonate behind. Through heating the sodium bicarbonate is decomposed into sodium carbonate (soda-ash), water and carbon dioxide.

The experimental factory is designed for the production of 20.000 ton soda-ash per year. The actual production has been around 10.000 ton per year, or even less. The amount of water that is required to produce 10.000 ton of soda-ash is in the order of 0.9 million m^3. This volume is based on an average sodium bicarbonate concentration of 16.8 g l^{-1}. Fluctuations between 10 and 27 g l^{-1} were reported for Lake Abyata (Legesse and Ayenew, 2006).

Bastiaanssen (2006) quantified the water use by the soda-ash plant at 1.4 million m^3, using remote sensing techniques. Although both calculation methods differ their results are in the same order of magnitude.

7.7 Synthesis water users

From the previous sections it can be concluded that the open-field irrigated production systems are by far the largest user of the surface water and groundwater resources. The present gross abstraction is in the order of 200 million m^3 of water. A portion of this water will, however, return to the hydrological system as groundwater recharge or surface runoff.

Table 19. Water abstraction by various stakeholders in the Central Rift Valley (mid 2006).

Water user:	Assumptions/remarks	Annual water use (million m^3)
Domestic	Population of 1.5 million, using Ethiopian average amount of water	7
Livestock	0.8 million TLU, average use	8
Closed irrigation systems	100 ha, 20000 m^3 ha^{-1} y^{-1}	2
Open field irrigation systems	7500-10000 ha, 20000 m^3 ha^{-1} y^{-1}	150-200
Soda ash factory		1

Also a portion of the domestic water and water used by the closed irrigation systems will return to the hydrological system as waste water or drainage water. The amount of drainage water from the closed irrigation systems is however small, both in absolute and relative volumes (given the relatively high irrigation efficiencies of 50-65%). The quality of this water can, however, still have major impacts on the hydrological system, as this water may be enriched with nutrients and pesticides or their residues, which can pose risks on other water-related services.

From Table 19 it can be concluded that the focus for (quantitative) water resources management should be on the water abstractions by the open field irrigation systems.

For these systems the irrigation water use efficiencies are in the order of 20-40%. This means that in the order of 50-100 million m^3 of the abstracted water is evaporated (and thus leaves the hydrological system). Part of the remaining water is also lost by evaporation (e.g. as a result of conveyance losses) and transpiration by weeds and the natural vegetation. Unfortunately this volume cannot be quantified with the available data.

The water that recharges the aquifers may still be reused, however in many areas the groundwater is salty or enriched with fluoride. In these areas the excess irrigation water can also be considered as lost for water-related services. To assess whether, for example, more efficient irrigation systems are feasible, the local water resources conditions should be analyzed in more detail.

8 Impacts of land development on water resources

8.1 Introduction

From Chapter 4.3 it was concluded that the relatively wet areas have significantly increased in size since 1999. The increase was approximately 13000 ha. This area does, however, not only include small irrigated plots, but also marshes and wetlands that may partly have emerged during the time of imaging. The small-scale irrigation has, however, significantly increased recently.

Also the large scale irrigated farms have increased, from approximately 3000 ha in 1999 to more than 5000 ha in 2006.

On the basis of land classification through satellite images and a field survey the present irrigated area is estimated at 7500-10000 ha. In addition, the rain-fed agriculture has intensified.

Most of the newly developed areas are situated in the catchment of Lake Ziway. The development of irrigated agriculture imposes increased pressure on the water resources. In Section 8.2 the impacts of these irrigation developments on Lake Ziway are assessed.

The present and potential future impacts on Lake Abyata are assessed in Section 8.3.

In Section 8.4 some remarks are made on the impacts of (intensified) rain-fed agriculture on the water resources.

The water resources in the CRV are not only affected by land developments. There are also rising concerns about the possible impacts of climate changes. A preliminary assessment is given in Section 8.5.

8.2 Impact of land developments on Lake Ziway

The relation between the inflow into Lake Ziway from the Meki and Ketar Rivers, being the main tributaries, and the level of the lake were investigated for the period from 1991 to 2005.

Discharge from Meki and Ketar catchments
Figure 24 and Table 15 show that there is no (substantial) decrease of the outflow of the Meki and Ketar River from their respective catchments. The reason that the discharges of these rivers have not significantly decreased is that most of the new land developments are concentrated around Lake Ziway and in the very downstream portions of its two main tributaries, i.e. downstream of the gauging stations. This is confirmed by the information on Figure 9. The land developments in the upstream

sections of the Meki and Ketar catchments are obviously still small in relation to the natural variability of the river discharges.

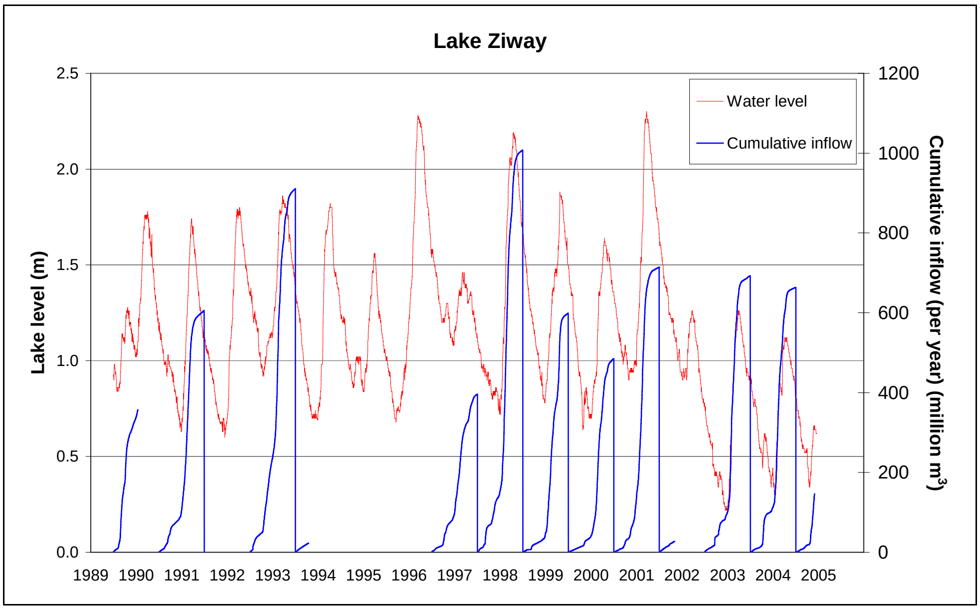

Figure 24. Relation between inflow and water level Lake Ziway[23]

The limited impact of upstream land developments is confirmed by Figure 25, presenting the differences in discharges between an upstream and downstream gauging station in the Ketar catchment. Figure 25 shows a slight increase in the differences in discharge between the downstream location 081019 and the upstream location 081011 between 1995 and 2000 (for the locations refer to Table 14 and Figure 20), but there is no clear evidence that this trend has continued after 2000.

[23] Note that the inflow in the years 1990, 1992, 1994, 1995, 1996 and 2002 do not cover the entire year due to missing data.

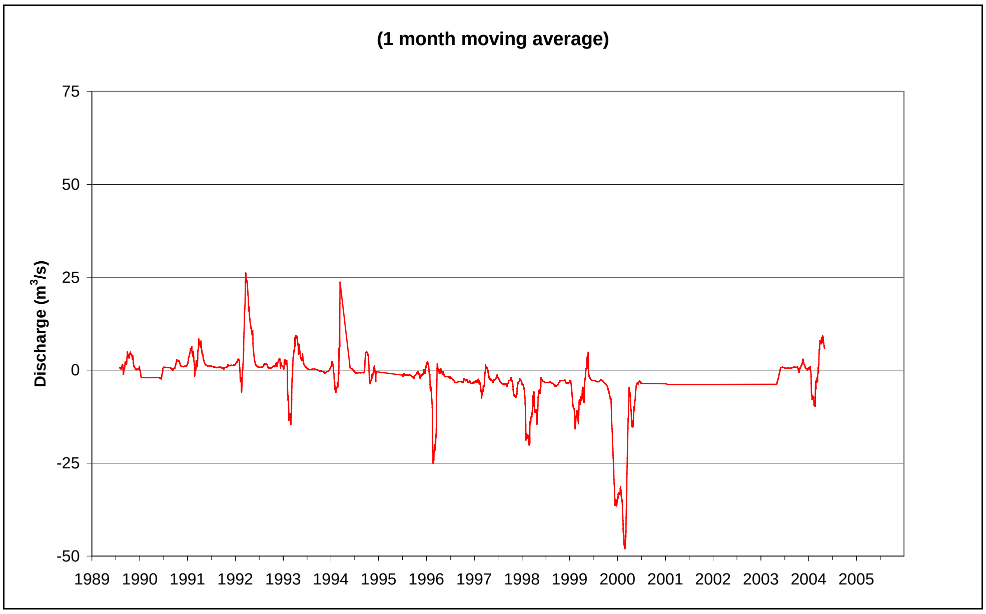

Figure 25. Differences between discharges at locations 081019 and 081011.

Water levels Lake Ziway

The minimum, maximum and average levels of Lake Ziway have significantly decreased since 2002. The year 2002 was a relatively dry year (Table 12), but the following year 2003 was an average year, both in terms of rainfall and river discharges (lake inflow). 2004 was also a fairly average year in terms of river discharge.

It is not plausible that the lower lake levels from 2002 to 2005 are the result of the dry year 2002. Figure 24 shows that previous years with relatively low river inflow (e.g. 1997 and 2000) had not resulted in long-term (more than one year) lower lake levels. The present lower lake levels indicate that more water is being been abstracted from Lake Ziway and/or the very downstream portions of the two tributaries since 2002.

The observed lowering of the lake level of approximately 0.5 meter corresponds with a volume of approximately 200 million m^3. This is more or less the equivalent required volume of water to irrigate 10000 ha of land.

Outflow to Bulbula River

The decrease of the water levels in Lake Ziway would also imply that less water is being discharged into the Bulbula River. Figure 26 shows indeed a rather direct relation between the water level in Lake Ziway and the outflow into the Bulbula River. In years with relative low lake levels (1995 and 2000) the outflow has also been low[24].

[24] In 1997 the peak level was also lower. In this year, the relatively high discharge by the Bulbula River is most probably the result of the relatively high water levels in the beginning of the year.

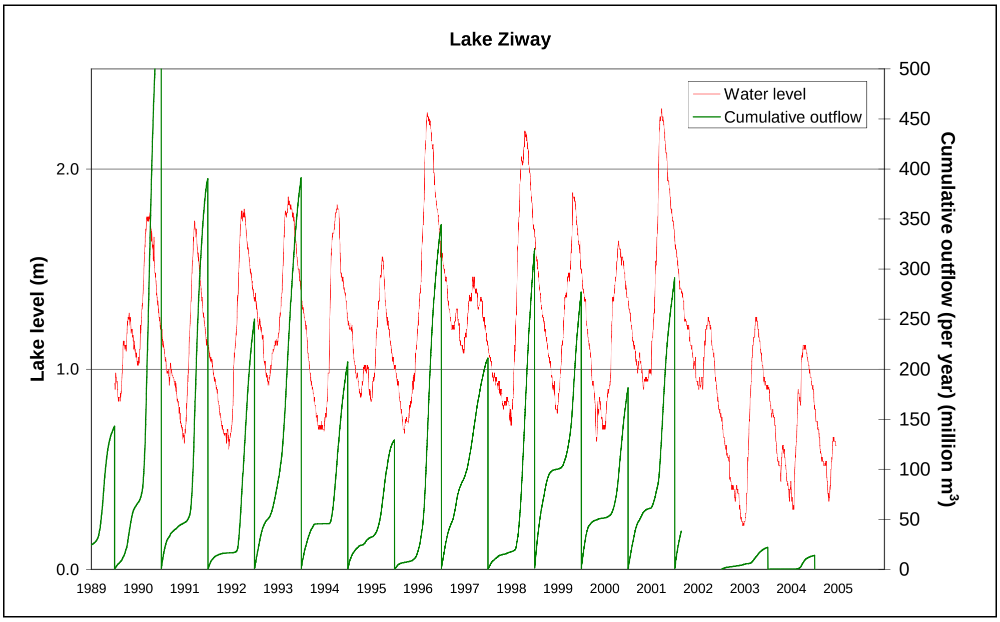

Figure 26. Relation between water level Lake Ziway and outflow to Bulbula River[25]

This especially applies to 2003 and 2004, when the discharges by the Bulbula River had decreased dramatically. Before 2002 the discharge was at least 200 million m^3 per year in average years. In 2003 and 2004 the annual discharge was less than 50 million m^3. Such a decreased discharge is very likely due to the decreased (average) water level of Lake Ziway[26]. The decreased discharge into the Bulbula River corresponds with the development (in the order) of 7500-10000 ha of new irrigated areas (being in line with the results of the land survey).

Water quality Lake Ziway

The impact of the new irrigation schemes on Lake Ziway is, presently, mostly limited to a decrease in the (average) water levels. The impact on the ecosystems that depends on Lake Ziway (including the fisheries) is unknown. There is, however, also a risk that the reduced outflow is not sufficient to maintain the salt balance in the lake (inadequate flushing).

A serious threat is that the further decrease of the water level may turn Lake Ziway into a terminal lake. This will cause that Lake Ziway eventually becomes saline (similar to Lake Abyata). Given the relatively shallow depth critical salinity levels could already be reached within 5-10 years. This will obviously have major repercussions for the recent floriculture developments and the local population, who depend on the lake water for their domestic water supply and their livestock watering.

[25] The outflow in 2002 does not cover the entire year due to missing data. In 2003 the series was discontinued from 8 March to 24 May. For this period the series was supplemented through interpolation. As the period from March to May still represents the low discharge period, the error introduced is relatively small. The year 2004 has, however, complete data (and shows the same trend).
[26] The location of the monitoring point is unknown. Given the land use assessment it is expected that the decrease of the river discharge is not (only) caused by developments along the Bulbula River.

8.3 Impact of land developments on Lake Abyata

The impacts of land developments in the study area accumulate in Lake Abyata, both in terms of impacts on water quantity and water quality. The decreased water level in Lake Ziway and the decreased outflow into the Bulbula River have obviously caused a reduced inflow into Lake Abyata. As a consequence the lake has decreased in size.

In an equilibrium situation the inflow into the lake from the Bulbula River, the Horakelo River, direct runoff from the surrounding area and groundwater inflow should equal the lake evaporation minus rainfall on the lake (approximately 165 million m^3)[27].

There is no evidence of major changes in the Horakelo and groundwater regimes. To obtain an idea of the impact of a decreased inflow from the Bulbula River on the level of Lake Abyata, the lake level was calculated for a decreased inflow of 100, 150 and 200 million m^3 per year (Figure 27). It can be concluded from Figure 27 that the size of the lake will stabilize at 60 % of its original size if the inflow is reduced by 100 million m^3 per year. Similarly it can be concluded that an abstraction of 200 million m^3 per year will reduce Lake Abyata to 20 % of its original size. This means that if the data presented in Section 8.2 are correct, Lake Abyata will further reduce in size and to a large extent disappear at relatively short notice.

The exact time span that this will occur depends on the geometrical (bathymetrical) characteristics of the lake. A steep shore will cause a faster depletion than a gentle shore.

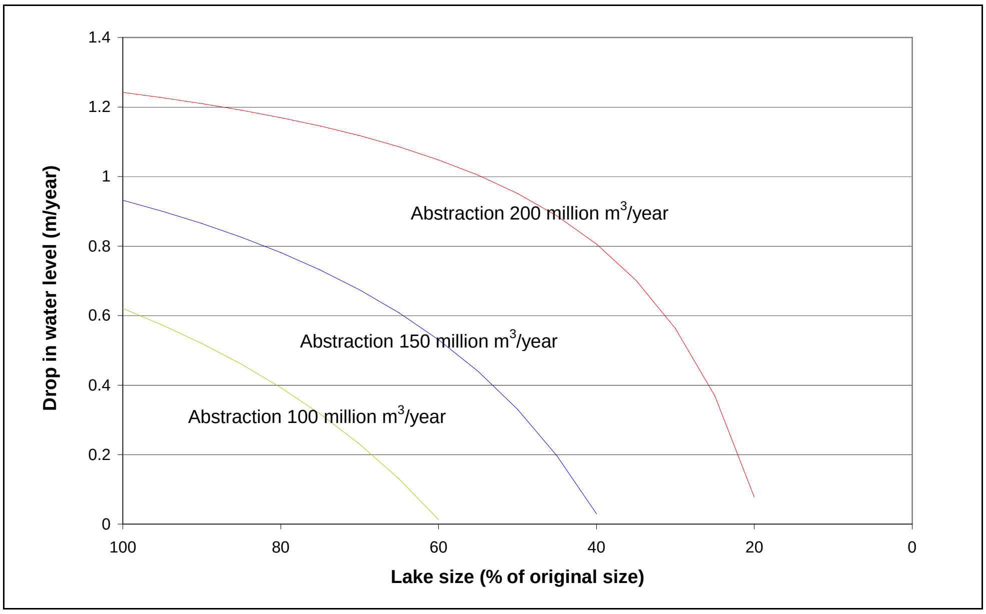

Figure 27. Calculated drop of the water table in Lake Abyata

[27] Assuming the lake area of the nineteen nineties.

8.4 Impacts of rain-fed agriculture

From Section 4.2 and 4.3 it can be concluded that the area of rain-fed agriculture has largely extended and that the total area of rain-fed agriculture is also an order of magnitude greater than irrigated agriculture.

As a consequence the water consumption by rain-fed agriculture is also an order of magnitude greater than for irrigated agriculture. Yet the impacts of these land developments are much smaller, because the variability of rainfall is rather directly reflected in the variability of the actual evapotranspiration, both by the natural vegetation and by the rain-fed agriculture. This means that years with low rainfall cause low actual evapotranspiration, which principally affects the farmers through reduced harvests.

Rain-fed agriculture can have impact on the surface runoff and on groundwater recharge (e.g. through land levelling and ploughing), but apparently this impact is still limited in the CRV. The rain-fed agriculture and natural vegetation thus act as a "buffer" for rainfall variability, unlike irrigated agriculture (where dry years result in more water consumption).

Because of the relatively limited surface water resources (despite of the presence of big lakes), in combination with the nature of closed basins (where the water resources are interlinked both spatially and temporally), the use of surface water resources can have large impacts, even for relatively small irrigated areas.

8.5 Climate change

From the previous sections it can be concluded that the development of irrigated agriculture has impacted on the water resources. There is, however, also increasing concern on the impacts that climate changes may have on the land and water resources in the CRV.

A tentative assessment of climate characteristics (based on temperature and rainfall) was made by analyzing the long-term weather data from four meteorological stations, namely Ziway, Meki, Butajira and Asela (the locations of these stations are presented in Section 3.2). The period of analysis covered 37 years for Ziway (1968-2005), 40 years for Meki, 50 years for Butajira and 51 years for Asela. The annual rainfall and temperatures were determined on the basis of monthly data[28].

Temperatures
The maximum daily temperature in Ziway shows an increasing trend, except for a period around the 1980s, which is probably caused by measurement or device errors (Figure 28).

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[28] Especially, in early years (before 1968) monthly data were missing. These data have been estimated using an interpolation procedure based on available data in other years. Years without any data were excluded from the analysis.

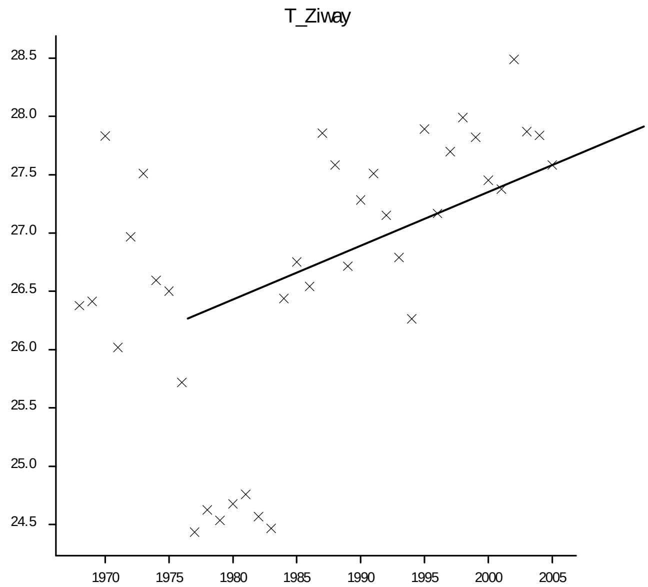

Figure 28. Maximum daily temperature in Ziway during the period 1968-2005 (See text).

Over a period of 37 years, the maximum daily temperature has increased with about 1.5°C. As a result the potential evapotranspiration will have increased in the order of 3-4 %. This will have caused increased water stress to the rain-fed agriculture (in the same order), while the evaporation from the lakes will also have increased (order of magnitude of 40 million m^3 per year).

The further increase of temperatures can, therefore, significantly impact on the availability of water resources and on the water stress that is already experienced in rain-fed agriculture and ecosystems.

Rainfall

The long-term annual rainfall at four meteorological stations in the CRV, and the observed trends are presented in Figure 29. The station of Asela shows a significant decreasing trend in rainfall. The rainfall at Butajira seems to have increased in the same period. At the stations of Meki and Ziway the annual rainfall does not show a clear increasing or decreasing trend.

In the period 1996-2005 a decreasing rainfall trend was observed (Section 6.3), based on 20 stations, however this period is too short to draw conclusions on (long-term) climate trends.

On the basis of this information it can, therefore, be concluded that there is no hard evidence of a long-term rainfall trend in the CRV. A more detailed assessment is required to draw more decisive conclusions with respect to the impact of climate changes in relation to the natural erraticness of rainfall.

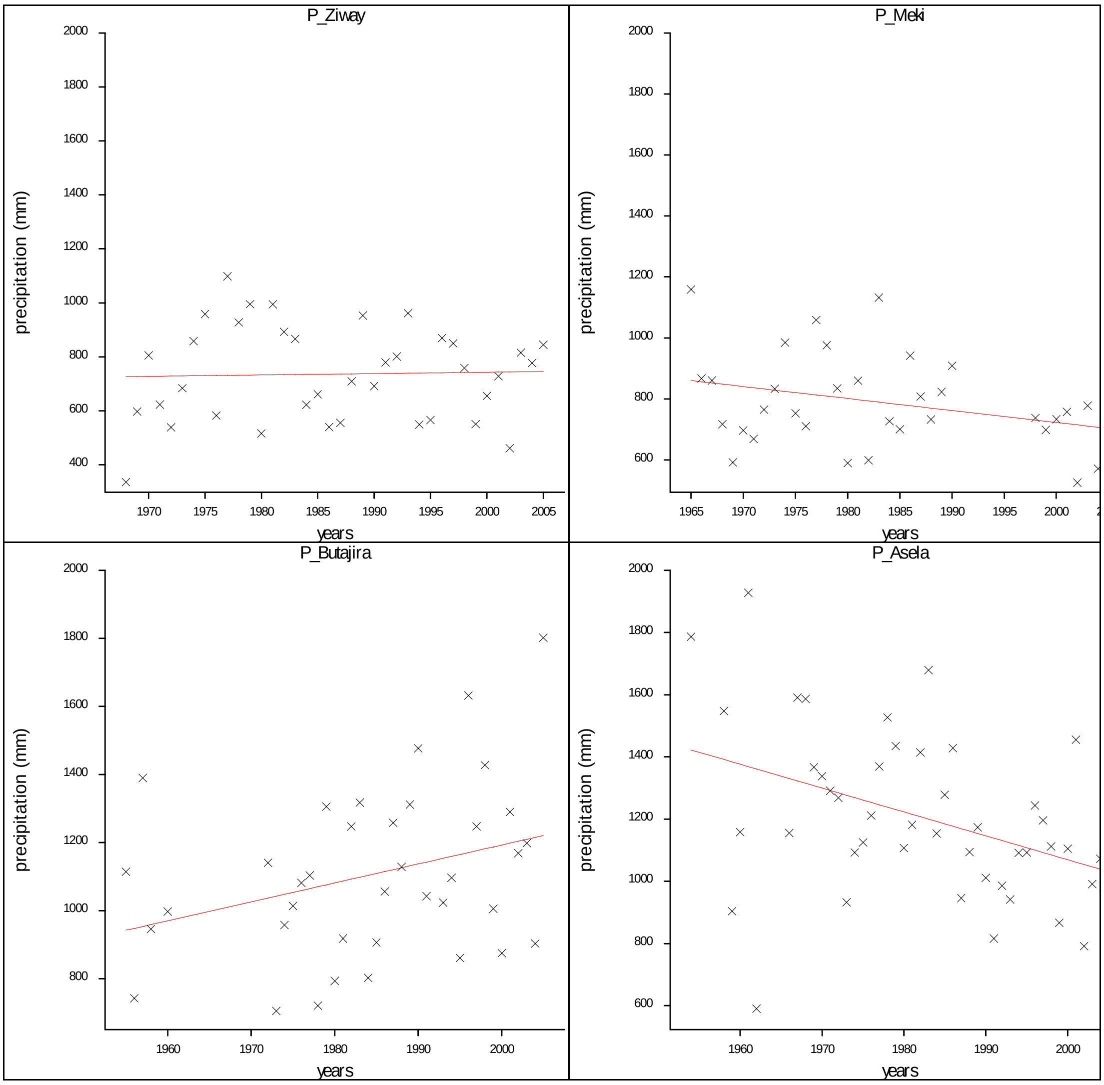

Figure 29. Long-term average annual rainfall in Ziway, Meki, Butajira and Assela.

The rainfall directly impacts on the availability of water for rain-fed agriculture (and terrestrial ecosystems) and on the volume of water in the lakes. The amount of rainfall also impacts on the available water in rivers, but the rainfall pattern is also a very determining factor for the river discharge (Section 6.5).

9 Conclusions and recommendations

9.1 Conclusions

The CRV is a closed basin, consisting of a chain of lakes (Lake Ziway, Langano and Abyata) and streams that are spatially and temporally strongly interlinked. The Meki and Ketar Rivers are situated in the upstream portions of the catchment. They discharge their water into Lake Ziway. From Lake Ziway water is discharged into the Bulbula River, which flows to Lake Abyata, being the terminal lake.

Any land intervention, either planned or not planned will have repercussions on the water resources and the environment. In the CRV increased pressure and overexploitation of the land and water resources are experienced. Further uncoordinated exploitation of resources can have dramatic consequences for the local population and development options.

Water resources
The discharges of the Meki and Ketar River (on average 675 to 695 million m^3 per year) have not significantly decreased. However the average level of Lake Ziway has decreased by approximately 0.5 meter since 2002. At the same time the discharge by the Bulbula River has decreased from more than 200 million m^3 per year in average years to less than 50 million m^3 in 2003 and 2004. The reduced inflow into Lake Abyata is associated with a reduction of the size of this lake to 60% of its original size.

Land resources developments
The decreased discharge into the Bulbula River corresponds with the development (in the order) of 7500-10000 ha of new irrigated areas. Most of this area is concentrated in the very downstream portions of the Meki and Ketar catchments and around Lake Ziway. Approximately 1000 ha is situated along the Bulbula River. Extraction of water from the Bulbula River has a direct impact on Lake Abyata.

The current gross water use by irrigated agriculture is in the order of 150-200 million m^3. An unknown portion of this water returns to the hydrological system through surface runoff and groundwater recharge. The remaining volume is evaporated by the crops (50-100 million m^3) and lost without returning to the hydrological system of the CRV.

It can be concluded that the development of irrigated agriculture, especially for open field vegetable and fruit production systems, have impacted on the water resources system and are the predominant cause of the observed reductions in water levels and river discharges.

Impacts
The impacts of the decreased (average) water level of Lake Ziway are:

- Impact on fisheries and lake-related ecosystems (not quantified);
- Reduced outflow to the Bulbula River:
    - negatively affecting water users along the Bulbula River (domestic water users, livestock and irrigated farms);
    - reducing the inflow into Lake Abijata, causing the shrinkage of this lake (currently to 60% of its original size) and the associated environmental degradation;
    - reduction of the flushing of Lake Ziway, causing increased salinity and pollution levels in Lake Ziway.

A serious future threat is that the further decrease of the water level may turn Lake Ziway into a terminal lake. This will cause that Lake Ziway, being the largest fresh water resource in the CRV, eventually becomes saline (similar to Lake Abyata). Given the relatively shallow depth critical salinity levels could already be reached within 5-10 years. The salinization of Lake Ziway will obviously have major repercussions for the recent floriculture developments and the local population, who depend on the lake water for their domestic water supply and their livestock watering.

Floriculture and smallholders
The present water use by the closed systems (floriculture) is minor. If the existing plans are realized the water consumption will increase to 20 million m^3 per year, which is still a small percentage of the total abstraction by irrigated agriculture. The main environmental risks are associated with the use of pesticides and herbicides and the fate of their residues in the soil and water.

From a tentative economic assessment it was concluded that the resource use indicators of flower production systems, especially water and land productivity, are much higher than those of other irrigated production systems. The performance indicators for smallholder irrigated production systems show a wide variety, as the results are very much determined by the (variable) product prices. Various sources have nevertheless indicated that the current economic performance of irrigated smallholder production systems can be improved considerably. Considering their impact on water resources focus should be more on improving the environmental and economic performance of current systems than the further development of these systems.

Rain-fed agriculture
Although water consumption by rain-fed agriculture is an order of magnitude greater than for irrigated agriculture, the impacts of these land developments are much smaller, because the variability of rainfall is rather directly reflected in the variability of the actual evapotranspiration. This means that years with low rainfall cause low actual evapotranspiration, which principally affects the farmers through reduced yields. For irrigated agriculture dry years result in more water consumption.

Because of the relatively limited surface water resources (despite of the presence of big lakes), in combination with the nature of closed basins (where the water resources are interlinked both spatially and temporally), the use of surface water resources can have large impacts, even for relatively small irrigated areas.

Climate change
Over a period of 37 years, the maximum daily temperature has increased with 1.5°C. As a result the potential evapotranspiration will have increased in the order of 3-4 %. This will have caused increased water stress to the rain-fed agriculture (in the same order), while the evaporation from the lakes will also have increased (order of magnitude of 40 million m^3 per year).

The further increase of temperatures can significantly impact on the availability of water resources and on the water stress that is already experienced in rain-fed agriculture and ecosystems.

On the basis of the available information there is no hard evidence of a long-term rainfall trend in the CRV. A more detailed assessment is required to draw more decisive conclusions with respect to the impact of climate changes in relation to the natural erraticness of rainfall.

9.2 Recommendations

On the basis of this study, the following recommendations are given:

- Integrated land and water development and management involving all stakeholders is imperative to ensure the sustainable development of the CRV. The existing CRV working group should be further equipped to take the lead in this process;
- the further development of smallholder irrigated production systems should be discouraged given the large impact that they have on the water resources and the environment; Instead, emphasis should be on improving the environmental and economic performance of current irrigated smallholders. In addition, more research is needed to investigate the possibilities to improve the performance of rain-fed agriculture as income alternative to the predominant poor population;
- the (potential) impacts of residues from the horticulture and floriculture systems on the surface water resources, particularly Lake Ziway, should be investigated and, if appropriate, mitigating measures identified and implemented;
- A more detailed water quality assessment should be conducted, focused on the risk of salinization of Lake Ziway;
- A more detailed study should be conducted to assess and anticipate the impacts of climate changes on the CRV in more detail.

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