Agricultural development in the Central Ethiopian Rift valley: A desk-study on water-related issues and knowledge to support a policy dialogue

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Table of contents

Summary

The Central Ethiopian Rift valley encompassing Lake Ziway, Lake Abyata, Lake Langano and Lake Shala forms a complex and vulnerable hydrological system with unique ecological characteristics. Recently, large-scale foreign and national horticulture and floriculture enterprises have been settling down in the area thanks to suitable climatologic and socio-economic conditions. These enterprises claim part of the available water resources in the area in addition to smallholder agriculture, domestic water use, fishery, industrial water use (soda extraction), nature and associated eco-tourism. Further competition for the limited water resources is expected in the near future. This desk-study takes stock of current and foreseen water issues in relation to on-going agricultural developments in the Central Rift valley. Scattered information and knowledge is collected to support a policy dialogue with all stakeholders.

The study shows that changes in land use and the associated increase in surface water extraction in the Ziway/Abyata catchment have resulted in lower lake water levels and increased salinity and alkanility of Lake Abyata. Since Lake Abyata is a terminal lake without an outlet, the hydrological and environmental impacts accumulate in this lake. Available data indicate that surface water resources are currently over-exploited, especially due to extraction of irrigation water along the Bulbula River connecting upstream Lake Ziway and downstream Lake Abyata. Water extraction from Lake Abyata for the production of soda ash seems much lower than the irrigation water extraction from the Bulbula River. Since there is no clear trend in rainfall during the past 40 years reduction of the water level of Lake Abyata is the result of human influences, rather than changes in rainfall patterns. It is unknown whether the deterioration of water resources are related to the reported low fish stocks of the lakes and the decline in the number of nesting waterfowl. In addition, effects of overgrazing, deforestation and conversion of land on the regional hydrology are not documented.

An accurate and quantitative assessment of the (potential) environmental impact of the floriculture and horticulture sector is not possible with the available information. However, both sectors, especially floriculture, are well-known for their high use of fertilizers and crop protection agents which may have detrimental effects on the environment. The horticulture sector is much bigger (area-wise) than the floriculture sector and we expect that the first will remain the largest water user in the near future. However, any additional water extraction by the floriculture sector will increase the pressure on the scarce water resources in the area. Considering the inefficient furrow irrigation systems currently used in horticulture, options to reduce irrigation water should be identified, such as changes in the irrigation system ('hardware'), e.g. the introduction of sprinkler or drip irrigation systems, as well as improvements in water management ('software'), e.g. better matching of water application with crop demand.

On-going development of the floriculture sector is mainly based on groundwater resources. There is a risk that large-scale groundwater abstractions will go beyond the safe (sustainable) yield of the aquifer, which will result in the decrease of groundwater levels and changes in the groundwater flows. This may impact on the rural drinking water supply, through increased pumping costs, wells falling dry and deterioration of the groundwater quality. A more detailed assessment of the groundwater resources should, therefore, be conducted in areas with future groundwater abstractions.

Due to the geohydrological conditions in the area, groundwater may contain trace elements that are hazardous to horticulture and floriculture, especially in the case that crops are grown in greenhouses without soil (hydroponics or similar methods). Another potential risk of irrigation with groundwater is the elevated concentration of bicarbonate, which may cause problems with respect to the soil structure and permeability. In addition, the sodium may be above the desired concentrations for rose cultivation. Finally, at many locations the sodium adsorption ratio indicates a risk that sodic soil conditions may develop. For rose cultivation most of the groundwater resources are, therefore, not suitable for direct use. The (spatial variability of) groundwater quality and -composition should be further investigated, as well as the impact of trace elements on floriculture and horticulture

Large parts of the natural vegetation in the Ethiopian Rift valley have already been converted and degraded due to the pressing need for natural resources by the local population. Considering the degradation of the natural vegetation and landscape, policy instruments need to be designed to reduce over-grazing, deforestation and land conversion. Proper measures should aim at increasing agricultural productivity in more favourable production areas and enable regeneration of the natural vegetation in fragile areas. The CER valley may loose its potential for development of (eco-)tourism if degradation of the natural areas and deterioration of the water resources continues. The tourist sector in the CER valley seems largely underdeveloped but may be an important contributor to the local economy. Exploration of the opportunities to further develop the (eco-)tourist sector may reveal its real contribution to the regional economy.

Introduction of floriculture in the Central Rift valley offers an opportunity to address the issue of competition for limited water resources by different stakeholders. Though floriculture entrepreneurs cannot be held responsible for current status of water resources in the area, it is also in their interest to address the issues identified in this report in a broad dialogue as the future viability of their businesses is at stake.

1. Introduction

The Central Ethiopian Rift valley is characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics. Increasing population pressure and economic developments put an increasing claim on the precious fresh water resources. Until recently, water from the lakes mainly supported agriculture and commercial fishery, domestic use, industrial soda extraction and recreation, while the lakes and surrounding wetlands supported a wide variety of endemic birds and wild animals. Recently, large-scale foreign and national horticulture and floriculture enterprises have been settling down in the area thanks to suitable climate conditions (high radiation, appropriate day-length, cool night and high daytime temperature, favorable humidity), availability of land and labor at low costs, favorable investment conditions (e.g. tax exemption), shorter distance to the European market than competitors (Kenya and Ecuador) while logistics and handling facilities are rapidly improving. These enterprises also claim part of the limited water resources for irrigation and processing purposes. In addition, it is expected that the agricultural development will attract people from other parts in Ethiopia, resulting in new settlements and associated domestic water demand. In addition to water quantity aspects, also water quality aspects will be increasingly at stake as a consequence of agricultural developments and settlements in the area, and the input use (pesticides and fertilizer nutrients) associated with the production of high value agricultural crops like vegetables and cut-flowers.

This study deals with the Central Ethiopian Rift valley lakes encompassing Lake Ziway, Lake Abyata, Lake Langano and Lake Shala. In the Central Rift valley major agricultural developments are planned while competition for available water resources is pressing. The limited available water resources in the Central Rift valley and the increasing scarcity affects all stakeholders in the region from smallholders, fishermen, soda industry, (aquatic) ecosystems, as well as the newly established horticulture and floriculture enterprises. In this study we distinguish between horticulture farms, i.e. open field irrigated vegetable production (a.o. haricot beans for export to the EU, tomato, onions and other vegetables for the local and regional markets), and greenhouse-based floriculture farms producing cut-flowers, mainly roses for export to the EU.

The objective of this desk-study is to take stock of current and foreseen water issues in relation to on-going agricultural developments in the Central Rift valley, with emphasis on horticulture and floriculture, and to collect information and knowledge on the ecosystem to support a policy dialogue. The information and knowledge compiled in this report can be used as a starting point in a policy process addressing the water-related issues in a broad dialogue involving all stakeholders. In addition, we identify topics for better understanding of the potential impact of agricultural development and actions aimed at improving water resources management in the Central Rift valley. The report focuses on the regional hydrological characteristics in relation to water extraction for agricultural development and describes the hydrological changes that took place until now. The desk-study is based on easily accessible information resources and is written in relatively short period. Therefore, the document is a “quick-scan” of available and relevant information rather than a comprehensive analysis. We have used the most recent available information, which gives an up-to-date insight in the on-going hydrological changes of the area. Used information is cited and referenced at the end of this report, which may be used as reference base to the dialogue between different stakeholders.

We start with describing the physical setting of the area, including the natural resource base and a description of the services it provides. In Chapter 3 we assess the available water resources in terms of quantity and quality. The suitability of the available water resources for agriculture is assessed in Chapter 4. In Chapter 5, input use and the associated environmental impact of the floriculture and horticulture sector is described. Conclusions and recommendations of the study are described in Chapter 6.

2. Physical setting

2.1 Location and topography

The Ethiopian Rift is created by volcanic and faulting activity that formed various volcano-tectonic depressions in the floor of the rift, which later became lakes. The Ethiopian Rift is part of the Great East African Rift Valley, also called the Afro-Arabian rift, which extends from Jordan in the Middle East, through Eastern Africa to Mozambique in Southern Africa. The Ethiopian Rift valley extends from the Kenyan border up to the Red Sea and divides the Ethiopian highlands into a northern and southern halve. The floor of the Rift valley encompasses three major water basins from NE to SW (Alimayehu *et al.*, 2004; Figure 1):

- Awash basin with the Koka, Beseka, Gemari, and Abe as most important lakes.
- Central Ethiopian Rift (CER) valley with the Ziway, Langano, Abyata and Shala lakes as most important lakes.
- Southern basin with Awassa, Abaya, Chamo and Chew-Bahir as most important lakes.

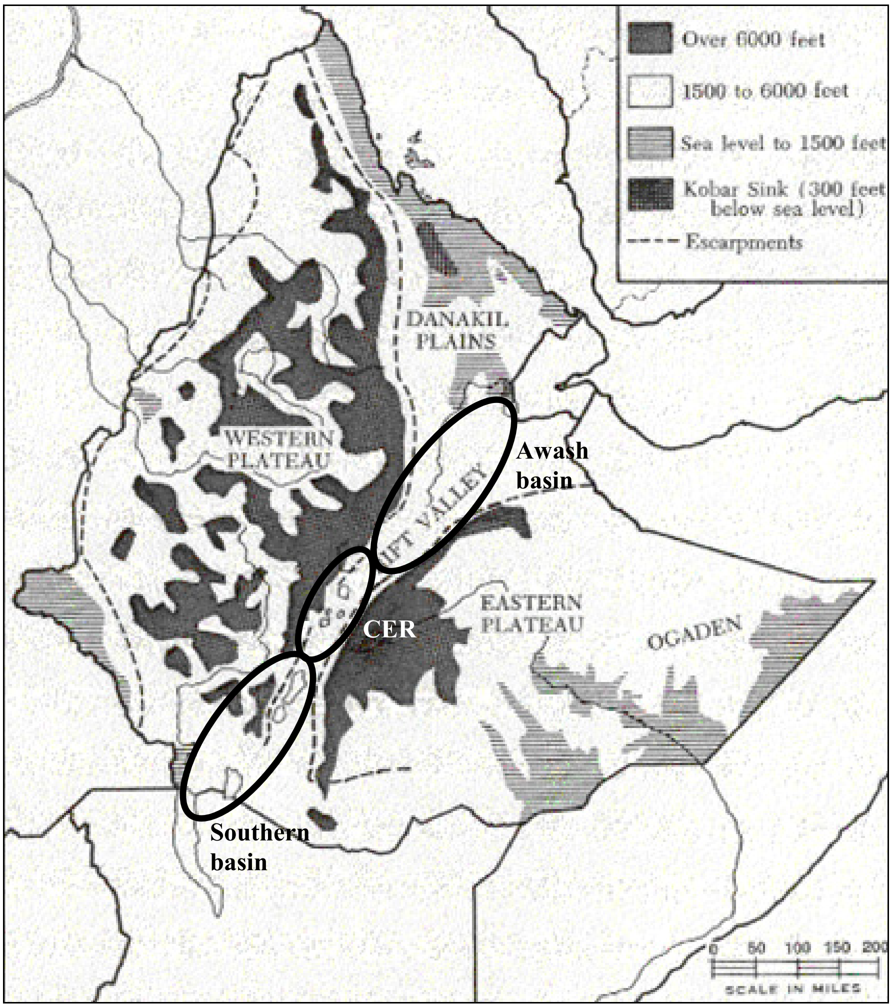

Figure 1. The three main water basins in the Ethiopian rift valley.

These three basins are not connected by surface water, but it is suggested that they may be connected by underground faults running in NE-SW direction (Ayenew, 2004). However, the geohydrology of the three main water basins in the Rift valley is highly complex and the spatial dynamics of groundwater resources are poorly understood.

This report focuses on the CER valley and its hydrology in relation to current agricultural developments. However, in the other two regions similar developments are taking place in which increasingly surface water and groundwater is diverted for agricultural expansion, for example northeast and northwest of Addis Ababa (Bech, 2004; Verschoor, pers. com.).

The two major lakes in the CER valley are Lake Ziway and Lake Abyata[1] (Figure 2). Lake Ziway is the centre of agricultural development. Lake Abyata and Lake Shala are important nature reserves and they belong to the Abyata-Shala Lakes National Park. The total area of the basin is 1.3 million ha (Ayenew, 2003).

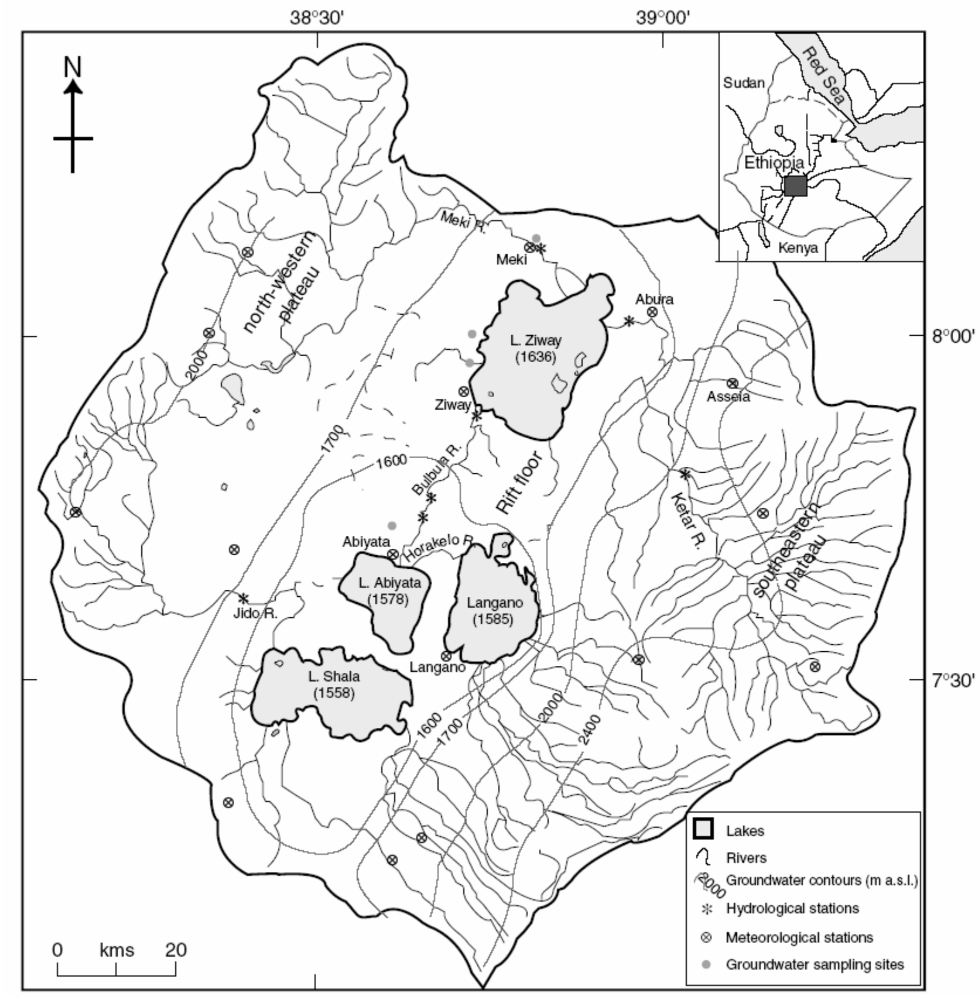

Figure 2. *General location map, topography, and drainage pattern of the Central Ethiopian Rift lakes (Legesse et al., 2004).*

Lake Ziway is located in the *Adami Tullu-Jiddo Kombolcha Woreda* district, in the East Shewa Zone, Oromiya region. The country's capital Addis Ababa is about 150 km to the north. The approximate coordinates of the lake are 8°00'N and 38°50'E. The town of Ziway is situated on the lake's western shore. The altitude of Lake Ziway is approximately 1636 m +MSL (above Mean Sea Level).

[1] Different spellings can be found in literature: Lake Ziway is also known as Lake Zeway, Lake Zwai, and Lake Abyata as Lake Abijata, Lake Abjata.

Lake Abyata is located in the Southern Nations Nationalities and Peoples region[2], at approximately 30 kilometers south-south-west of Lake Ziway. Approximate coordinates are 7°35'N and 38°35'E. Lake Abyata is situated at an altitude of approximately 1578 m +MSL.

The valley with the lakes is bounded to the east and west by highlands, with an altitude of around 2000 m +MSL (above mean sea level) and a peak of 4245 m +MSL (Mount Kaka east of the lakes). Most of the rivers and lakes in the CER valley are situated at an altitude of about 1500 m. Hills, ridges and volcanic-tectonic depressions separate the lakes.

2.2 Climate

The rainfall pattern is largely influenced by the annual oscillation of the inter-tropical convergence zone, which results in warm, wet summers (with most of the rainfall occurring from June to September) and dry, cold and windy winters.

The main rainy season accounts for 70-90% of the total annual rainfall. Minor rain events, originating from moist south-easterly winds, occur between March and May. Due to their nature, these rainfall events are more pronounced in the highlands.

Rainfall in Ethiopia is erratic and subject to large spatial variability, which is largely determined by altitude. Areas above 2500 m may receive 1400-1800 mm y^{-1}, mid-altitude regions (600-2500 m) may receive 1000-1400 mm y^{-1}, and coastal lowlands generally receive less than 200 mm y^{-1}.

Lake Ziway and Lake Abyata are both located in mid-altitude regions. Mean annual rainfall varies in the valley from approximately 500 mm (weather station at Lake Langano) and 650 mm (weather station Lake Ziway) to 1150 mm on the plateau. Annex I presents monthly climate data from Lake Ziway and Lake Langano. There is no clear trend (increase or decrease) in rainfall characteristics in the region during the last 40 years (Alemayehu *et al.*, 2006).

Highlands flanking both lakes intercept most of the rainfall in the region. Open water evaporation (lake evaporation) is in the order of 1800-2000 mm per year[3] (Legesse, 2004; Ayenew, 2003). Actual evapotranspiration depends on the land use and availability of water and varies between 700 and 900 mm per year (Ayenew, 2003). Reference evapotranspiration[4] (based on Penman-Monteith) is about 1400-1500 mm per year.

In Ethiopia five agro-climatic zones can be distinguished, ranging from alpine-type to desert. Lake Ziway and Lake Abyata are both located in the sub-tropical (monsoon) agro-climatic zone. The prevailing temperatures largely depend on the altitude. At Lake Ziway the monthly maximum temperature varies from 25 to 30° C. The minimum temperature ranges between 10 and 20° C. The mean annual temperature in the highlands is approximately 15° C (Ayenew, 2003; Legesse, 2004). The number of daily sunshine hours varies from 5.7 hours in September to 9.5 hours in November/December. The annual average is 8.3 hours per day (see also Annex I).

2.3 Land use

Most of the natural vegetation consists of woodland and savannas. In the highlands (between 2000 and 3000 m +MSL) afro-montane forests are found. Cultivated land is mostly located in the valley floor and major field crops are teff, barley, maize, lentils, horse beans, chickpeas and field peas. Most important vegetables are grown under irrigation and include haricot beans, tomato, onion, cabbage and broccoli (Moti Jaleta, 2002). Table 1 presents a

2 The lakes are located in the vicinity of the state borders of Oromiya and the Southern Nations Nationalities and Peoples but the exact location of the state border lines is unclear since they have been modified during the last decades. Most likely, at least parts of catchments belong to different states.

3 This corresponds with 18000 - 20000 m^3 water per ha, 1.8 - 2.0 m^3 m^{-2}, or 1800-2000 l m^{-2}.

4 Reference evaporation is the theoretical quantity of water lost by evapotranspiration from a specified crop or surface, reflecting the prevailing climate conditions on site (Ritzema, 1994).

land use classification for the entire basin, including Lake Ziway, Lake Abyata, Lake Langano and Lake Shala (Ayenew, 2003).

Table 1. Land use in the Central Ethiopian Rift valley (after Ayenew, 2003).

Land use	Coverage (%)
Open water	11.1
Marshy lands	1.4
Irrigated agriculture	0.7
Large-scale rain-fed agriculture	1.2
Pasture and farm plots with scattered trees and orchards	66.1
Grassland	3.6
Bushes, shrubs and grassland	7.3
Woodland	8.4
Major settlement areas	0.2

Moti Jaleta (2002) describes that about 49% of the *Adami Tullu-Jiddo Kombolcha Woreda* district (total 140300 ha) is cultivated of which 1267 ha (or 1.85% of the cultivated land) is being irrigated[5]. A major part of the irrigated agriculture is located along the Bulbula River, where vegetables are produced and also a livestock farm extracts river water (Legesse *et al.*, 2004).

Information on the current area cultivated by large-scale farms with open field vegetables (haricot beans) and greenhouse cut flowers (roses) for export purposes in the CER valley is unknown. Bech (2004) estimated that 1750 ha is leased by the Oromo Investment office, while an additional 1400 ha is in the process to be identified for lease. However, it is unknown whether these areas are all located in the CER valley, nor whether these areas are dedicated to floriculture, or also to horticulture. For reasons of comparison, the total floriculture sector in Kenya covers about 2100 ha. Currently, an area of about 300 ha on the Eastern shore of Lake Ziway, - previously cultivated by local smallholders -, is being prepared for cut-flower cultivation (Sher, 2005).

2.4 Surface water

Lake Ziway and Lake Abyata are situated in a closed basin (i.e. without an outlet to major rivers or to the sea). This basin is referred to as the Ziway/Abyata catchment.

Lake Ziway contains fresh water. The major incoming rivers are the Ketar River and Meki River (Figure 2). The Meki River discharges the runoff from the plateau west of Lake Ziway. The Ketar River discharges the water from the eastern and south-eastern plateaus. The catchments of these two rivers cover 5610 km^2 (Legesse *et al.*, 2004).

A major part of the water inflow of Lake Abyata originates from Lake Ziway through the Bulbula River. Hence both lakes are hydrologically connected. Considerable less water (on average one-third) is discharged from Lake Langano to Lake Abyata through the Horakelo River. Lake Abyata is the terminal lake of the catchment, from where the water evaporates. Lake Shala and its catchment do not have a surface water connection with the other lakes in the CER valley. There is no evidence of significant groundwater outflow (Legesse, 2004; Alemayehu *et al.*, 2006). Table 2 shows the (tentative) annual water balances of the lakes (Ayenew, 2004).

[5] Other sources suggest that more than 2500 ha is under irrigated agriculture along the Bulbula River (Poley, pers. com.). This difference may be due to the location of irrigated agriculture outside *Adami Tullu-Jiddo Kombolcha Woreda.* Considering the estimated amount of irrigation water extracted from the Bulbula River (section 3.2.1) an area of 2500 ha is more likely.

Table 2. Estimated long-term (1970-1996) mean annual water balance of the lakes in the CER in 10^6 m^3 (Based on Ayenew, 2004).

Lake	Inflow				Outflow			Difference Inflow-outflow
	P_I	R_I	G_I	S_I	E_O	R_O	A_O	
Abyata	113	230	- [1)]	15	372		2.25-15 [2)]	- 16.25 / - 29 [3)]
Langano	186	212	63	-	463	46		- 48
Shala	232	245	18	40	781			- 246
Ziway	323	656.5	-	48	890	184	28	- 74

P_I = precipitation in the lake *G_I = groundwater inflow* *E_O = Lake evaporation* *A_O = abstraction*
R_I = inflow from rivers *S_I =surface run-on* *R_O = river outflow*

[1)] *It is unlikely that groundwater inflow is zero in the lowest lake of the Ziway/Abyata catchment. Legesse et al. (2004) estimate groundwater inflow at 27 million m^3.*

[2)] *Different estimates from Legesse et al. (2004) and Ayenew (2004), respectively. See also section 3.2.1.*

[3)] *Not accounted for groundwater inflow (see note 1).*

Table 2 suggests that the outflow of water exceeds the inflow in all lakes. For example, the annual difference between outflow and inflow for Lake Ziway is 74 million m^3, which would imply an average annual drop in water level of Lake Ziway of about 15 cm. If this figure is correct, the river outflow component (R_O) would also gradually decrease. In addition, the difference between inflow and outflow for Lake Shala suggests a drop in water level of about 74 cm per year, for which there is no evidence (Poley, pers. com.). Therefore, the data in Table 2 should be considered as tentative. They indicate the relative magnitudes of flows rather than absolute figures.

2.5 Groundwater

The groundwater system in the Ziway/Abyata catchment is largely determined by the East African Rift Valley, being a major structural feature with a width of 40-60 km and at places a depth down to 1000 m below the flanking plateaus. The floor of the Rift Valley reaches its highest level north of Lake Ziway (at approximately 1800 meters +MSL).

The areas around Lake Ziway and Lake Abyata predominantly consist of volcanic rocks associated with the Rift system and sediments of various ages. The Rift and the mountains and plateaus flanking the Rift Valley are composed of volcanic rocks, with alkaline lavas, ashes and ignimbrites, mainly of Tertiary and younger age. The volcanic rocks are silica-rich, including much ash and pumice (Gasse *et al.*, 1978; British Geological Survey, 2001).

The sediments covering the volcanic rocks in the Rift are, generally, mixed deposits of sandstone, limestone and silts, with frequent occurrences of evaporite minerals. In addition, recent (Quaternary) unconsolidated alluvial and lake sediments are present (British Geological Survey, 2001). These unconsolidated sediments have, generally, good hydraulic properties and allow for high groundwater abstraction rates.

The unconsolidated alluvial and lake sediments form a multi-layered aquifer in which 2 main aquifers can be distinguished. The shallow aquifer predominantly consists of alluvial deposits. This aquifer is the main groundwater resource for the water supply of the villages. The aquifer is in direct contact with the lakes. The two aquifers are, generally, hydraulically connected, although local clay lenses may cause the deep aquifer to be confined.

In addition, a number of springs are present, which are associated with the faulting of the rift system (tectonics) and the successive volcanic deposits in the highlands.

The groundwater flow is to the lowest point of the Ziway/Abyata catchment. It was estimated that groundwater contributes approximately 20 % of the total inflow into Lake Abyata (Travi *et al.*, 1997; Chernet, 1998). Legesse *et al.* (2004) report 180 mm year^{-1} (which corresponds with 27-36 million m^3, being approximately 10 % of the total inflow). Both figures are much higher (more than a factor 10) than estimations by Ayenew (7011 m^3 day^{-1}, being 2.5 million m^3 year^{-1}). In general, the groundwater is largely controlled by the rift faults.

Lake Abyata and the nearby southerly, lower situated) Lake Shala are not hydraulically connected, a volcanic caldera rim obstructing groundwater flow to the south (Legesse *et al.*, 2004).

At many locations the groundwater is slightly brackish; this is, most probably, the result of the dissolution of evaporite minerals that are locally present in the subsoils.

Groundwater is a major source for domestic water supply, supplementary to surface water of Lake Ziway,.

2.6 Ecology

The CER valley is well-known for its biodiversity. The vegetation in the CER valley is characterized by *Acacia* open woodland, now extensively overgrazed, while deciduous forest occupy the ridges and slopes (Vallet-Coulomb *et al.*, 2001). The montane forest, between 2000 and 3000 m on the Eastern Ethiopian plateau bordering the Rift is dominated by the *Podocarpus gracilio*. Since the 1970's, it has been heavily deforested and exotic species have been introduced (e.g. *Pinus patual* and *Eucalyptus regnans*). The *Ericaceae* bush, which tolerates low temperature, extends up to 3600 m, where it grades in afro-alpine grassland vegetation.

Human pressure in the Rift valley is very high and the natural flora and fauna is disappearing rapidly (Feoli & Zerihun, 2000). Increased human activity has resulted in open vegetation which is floristically poor and uniform. Population pressure during the last three decades has resulted in the conversion of natural vegetation, overgrazing of natural grasslands, removal of natural shrub for fire wood and clearing of forests for construction material. As a consequence of these changes in land use/cover, vulnerable sloping areas in the area face increased erosion and depletion of nutrients required for vegetative growth. Increased erosion and resulting sedimentation elsewhere can have a major impact on the regional hydrology such as near Lake Cheleleka in the Awash basin (Ayenew, 2004).

About 50% of the bird species in Ethiopia have been recorded in the Rift valley thanks to the proximity of numerous and diverse aquatic and terrestrial habitats in the area (http://www.ethiopiatravel.com/Birdwatching%20 Ethiopia.htm). The Abyata-Shala Lakes National Park (87000 ha) was created primarily for its aquatic bird life, particularly those that feed and breed on the lakes Abyata and Shala. Lake Abyata, which is known as Ethiopian Nakuru, is a feeding site for a great number of lesser and greater Flamingos, White Pelicans and other water fowl. Pelicans nest in large numbers on an island in the neighboring Lake Shala, which is almost fishless. Every day birds have to thermal up and across the isthmus separating the two lakes to feed. In years that Lake Abyata recedes due to drought or other causes, fish dies and the algae composition changes due to the increased alkalinity of the water. Pelicans then feed in lakes Langano, Ziway, Awash and even Chamo and Abaya, while the Flamingos move further away into neighboring countries. In the mid 1960's, Lake Shala's colony of White Pelican was the second largest colony of this species in Africa with 6000 to 8000 nesting pairs per year. Nowadays the number of nesting birds has decreased to a few hundreds pairs (Izhaki *et al.*, 2002). The Abyata-Shala Lakes National Park is well-known spot for bird-watchers and other nature lover. Near Lake Langano are few eco-tourists resorts but we could not determine the extent of the eco-tourism industry, nor its impact on the local economy within this study.

Traditionally, Ethiopian freshwater fish resources have been used at small scale, and the impact of fisheries on the environment limited. National average fish consumption is the lowest in Africa, and fish eating habits have been influenced by the Orthodox Church (Bjorkli, 2004). Pressure from human activities on fresh water resources has been increasing. Introduction of improved fishing technologies in Lake Ziway and Lake Abyata have been stimulated with EU funds since the 1980's. Current commercial fisheries covers most of the countries freshwater resources, including lake Ziway which is one of the most intensively fished lakes in Ethiopia with an estimated annual production of 3000 t in the 1960's (Ayenew, 2004). More recent data suggest that production has been reduced due to human influences (Gebremariam, 1994). Fishery mainly consists of *Oreochromis niloticus* (Nile tilapia), which represents 90% of the landings in Lake Ziway as in many other Ethiopian lakes (Bjorkli, 2004). Based on an average lake area of 450 km^2 and a sustainable annual production of 5 t fish km^2 as defined by Reintjes *et al.* (In: Bjorkli, 2004) Lake Ziway could produce 2250 t fish on annual basis. In Lake Abyata there is no significant commercial fishing.

3. Water resources assessment

3.1 Lake Ziway

3.1.1 Water quantity

The area surface of Lake Ziway is reported to be 43400 - 48500 ha (deviating data were reported by the various sources). The maximum depth of the lake is 9 m, while the average depth is only 2.5 m. The volume of the lake is approximately 1.1 billion m^3 (ILEC, 2001).

Lake Ziway contains fresh water, which principally originates from the two incoming rivers, being the Ketar River and Meki River (Figure 2), and rainfall. Both rivers are perennial rivers. They used to have substantial base flows, which have, however, reduced as a result of uncontrolled water abstractions for small-scale irrigation schemes in the upper reaches of the catchments.

The residence time[6] of the water in the lake was reported to be approximately 1 year (ILEC, 2001), which would mean that the total inflow is in the order of 1.1 billion m^3 per year. Ayenew (2004) reports that the annual inflow from the Meki and Ketar River is, respectively, 264.5 and 392 million m^3, and that 323 million m^3 originates from direct rainfall (Table 2). These data are well in line, but should preferably still be verified with other studies.

The major portion of the inflowing water from the Ketar River and Meki River returns to the atmosphere by evaporation. Only a small portion discharges through the natural outlet (Bulbula River) towards Lake Abyata. It is estimated that under natural conditions approximately 10% of the inflowing water (110 million m^{-3}) will discharge towards Lake Abyata through the Bulbula River (Gilbert *et al*, 1999). The present discharge is, however, reported to have decreased.

The level of the lake is not regulated. The (normal) annual fluctuation of the water level of the lake was reported to be 0.8 m (Welcomme, 1972), but larger fluctuations, up to 2 meters, may occasionally occur (Ayenew, 2004).

Current total surface water abstraction from the Ketar River and Meki River is in the order of 28 million m^3 per year, which is used for irrigation (Ayenew, 2004).

3.1.2 Water quality

Lake Ziway is one of the Rift Valley fresh water lakes, having a low salt concentration. The total dissolved solids range between 200 and 400 mg l^{-1} (Kebede, 1994; Gashaw, 1999).

The total dissolved solids in the Bulbula River (outflow from lake) and Meki River are similar (300-400 mg l^{-1}), the salt concentration of the water in the Ketar River is less than 200 mg l^{-1} (Gashaw, 1999).

The pH is neutral to slightly alkalic. The predominant ions in the Meki and Ketar River are calcium and bicarbonate. The Bulbula River and Lake Ziway have a relative abundance of sodium and bicarbonate. The different water composition can be explained by the geology of the area. The main source for sodium is the dissolution of sodium containing rock minerals. As there is relatively much interaction between water in the (shallow) lake and the rocks, the sodium concentration rises in the lake (as well as in the out flowing Bulbula River). The same is also valid for the concentrations of fluoride.

The contents of silica (SiO_2) in the river water is, relatively, elevated (30-50 mg l^{-1}). This is, most probably due to the dissolution of feldspars in the weathered ignimbrites. The silica concentrations in Lake Ziway are lower than in the

6 Residence time is the average time that a water molecule will remain in the reservoir.

rivers, which can be explained by the relatively low temperature of the lake compared to the temperature of the inflowing rivers and the extraction of silica by organisms for shells and skeletons (Gashaw, 1999).

3.2 Lake Abyata

3.2.1 Water quantity

The surface area of Lake Abyata is approximately is about 20500 ha. The maximum depth of the lake is 13 m, while the average depth is 7.6 m. The volume of the lake is approximately 750 million m^3 (ILEC, 2001). Hence the average depth of Lake Abyata is approximately three times the depth of Lake Ziway (7.6 versus 2.5 m). However, volumes reported by ILEC (750 million m^3) and Ayenew (2004) (957 million m^3) do not match with the reported area and reported average depth.

The catchment of Lake Abyata (alone) is approximately 163000 ha (Balarin, 1986; ILEC). Legesse *et al.* (2004) report a catchment area of 111800 ha.

The level of the lake cannot be regulated. The level of the lake has decreased after 1985, when water abstractions and land use changes increased dramatically (Ayenew, 2004). Since the 1970's the lake level has dropped about 5 m (Ayenew, 2004; Alemayehu *et al.*, 2006). Legesse *et al.* (2004) reported that a state farm established in the early 1980s south of Lake Ziway pumps water from the Bulbula river for irrigating 1004 ha of vegetable crops (data 2001). The same authors estimated that associated irrigation water extraction corresponds with about 24 million m^3 per year. Water consumption for domestic use and smaller irrigation schemes along the Bulbula river is unknown but Legesse *et al.* (2004) estimated total extraction (including state farm) at about 59 million m^3., which is about 38% of the mean annual Bulbula river discharge recorded over the past 30 years (Table 2). Annual water use for soda extraction from Lake Abyata through an artificial evaporation basin is estimated at 2.25 million m^3 (Legesse *et al.*, 2004) and 15 million m^3 (Ayenew, 2004).

3.2.2 Water quality

Lake Abyata is a saline, soda-type lake which is typical for the Rift Valley. The water in Lake Abyata has a pH of around 10 (Gilbert *et al*, 1999; Zinabu, 2002). Being the terminal lake, Lake Abyata is subject to evaporative conditions, resulting in increased salinity and increased alkalinity. The increase of alkalinity is a result of the disequilibrium between bicarbonate and earth-alkali elements. Hot springs that discharge directly or indirectly into the lake also contribute to the elevated salinity and alkalinity.

The mineralization (salinity) ranges between 12000 and 24000 mg l^{-1} (Kebede, 1994). However, the mineralization may have increased further since 1994 (comparison: sea water has a salinity of approximately 35000 mg l^{-1}). Sodium and chloride are the dominating ions (Loffredo & Maldura, 1941; Talling, and Talling, 1965).

The salinity and alkalinity of the lake have been increased by a factor of 2.6 and 4, respectively, between 1926 and 1991 (Kebede, 1994). The seasonal fluctuation may only account for a factor 1.6 in alkalinity (Kassahun, 1982). The increase of salinity with a factor 2.6 cannot be explained by the evaporative process of the terminal lake. The salinity in 1926 and 1938 was around 8000 mg l^{-1}. The present salinity is more than 20000 mg l^{-1}. Over 75 years evaporation can account for a salinity increase of a few grams per liter only. Increased extraction of water along the Bulbula River and extraction of water for soda ash production are most likely the main causes of this increase in salinity.

The lake has very high concentrations of fluoride (in the order of 200 mg l^{-1}). Elevated concentrations of a range of heavy metals (arsenic, chromium, copper, mercury, molybdenum, lead and selenium) were also reported (Zinabu *et al.*, 2003). These elevated concentrations are probably associated with hot springs that discharge directly or indirectly into the lake.

3.3 Groundwater

Groundwater quality data from 26 boreholes and 8 shallow wells were reported in (Gashaw, 1999). These data show that approximately half of the wells are slightly brackish, with total dissolved solids above 1000 mg l^{-1}. Moreover, high concentrations of fluoride occur in many wells. The high fluoride concentrations are typically associated with the volcanic rocks that prevail in the area.

The pH of the groundwater is neutral to slightly alkalic (ranging from 7 to 9). The predominant ions in the groundwater are sodium and bicarbonate. The abundance of sodium and the elevated concentrations of fluoride are the result of interaction (dissolution) between the groundwater and the volcanic rocks. The abundance of bicarbonate is the result of the presence of atmospheric and magmatic CO_2 in combination with a relatively high acid buffering capacity (high pH) of the volcanic rocks.

To the southwest of Lake Ziway and near the rivers relatively high concentrations of calcium indicate recharge from irrigated lands and recharge from rivers, respectively.

4. Suitability of water resources for agriculture

4.1 Lake Ziway

The concentrations of the major elements in the lake and rivers do not impose major limitations to use the water for irrigated agriculture and human consumption. However, the concentrations of fluoride are slightly elevated. In Lake Ziway and the Bulbula River fluoride concentrations of 1.4 mg l^{-1} were registered (Gashaw, 1999). These concentrations are not toxic to crops, neither is there a risk of fluoride accumulation in the crop (Jansen, 2003). The maximum permissible fluoride concentrations for rose cultivation are, however, not known. It must also be realized that fluoride concentrations are likely to be subject to temporal fluctuations, as a result of temporal fluctuations in river discharge. Additional monitoring is, therefore, recommended. Also some precautions are recommended if sensitive livestock is to be watered.

A possible risk is the elevated concentration of bicarbonate, which may cause problems with respect to the soil structure and permeability (precipitation of salts), depending on the soil properties. Measures to reduce the concentration of bicarbonate in the soil are a.o. leaching and amendments (Ritzema *et al.*, 1994).

The concentrations of sodium in the surface waters are low, but may still be above the desired concentrations for rose cultivation. This may require more flushing of irrigation water to maintain good quality irrigation water in floriculture.

Data on other trace elements (including some of the heavy metals) show that the concentration of selenium is slightly above the WHO drinking water standards (Zinabu, 2003). The water can, however, be used for (long-term) irrigation, without the risk of accumulation in crops to concentrations that are toxic to animals. Arsenic, being a metal that is common in waters in contact with volcanic deposits, was well below all norms.

As not all critical chemical parameters are known, an exclusive assessment of the suitability of the surface waters water cannot be given. Based on the available information it is expected that quality of the lake and river water will not impose major limitations for irrigated agriculture, however the cultivation of roses may require specific quality characteristics. To be on the safe side, it may still be considered to investigate the concentrations of boron[7], as well as some other (heavy) metals that may be present in volcanic deposits.

Although it was reported that the water from Lake Ziway and the Bulbula River have poor qualities for irrigation due to the relative abundance of sodium (Gashaw, 1999) there is no evidence for this statement from the hydrochemical composition. The sodium adsorption ratio in the surface waters (lake and rivers) is below the critical level at the four investigated locations in Lake Ziway, Keti, Mekar and Bulbula River (see also Ritzema *et al.*, 1994). In addition, water from the Bulbula River is currently being extracted for irrigation purposes.

4.2 Lake Abyata

It is obvious that the saline water of Lake Abyata is not suitable for irrigation. At present there is no significant fishing from the lake. Fishing is also not advisable given the elevated concentrations of heavy metals that may accumulate in the fish.

[7] Since boron often can be found in elevated concentrations in volcanic sediments and it affects crop productivity negatively in high concentrations.

4.3 Groundwater

With the existing information it was not possible to assess the spatial variability of the suitability of groundwater for agriculture. Therefore, only the general trend in terms of groundwater suitability is presented.

Fluoride
The elevated concentrations of fluoride are one of the major water-related health problems in Ethiopia (causing dental and skeletal fluorosis). The groundwater in the Ziway/Abyata catchment very often contains fluoride with concentrations above the WHO guideline of 1.5 mg l^{-1}. Concentrations are often above 10 mg l^{-1}. Such concentrations can impose serious health problems.

The high concentrations of fluoride at many locations also impose limitations to use the groundwater for irrigated agriculture. In addition, most of the groundwater is not suitable for livestock watering (Jansen, 2003). In the case that groundwater nevertheless be used for irrigation or livestock watering, the critical compounds should be monitored adequately.

The observed fluoride concentrations should be further evaluated with respect to their direct toxicity to crops and the risk of accumulation in the soils (or crops). More details on the occurring soils (soil texture and current quantities of fluoride in the soils) and crops should, therefore, be collected. If the soils already contain significant amounts of fluoride, any irrigation practices need to be adapted accordingly.

It is noted that the risks of negative impacts by fluoride are greater in the case that commercial floricultural crops are grown in greenhouses without soil (hydroponics or similar methods), as under these conditions there is no natural capacity of the soils to deactivate fluoride. It is also noted that the risks are somewhat less for potted plants, as they normally receive water for limited periods.

Sodium
The observed sodium concentrations may impose a risk of accumulation of sodium to toxic levels in the crop. The actual impacts obviously depend on the sensitivity of crops to foliar absorption.

Except for sodium, the concentrations of major compounds do not impose risks to irrigated agriculture.

Trace elements
Data on trace elements, other than fluoride, are not available. It is, however, noted that hazardous concentrations of arsenic and boron could be locally present in the groundwater, given the geological environment. Given the risks associated with these compounds, their concentrations should be investigated, if groundwater resources are to be developed.

Sodium adsorption ratio
The sodium adsorption ratio (SAR) is an index of the potential of irrigation water to induce sodic soil conditions that may impact on the soil structure and crop yields. The composition of most of the groundwater may impose such a risk. The actual risk depends on the soil texture and chemistry. Further investigations are required if groundwater is to be used for agriculture.

5. Floriculture and horticulture: input use and environmental impact

Currently, the main high-input crops grown in the region are vegetables (e.g. onions, tomatoes, haricot beans) and cut flowers (mainly roses). Some vegetables are grown during the rainy season (Moti Jaleta, 2002), but most of the haricot beans production for export to the EU takes place from October to April, when supply from Egypt is low (Verschoor, pers. com.). Flower production occurs year-round in plastic greenhouses, while the vegetables are grown in the open field. In both floriculture and horticulture input use in terms of water, fertilizers and crop protection agents is high, which may affect the quantity and quality of local water resources. In the next section, we further characterize resource use in both horticulture and floriculture.

5.1 Water use

The cultivation of roses in plastic greenhouses entirely depends on irrigation water. The amount of water used depends on many factors, such as the type of greenhouse (with or without recirculation system), water and climate management, etc. Re-use of drainage water using recirculation systems can considerably decrease the amount of water used. Annual evapotranspiration of roses grown under Ethiopian conditions is estimated at 13000 m^3 ha^{-1} (1300 mm). In recirculation systems about 10-20% extra water is required for losses and flushing of water with a too high salt content. Depending on the quality of the used irrigation water more or less flush water is required. In non-circulation water systems it is expected that water needs are higher. Part of the water needs can be covered by installation of rainfall collectors from the greenhouse canopy. Based on an annual rainfall of 600 mm, a basin surface of 1800 m^2 (and associated evaporative losses), it is estimated that between 2000 and 4000 m^3 water per ha of greenhouse canopy can be collected from rainfall and, subsequently, used in greenhouses for irrigation water.

Information is lacking on the amount of irrigation water currently used in the open field vegetable production of the CER valley. Depending on the type of vegetable crop, it is estimated that about 500-800 mm ha^{-1} (5000-8000 m^3 ha^{-1}) of irrigation water is required to ensure the evapotranspirative crop demand during the growing season. However, used furrow and flush irrigation method is highly inefficient: Twice as much water as required for meeting the evapotranspirative crop demand may be applied, especially in vegetables grown in the dry season. It is unknown how much of the irrigation water excess from the open field vegetable production returns through natural drainage to local water resources.

5.2 Fertilizer use

In floriculture, the use of fertilizer nutrients is extremely high due to the high crop demand and the year-round production of cut-flowers. Data for Ethiopia are not available, but the Dutch standards are 1190 kg N ha^{-1} and 280 kg P ha^{-1} for roses cultivated under artificial light (College van deskundigen, 2003). It is expected that nutrient rates in Ethiopia are in the same range. In non-circulation systems fertilizer use may be higher due to leaching losses.

In general, fertilizer use in vegetables crops is high, but no location-specific information is available on the current fertilizer input. Haricot beans are legumes, i.e. they are N fixing plants, and thus N fertilizer use may be lower than for other vegetables. Yet, in combination with the inefficient flush irrigation method, a major share of the fertilizer nutrients may be lost to the environment mainly through run-off and leaching. As a consequence, farmers may over-use fertilizers in haricot-beans and other vegetables to compensate for these losses. Verschoor (pers. com.) indicated the presence of water hyacinths near the Western shoreline of Lake Ziway. This plant species is an indicator of eutrophication, which suggests nutrient enrichment of Lake Ziway.

5.3 Crop protection agents

The use of crop protection agents in floriculture generally is high, especially in roses. Data for Ethiopia are not available, but in the Netherlands producers of roses use on average 68 kg active ingredients (a.i.) per ha (Teunissen, 2005). The Netherlands has a very strict admission policy for crop protection agents and most toxic agents are not any longer permitted. The policy of the Ethiopian government in this respect is unknown but most likely less regulated. Therefore, total use of crop protection agents in Ethiopia may be lower but may contain more toxic substances. In a fairly new production environment as Ethiopia pest and disease pressure (and related use of crop protection agents) may be initially lower, but it will soon reach levels as in other production areas requiring similar input levels as elsewhere. For rose cultivation insects are a greater threat than for vegetables, while insecticides are most toxic for humans and aquatic organisms. In open field vegetable production less toxic herbicides and fungicides are used more frequently. Although no data are available on the amount of crop protection agents applied for open field vegetables in the CER valley, it can be quite high depending on the type of vegetable.

5.4 Environmental impact of horticulture and floriculture

Since the producers of flowers use closed systems, they are much better able to control input use (water, nutrients and pesticides) than vegetable growers, which depend on prevailing rainfall conditions, drainage characteristics of the soil, airborne crop infections, etc. Especially in greenhouses equipped with recirculation systems, input use can be managed better.

In general, input use *per se* is not an adequate indicator of emissions to the environment in floriculture. Emissions will depend on the type of applied crop protection agent (mobility, decomposition rate, etc.), practiced irrigation regime, intensity of drainage and recirculation, type of substrate, etc. Therefore, emissions of greenhouses are very location (greenhouse)-specific and it is hard to draw general conclusions (Teunissen, 2005).

Much information is lacking, which is required for performing a proper environmental impact assessment of the horticulture and floriculture sector in the CER valley. However, the little data available gives an indication of the potential impact of floriculture development on the regional water resources in relation to current open field vegetable production. In general, input use (water, fertilizers and crop protection agents) per ha is higher in greenhouses than in open field vegetable production as a consequence of the crop characteristics, quality requirements for export to the EU and the year-round production. Important, however, is the difference in scale, i.e. the area of floriculture (greenhouses) compared to the area irrigated open field vegetable production. The area with open field vegetables is much larger than the area with greenhouses since the market demand is much higher than for cut-flowers. In addition to the production of vegetables for export to the EU, Ethiopia also has a large local and regional (e.g. Djibouti) market for vegetables. In Kenya, where the floriculture sector is well-developed the total area with cut-flower greenhouses is about 2100 ha. Current irrigated area along the Bulbula river, including vegetable and livestock production covers at least 1300 ha and may exceed 2500 ha (section 2.3). Legesse *et al.* (2004) estimate current water extraction from the Bulbula River for domestic and irrigation water at 58 million m^3 of which the majority is used for irrigation water purposes. An area of 200 ha of greenhouses with an annual water use of 15000 m^3 ha^{-1} would increase the irrigation water extraction with only 3 million m^3.

Differences in emissions of polluting substances, such as nutrients and residues of crop protection agents should be considered in the same (scale) context. The use of fertilizers and crop protection agents per ha will be higher in floriculture but the related environmental impact depends on the scale of production. While input use per ha in vegetables may be lower; it is still relatively high compared, for example, to cereals. Floriculture has better opportunities to manage their waste water than open field vegetable production: Artificial wetland schemes (biofilters) with reed or fast growing trees nearby the discharge point of greenhouses may provide an environmental and social friendly solution to clean waste water and to provide biomass (for burning, construction or compost) for the local population and/or farm labor (http://www.f-h.biz/environment.asp?bandwidth=small).

6. Conclusions and recommendations

6.1 Water resources

The CER valley encompassing Lake Ziway, Lake Abyata, Lake Langano and Lake Shala forms a complex and vulnerable hydrological system because three lakes have surface water connections and two lakes are terminal lakes without an outlet. Impacts of land and water interventions on water levels and water quality is felt most in both terminal lakes, Lake Abyata and Lake Shala, where hydrological and environmental impacts accumulate. Therefore, any decrease of the inflowing water discharged from Lake Ziway to Lake Abyata will have a direct environmental impact. Changes in land use and increased water abstractions along the Bulbula river have resulted in lower inflows to Lake Abyata and, consequently, lower water levels, and increased lake water salinity and alkalinity.

The water resources are currently over-exploited, especially due to irrigation water extraction. Although the available data are not consistent, water extraction from Lake Abyata for the production of soda-ash seems relatively low compared to the extraction of (upstream) water for irrigation and domestic use.

Rainfall in the CER valley is erratic and subject to large spatial variability. As the discharge of rivers in the CER valley has a large component of direct runoff, fluctuations of the lake water levels follow the rainfall regime. Since there is no clear trend in rainfall during the last 40 years, the reduction of the water level of Lake Abyata is a consequence of human influences, rather than changes in rainfall patterns.

Existing groundwater abstractions are mostly from the unconsolidated alluvial and lake sediments that cover the volcanic rocks. These sediments have, generally, good hydraulic properties. The sediments are in direct contact with the lakes. The water divide of groundwater mirrors the surface water divide. There is no (significant) groundwater flow towards Lake Shala, Lake Abyata being the principal groundwater discharge location.

With the available data the impact of large-scale groundwater abstraction for cut-flower production on the Eastern shore of Lake Ziway on the regional hydrology cannot be quantified. Groundwater abstractions for agriculture that are beyond the safe (sustainable) yield of the aquifer will result in the decrease of groundwater levels, which may have an impact on the rural drinking water supply, through increased pumping costs, wells falling dry and the deterioration of the groundwater quality.

Recommendation 1

More detailed resource assessment of groundwater, including sustainable abstractions (safe yields) and the spatial variability of groundwater quantity and quality. Particularly, the potential impact of large-scale groundwater abstractions for cut-flower production near the Eastern shore of Lake Ziway on the regional hydro(geo)logy and environment of the CER lakes, with special attention to the impacts on rural drinking water supplies.

6.2 Water suitability

Concentrations of the major compounds in the water from the Ketar River, Meki River, Bulbula River and Lake Ziway comply with the water quality guidelines for irrigated agriculture. A possible risk is, however, the elevated concentration of bicarbonate, which may cause problems with respect to the soil structure and permeability (precipitation of salts), depending on the soil properties. The concentrations of sodium are low, but may still be above the desired concentrations for rose cultivation[8].

At many locations in the catchment the groundwater is slightly brackish, while relatively elevated concentrations of fluoride and sodium occur, which may constrain agricultural production. For rose cultivation most of these groundwater resources are not suitable for direct use. At many locations the sodium adsorption ratio also indicates a risk that sodic soil conditions may develop. With the existing information it was not possible to assess the spatial variability of the suitability of groundwater for agriculture.

The chemical composition of water resources in Ethiopia can be entirely different from The Netherlands. This is specifically valid for groundwater resources. The hydrogeological conditions in the Ziway-Abyata basin result in the presence of typical trace elements. These trace elements are often not significant in The Netherlands. As a result Dutch entrepreneurs may neglect their potential impacts on the production in other countries, where such trace elements can be significant. The risk of negative impacts from trace elements on the horticultural and floriculture production is more pronounced when crops are grown in greenhouses without soil (hydroponics or similar methods), as under these conditions there is no natural capacity of the soils to deactivate hazardous compounds.

Recommendation 2

Assess the sodium and bicarbonate concentrations in surface water (and/or groundwater) of areas where rose cultivation is planned and, where necessary, develop measures that mitigate the impacts on crop production.
Assess groundwater quality with respect to trace elements (fluoride, selenium, boron, arsenic and other compounds that are typical for volcanic environments) and assess their impact on agricultural production (with emphasis on floriculture and horticulture).
Assessment of the risk of sodification of soils as a result of groundwater irrigation.

6.3 Environmental impact of floriculture and horticulture

Except for the water extraction by the horticulture sector, current environmental impact of the floriculture and horticulture sector is difficult to quantify due to a lack of information. Yet, there is no doubt that further agricultural development in the area will increase environmental impacts.

The open field vegetable sector and its associated claim on water resources is much larger than that of the floriculture sector. We expect that the horticulture sector will remain the largest water user also after introducing more efficient irrigation strategies since the scale of production (area) is much larger. We estimate that an area of 200 ha of greenhouses along the Bulbula River would increase current annual water extraction from this river with about 5% or 3 million m^3 (section 5.4). Although this percentage is small, water of the Bulbula River is already over-exploited resulting in lower inflows in Lake Abyata and falling lake level.

The use of fertilizers and crop protection agents in horticulture and floriculture imposes an additional environmental threat. Data from the Dutch floriculture sector indicate that especially in the cultivation of roses inputs of nutrients and crop protection agents is very high. Emission of nutrients with flush or percolation water may result in the pollution of water resources, eutrophication and changes in the composition of phytoplankton in the lakes. In addition, emissions of crop protection agents or their residues may accumulate in fish and other aquatic organisms, and in water fowl. As with the water requirements of the floriculture sector, the level of emissions will depend on the scale of production. More insight is required in the use of fertilizers and crop protection agents under prevailing

[8] Many existing water quality standards have been developed with respect to potential health implications, either directly (e.g. through drinking water, livestock watering) or indirectly (accumulation of hazardous compounds in edible crops). Existing water quality guidelines for horticulture and floriculture are mostly related to production aspects only, not being formalized in legislative norms. These guidelines focus on the critical compounds that occur in countries where most of the existing horticulture and floriculture is practiced.

conditions, possible emission pathways to the environment and in options to reduce these inputs, for example, the use of crop protection agents through the use of integrated pest management.

Recommendation 3

An environmental impact assessment of the horticulture and floriculture sector and the identification of options to reduce or mitigate their environmental impact. For example, options to reduce irrigation water in both the horticulture and floriculture sector. Possible options are changes of the irrigation systems ('hardware', e.g. sprinkler or drip irrigation systems instead of the current furrow irrigation systems in open field vegetable production) and in modification of current water management ('software', i.e. better fine-tuning of water application with crop needs).

6.4 Biodiversity/land use

As in other parts of Ethiopia, deforestation and over-grazing in the CER valley has resulted in increased erosion and run-off of rainwater, which may have affected the regional hydrology. However, within our study we did not find information on changes in land use and on how they may have affected the hydrology of the study area. Recovery of degraded areas is possible if appropriate enabling opportunities are created. The gene pool necessary for recovery of natural vegetation is still available in the area. Therefore, proper incentives should enable the recovery of the vegetation in the natural state. Associated management should include the prohibition of cutting trees, reducing the stocking rate of the livestock and limiting the cultivation to less marginal areas (Feoli & Zerihun, 2000).

Recommendation 4

Identification and design of policy instruments to reduce over-grazing and deforestation resulting in increased erosion and changes in the hydrology of the CER valley. Such measures may be focusing on reducing animal stocking rates, introducing cut-and-carry animal feed systems, limiting arable agriculture in marginal and vulnerable areas, promoting reforestation, etc. Appropriate measures should enable the regeneration of the natural vegetation and increase agricultural productivity in more favorable production areas.

6.5 Eco-tourism

Quantitative data on the economic importance of tourism in Ethiopia are lacking, but available information suggests that this sector is still largely underdeveloped compared to other countries, while the European tourist market is relatively close. The Rift area has a potential for further development of eco-tourism thanks to its scenery, abundant bird-life, and rich and largely undiscovered culture by European tourists. However, considering the rapid deterioration of the hydrology, flora and fauna in and around Lake Abyata a rapid and concerted action is required to prevent further loss of the natural habitat. The CER valley may loose its potential for development of (eco-)tourism if degradation of the natural areas and deterioration of the water resources continues. Lake Abyata and the neighboring lakes are an important feeding place for migratory birds and further disturbance of these habitats may have consequences for birdlife elsewhere. From our study it is not clear whether on-going deterioration of water resources (such as in Lake Abyata) are related to the reported low fish stocks and the decline in nesting waterfowl (especially White Pelicans).

Recommendation 5

Inventory of the existing tourist sector in the CER valley, analysis of its impact on the local economy, and exploration of the opportunities to further develop the eco-tourist sector and its potential contribution to the regional economy.

6.6 Concluding remarks

This study addressed the regional hydrology in relation to agricultural developments in the CER, with a special focus on the potential impact of developments near Lake Ziway for Lake Abyata. The closed catchment of Ziway/Abyata is rather unique, but more of these closed catchments exist in Ethiopia, especially in the Ethiopian Rift Valley. Many observations and conclusions drawn in this report are relevant for these catchments as well. Floriculture and horticulture developments in Ethiopia also occur in areas where groundwater is the main water supply. Analysis of such systems requires very location-specific information, but the general threat is similar to surface water based agricultural developments. Over-exploitation of (ground)water resources by various stakeholders will certainly result in water scarcity problems and environmental degradation in the future. The experienced changes in the lacustrine environment are also not unique for the Ziway/Abyata catchment. The same phenomena are reported for other rivers and lakes in the Central Rift areas.

Large parts of the natural vegetation in the CER valley have already been converted and degraded due to pressing need for natural resources by the local population. Surface water extraction for irrigation, industrial and domestic use is continuously increasing in the CER valley. The limited available data indicate that the limits of sustainable water extraction have been reached. The water level of Lake Abyata is dropping since the 1980's, which is a good indicator of over-exploitation of water resources. Floriculture development in the area will increase the pressure on the local water resources, but - if the development remains within limits - it is most likely not the major water user in the catchment. However, the use of fertilizers and crop protection agents will impose an additional environmental threat from floriculture; special attention should be paid to the proper use of these inputs. Any spread of these components to the environment should be avoided.

Introduction of floriculture in the CER valley offers an opportunity to address the issue of competition for limited water resources by different stakeholders. Though floriculture entrepreneurs cannot be held responsible for the current status of water resources in the area, it is also in their interest to address the issues identified in this study in a broad dialogue as the future viability of their businesses is at stake.

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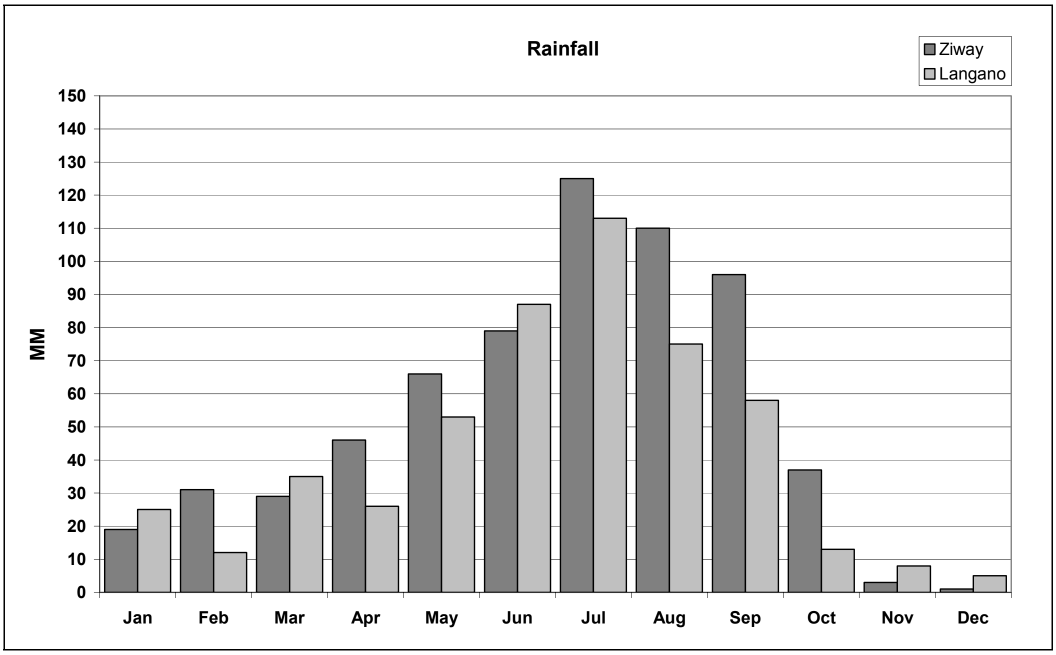
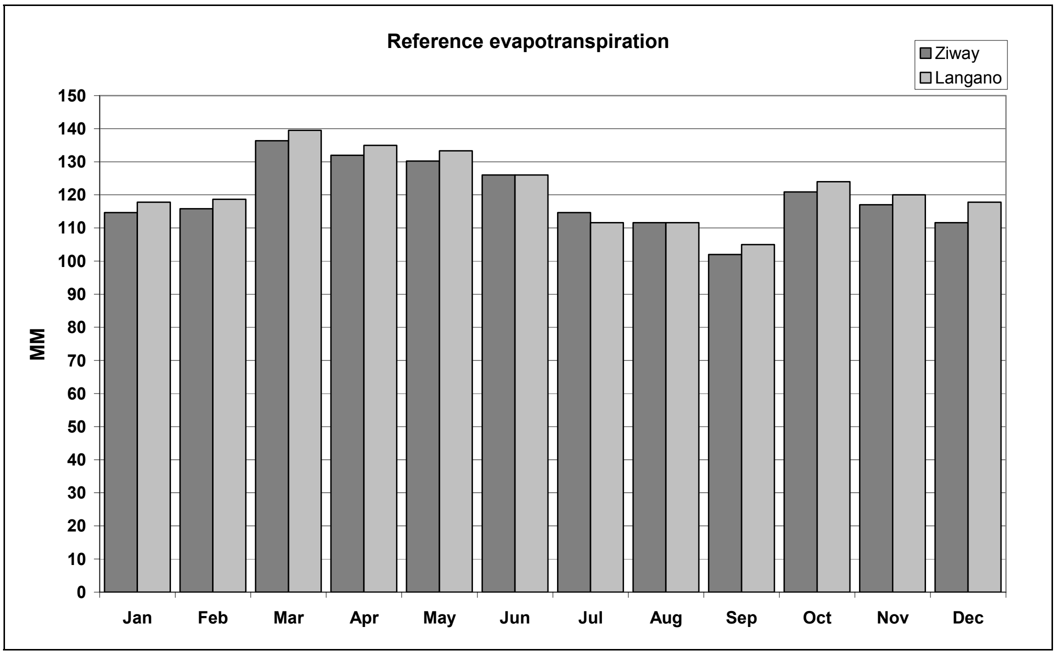
Annex I.

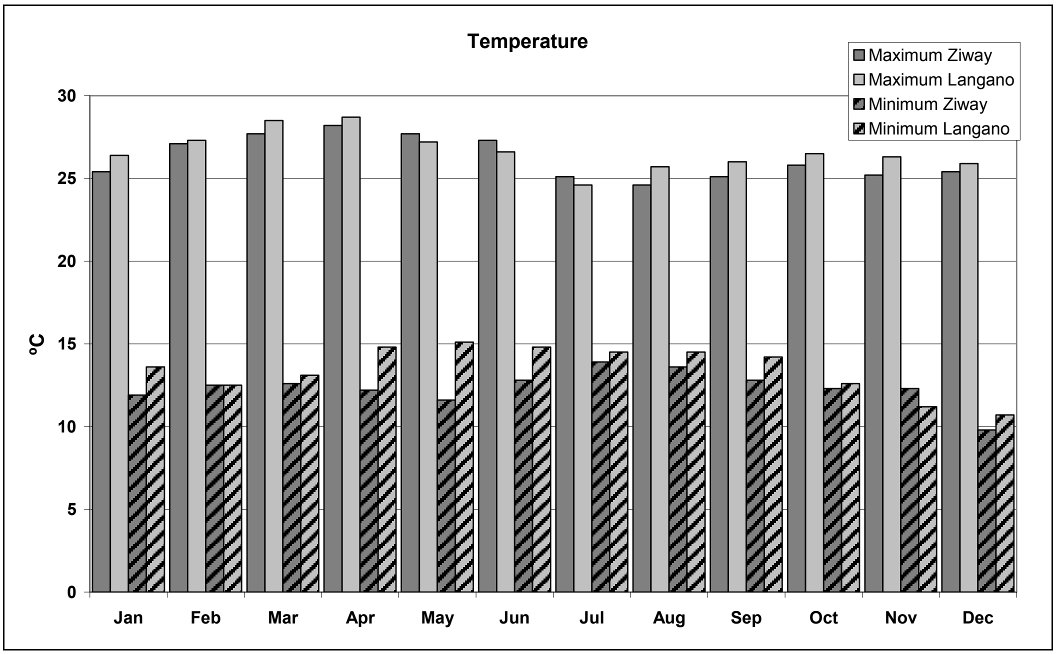
Climate characteristics of Lake Ziway and Lake Langano



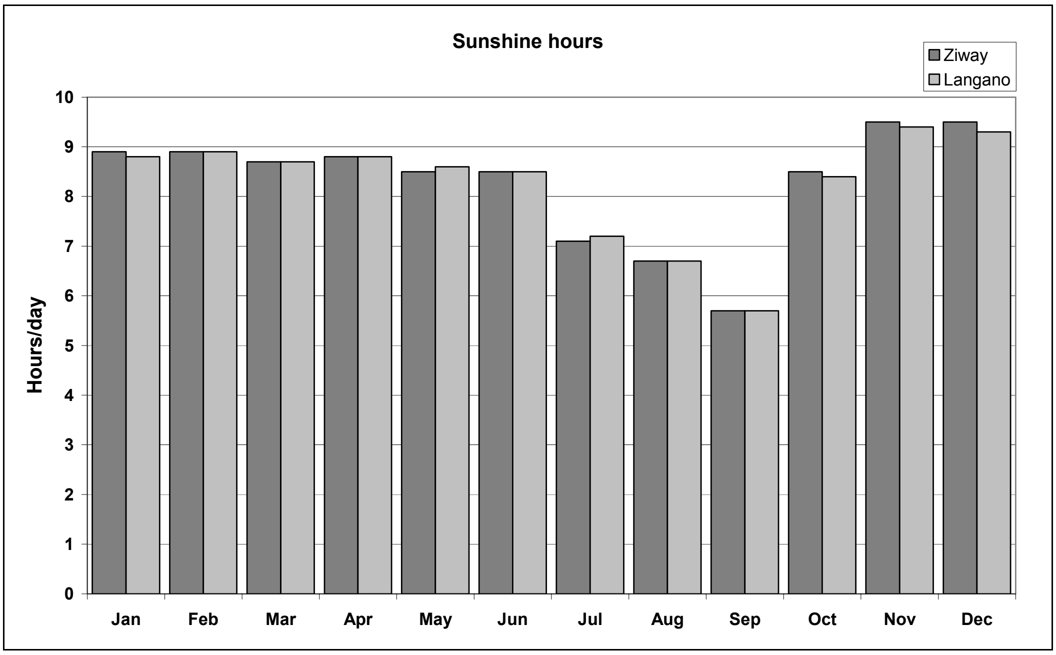
Monthly rainfall at the Ziway and Langano weather stations.



Monthly reference evapotranspiration at the Ziway and Langano weather stations.



Monthly average temperatures at the Ziway and Langano weather stations.



Monthly average sunshine hours at the Ziway and Langano weather stations.