Environmental Impact Analysis of Two Large Scale Irrigation Schemes in Ethiopia

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Abstract

This article presents the finding of a study undertaken to assess the status-quo and significant environmental impacts of two selected large-scale irrigation on natural resources in Ethiopia. Main focus is on the environmental impacts of irrigation on natural resources with special emphasis on soil quality, water quality and downstream impacts, hydrology and potential interference with ecosystems. For this purpose two schemes were selected. Wonji/Shoa Sugar Plantation is located in the Upper Awash Basin and Finchaa Valley Sugar Estate located in the Blue Nile Basin.

It is well known that irrigation projects can have several adverse environmental impacts that may threaten the sustainable production of agricultural goods, which is of major importance and interest in Ethiopia since it contributes 44 percent to Ethiopia's GDP, employs 80 percent of the labor force, and provides a livelihood to 85 percent of the nearly 80 million population (Awulachew, 2006, Government of Ethiopia, 2006, UNDP, 2006).

Irrigation projects inter alia can have potential impacts on the hydrological characteristics of aquifers, quality of downstream water bodies, quality of soils and ecosystems.

The most prominent results and environmental impacts of the selected case study sites could be summarized as follows. In general the irrigation water is of good quality, but the electric conductivity is unfavorable to the adjusted sodium ratio, which leads in some instances to soil crusting and has a negative impact on infiltration rate. In Wonji/Shoa the groundwater table has risen due to improper irrigation management and seepage of reservoirs. In Fincha a valuable ecosystem has been destroyed due to the establishment of the scheme and increased migration.

Key words:
Large-scale Irrigation / Environmental Impact / Water / Soil / Ecosystem / Ethiopia / Finchaa / Wonji/Shoa

Introduction

Under the title "Irrigation Infrastructures Development for Food Security and National Economic growth" the Ethiopian government started an irrigation development program in order to meet the ambitious efforts of the 15 years Water Sector Development Program, which is scheduled from 2002 until 2016. The investment in large-scale irrigation projects should guarantee to meet the demands for industrial raw materials for Agro-industries, cash crops and food crops. 26 medium and large-scale irrigation projects are planned to be implemented. Irrigation infrastructures in the country will more than double at the end of the program period, which is the year 2016 (currently only 200,000ha, this will grow by 275,000 ha). More recently, the irrigation sector development program is revised and the country has stepped up its efforts to bring additional irrigated area of 430,000 in five years, see MOFED PASDEP (2006)

In Ethiopia, irrigation projects with command areas larger than 3000 ha are classified as large scale schemes according to MoWR (2002). Werfring et al (2005) distinguish between four different types of irrigation schemes in Ethiopia: traditional, modern communal, modern private and public. Most of the medium and large scale irrigation schemes are located in Oromia and Afar region respectively. According to Tilahun and Paulos (2004) 31.981 ha and 21.000 ha of irrigated land are classified as large or medium scale schemes in these regions. In total 61.057 ha are identified as large or medium scale irrigation schemes in Ethiopia.

Since the Ethiopian Government has started to focus its development strategies on the extension of irrigated agriculture especially of large scale projects during the last decade it has become more important to explore the nexus between irrigation investments, sustainable agricultural development and potential environmental impacts in the Ethiopian context. In Ethiopia very little information and baseline date are available regarding irrigation and its environmental implications. Hence research has to be undertaken to fill this knowledge gap.

This article presents the finding of a study undertaken to assess the status-quo and significant environmental impacts of large-scale irrigation in Ethiopia. The main focus of this report is put on the environmental impacts of irrigation on natural resources with special emphasis on soil quality, water quality and downstream impacts, hydrology and potential interference with ecosystems.

In several studies a number of different environmental impacts have been identified which are directly caused by irrigation projects. Sectoral guidelines to conduct environmental impact assessments of irrigation projects (e.g. FAO, MoWR) use checklists which include the pertinent environmental impacts. These potential impacts are grouped into impact categories such as economic, socio-economic, natural resource and ecological impacts. This article puts its focus on impacts on natural resources and ecosystems which are closely related to in-field impacts on soil, water quality, hydrological issues and destruction of ecosystems due to irrigation development. In Tab.1 some of the potentially significant adverse impacts are listed.

Table 1: Typical environmental impacts of irrigation on natural resources

Impact category	Potential adverse impact	Cause
Hydrology	Rise of local water table, Water logging, Changes to the low flow regime	Improper irrigation management, Poor water distribution system Low irrigation efficiency, Seepage losses
Quality of irrigation source	Pollution of soil, Toxicity of products	Inadequate assessment of the quality of supplied water
Downstream water quality	Pollution of downstream water bodies	Improper use of fertilizer and pesticides
Soil degradation & damage of soil structure & change of soil properties	Alkalization	Quality of irrigation source
	Soil acidification	Long term leaching, Improper use of fertilizer
	Salinisation	Saline groundwater,Saline irrigation water, Saline soils, Improper irrigation management, Insufficient drainage
	Reduction of fertility	Intensive cultivation without additional amendments
	Water logging	Improper irrigation management, Soil degradation, Raise of water table, Improper drainage
	Erosion	Operation, Construction of the scheme
Ecosystem, Water bodies,	Creation of aquatic habitats	Construction of reservoirs and canals
	Destruction of ecosystem within the	Scheme construction

Wetlands	project area	
	Eutrophication and pollution of water bodies, Change of return flows	Reduced quality and amount of return flows
	Destruction of ecosystem in the adjacent area of the project	Migration tendencies, Improper land use strategy

Methodology

Study area

The study areas have been chosen for their diversity in terms of climatic conditions as well as soil types. Two large scale irrigation projects in Ethiopia were selected as case studies where primary and secondary were collected, Wonji/Shoa sugarcane plantation and Finchaa Valley Sugar Estate.
The major predominant soil types in the area of Wonji/Shoa sugarcane plantation are described as Fluvisols, Andosols and Laptosols according to FAO soil classification. Soils of Wonji/Shoa are of alluvial-colluvial origin developed under hot, tropical conditions (Fig. 1). In the region diverse soil types are observed which also vary in their production potential. (Ambachew et al, 2000). In general, soils of Wonji/Shoa can be described as a complex of grey cracking clays in the topographic depressions and semiarid brown soils. On the basis of texture they are categorized into light (coarse textured) soils and heavy soils (clayey black types) which are more common in Wonji/Shoa Sugarcane Plantation (Ambachew et al, 2000).

The soils in Finchaa valley are made of alluvial and colluvial materials from the surrounding escarpments. Five major soil types can be found in the area of Finchaa Sugar Estate of which Luvisols and Vertisols are predominant. These soils account for more than 95 percent of the cultivated and irrigated land. The irrigation scheme is divided by Finchaa River into East and West Bank (fig. 2). Currently only the West Bank is under cultivation, but the extension of the irrigated area to the East bank is planned.

Table 2: General description of the selected case study sites

	Finchaa Valley	Wonji/Shoa
Size	8064 ha	7000 ha
Location	9°30’-9°60’N; 37°10’-37°30’E	8.40°N; 39.25°E
Altitude	1550 m	1540 m
Date of Establishment	1995	1956
Type	Public, large scale irrigation	Public, large scale irrigation
Management	Government Agency	Government Agency
Basin	Blue Nile Basin	Awash Basin
Water source	Lake Chomen, Finchaa River	Awash River, Reservoir (reused water from factory)
Diversion	Pump	Pump
Irrigation	Pump, Gravity, Sprinkler	Gravity, Furrow,
N/ETo (mm/y)	1300/1500	747/2519
Agro-ecology	Weyna Dega (1500-2300m)	Weyna Dega (1500-2300m)
Main crop	Sugarcane (monoculture)	Sugarcane (monoculture)
Major Soil Type	Luvisol	Fluvisol

Figure 1: Scheme layout of Wonji/Shoa Sugar Plantation

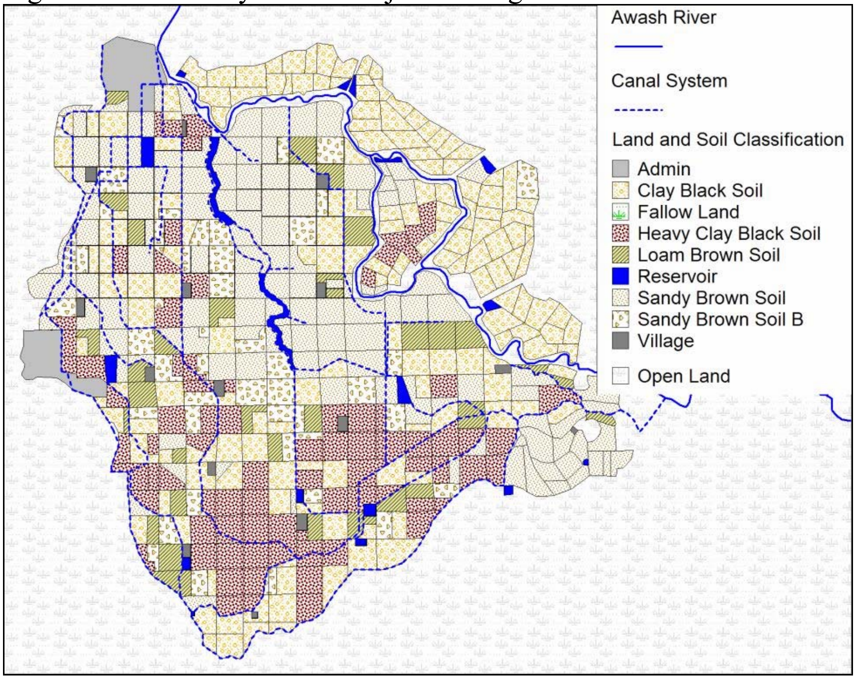
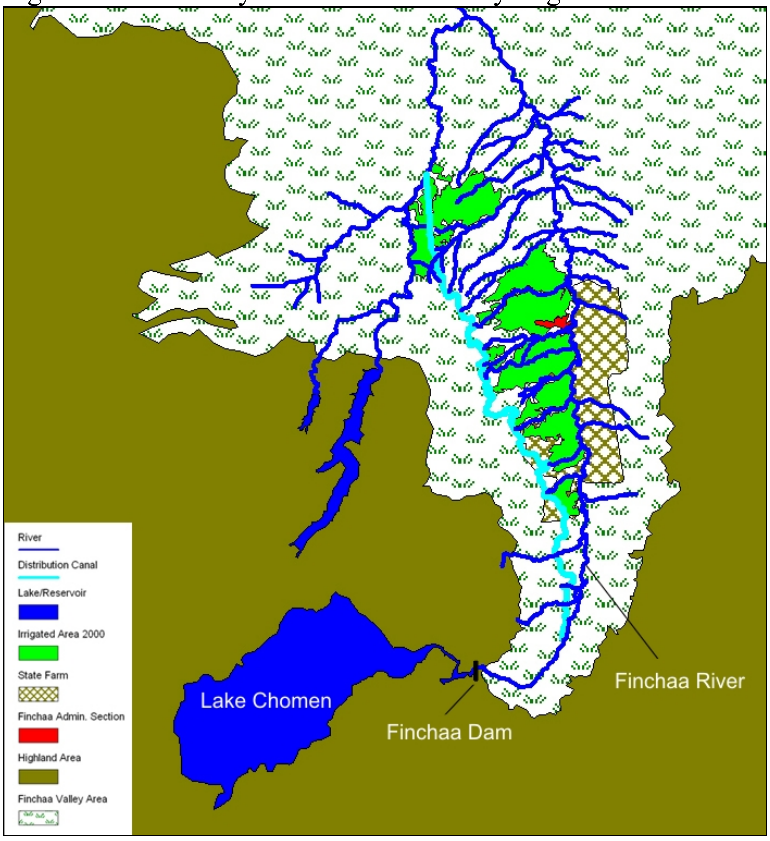


Figure 2: Scheme layout of Finchaa Valley Sugar Estate



Data Collection and Analysis

Both secondary and primary field level data were collected. Secondary data included general description of the scheme, hydrological and meteorological relevant data, information about the topology and geological characteristics of the area and about irrigation infrastructure. Research and data collection have been conducted using the "with or without" and when ever possible the "before and after" approach comparing secondary and primary data sets. The availability of

secondary soil and water quality data in the two case studies allows, to some extent, impact analysis using the "before – after" approach. Whenever possible, baseline and secondary data of research documents have been collected.
For data collection activities, specific data sheets have been designed for field level research as well as for secondary data collection.

Because only few data or baseline data were available to compare time series data and carry out before and after type of analysis, soil samples were taken from non irrigated and irrigated fields but also from cultivated and uncultivated plots to assess potential impacts of irrigation on chemical and physical soil parameters. Disturbed soil samples were taken from the predominant soil types at different spots, depending on the accessibility and influence of irrigation on the spots, using the comparative soil sampling method. From each plot samples of different depth were taken, depending on the structure of the soil and the depth of soil horizons. Every soil horizon over 10cm was sampled, at least from 0-30, 30-60 and 60-90 cm depths (FAO 1986).
Water samples were collected from the irrigation source and potentially influenced water bodies using 1 litre plastic bottles and immediately stored in a cooling box. As some parameters may change rapidly after sampling (e.g. Nitrate) the pH was brought down to 2 by adding acid (HNO_3) to the samples to stop chemical reactions. The samples were analyzed either using in-field measurements and tests or laboratory analysis. Water sampling locations were chosen based on the spatial variations in the water stream and irrigation system (irrigation sources, the distribution canals, reservoirs, the main drain and from downstream water bodies) in order to obtain a representative sample. In table 3 chemical and physical parameters are listed which had been analysed either in the field or using laboratory facilities.
The standards and threshold values for water quality analysis were chose with respect to irrigation (FAO 1989). The widely accepted threshold values for classifying the suitability of water for irrigation are presented in table 4 (FAO, 1998). The standards and threshold values for soil chemical and physical were taken from the Ethiopian Ministry of Water Resources (2002).

Table 3: Measured chemical and physical soil and water parameters

Samples	In-field measurement	Laboratory Analysis - chemical & physical parameters
Water	Electric Conductivity	pH, Electric Conductivity
	Temperature	Cations: Na, Ca, Mg, K
	Nitrate	Anions: SO_4, PO_4
	pH	Toxic substances B, Cl
		Nitrogen: NH_4-N, NO_3
		Alkalinity (CO_3+HCO_3)
		Trace elements Fe, Mn
		SAR, adj. RNa
Soil	Profile Pit investigation	Particle size distribution of silt, clay, sand, soil texture
		pH, Electric Conductivity
		Nutrients: Na, K, Ca, Mg, P, tot N, Fe, Mn
		CEC, ESP, BSP
		Organic Matter, Nitrate

Results and Discussion

Wonji/Shoa Sugar Plantation - Water Quality Anylsis

In general the irrigation water used in Wonji/Shoa Sugar Plantation is of high quality.

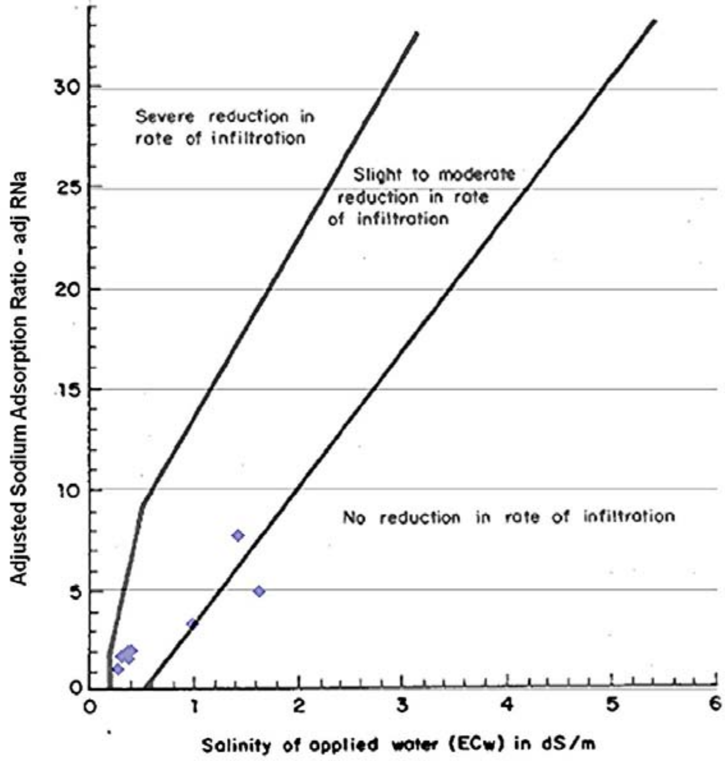
Hardly any adverse impacts on the soil quality resulting from irrigation activities are to be expected on this scheme. However **SAR/adj R_{Na}** to **EC** ratio (fig. 3) indicates that a slight to moderate reduction in the infiltration rate might occur. Low salinity water (< 500 µS/cm) is corrosive and tends to leach surface soils free of soluble minerals and salts (FAO 29, 1989). The EC value of Awash River, the irrigation water source of Wonji/Shoa, is 293 µS/cm. The tested soils show an EC from 151 to 475 µS/cm and can be rated as salt free according to the Eth. Ministry of Water Resources (2002). The absence of salt in the soil indicates an ongoing dispersion process which leads to sealing of the soil and thus reduces the soils infiltration rate (FAO, 1989). During the field study and the analysis in a soil pit destruction of the natural structure of the soil in some places could be observed. To a certain extent this destruction of the soil structure might be due to unfavourable SAR values and SAR/adj R_{Na} to EC ratio in the irrigation water of some of the water samples. Moreover soil tillage with heavy machines might also have destructive effects on the soil structure, particularly where waterlogging and high water tables occur.

Girma A. (2005) states that in most sugarcane fields of Wonji/Shoa slight to moderate soil infiltration problems are expected if groundwater occurs at shallow depths. In this regard, the groundwater depth was at all the times too shallow (in the root zone) for nearly all sugarcane fields considered in this study. This indicates that in Wonji/Shoa, sugarcane fields are prone to waterlogging and physical degradation of topsoil. Drainage water and factory used water are stored in reservoirs and reused for irrigation, therefore it is of major importance to monitor the quality of this irrigation source. The drainage water and the reservoir water shows EC values increased values compared to the irrigation water, 357 and 388 µS/cm respectively. With regard to salinity the water is still of very good quality and should not pose any problems on soils in case it is reused for irrigation. These findings are confirmed by the study conducted on irrigation water quality by Girma A. (2005). Irrigation water (i.e. Awash River water) and factory used water were free of potential hazards of salinity, sodicity and specific ion toxicities. Moreover, drainage water was nearly of similar quality. As pointed out in the previous section this could cause from slight to moderate problems regarding infiltration. The total salt content of groundwater for some sugarcane fields was relatively high (i.e., EC values exceeded 700 µS/cm); a critical limit above which osmotic effects are known to occur. SAR values (fig. 3) were low in all groundwater samples. The potentially toxic ions Na^+, Cl^- and Boron were also found at low concentrations.

The values for the **pH** of Wonji/Shoa irrigation system are in the normal/neutral range (pH = 6.5 to 8.5) for all water samples. Only the drainage water shows a lower pH of 6.3 which indicates slightly acidic water. Generally the pH in all the water samples taken does not seem to be influenced by irrigation. Similar results are given by Girma A. (2005). The measured pH values of both irrigation water and Factory used water samples varied from 7.4 to 8.1 (from near neutrality to medium basic in reaction). pH values of drainage water samples varied from 7.0 to 7.8 (normal range). All groundwater samples varied in pH values from 7.1 to 8.3.

The highest values for **chloride** and **boron** are 3.6 meq/l and 0.45 meq/l respectively. Therefore the threshold values from no restriction on use to slight to moderate restriction on use (4 meq/l for chloride, 7 mg/l for boron) were not obtained by any of the water samples.

Figure 3: Effect on Infiltration rate due to Sodicity of sampled water sources (Wonji/Shoa Sugar Plantation)



Wonji/Shoa Sugar Plantation - Soil Quality Analysis

As mentioned the tested soils show an EC from 151 to 475 µS/cm and can be rated as salt free according to the Eth. Ministry of Water Resources (2002).

The **pH** of all soil samples ranges from 7.4 to 8.4 indicating moderately alkaline soils which is typical for soils of these climates (dry, arid climate most of the year). This indicates low availability of phosphorus and other micro-nutrients (MoWR, 2002).

With a **CEC** from 46.2 to 58.4 meq/100g the soil samples are all in the range of very high CEC, according to the ratings of the Ethiopian Ministry of Water Resources (2002). This indicates good agricultural soil. The **BSP**, ranging from 62.6 to 96.65% can be rated as high for almost all soil samples which indicates a high fertility of the soil. The **ESP** of the soils lies below 6% (0.99 to 5.88%) which is definitely below the threshold of 15% and therefore the soils can be rated as non sodic. Decreases in yield would only be expected for extremely sensitive crops (ESP = 2–10) but not for sugar cane.

The content of **total Nitrogen** can be rated as high for all soils (ranging from 0.071 to 0.114%). The rating for **Potassium** is high and very high for all soil samples ranging from 1.08 to 2.63 for irrigated land and from 3.68 to 4.05 for the virgin soil. The comparison of irrigated soils and non-irrigated virgin soil shows that the content of Potassium is much higher in the virgin soil (4.05 meq/100g). The distribution of some parameters over the soil depth does not seem to be natural anymore for the cultivated soil. In general there are hardly any obvious differences between irrigated soils and the virgin reference soil as far as the chemical properties are concerned. The reason might be that the irrigation water has a very good quality and therefore no severe impacts on the soil are to be expected. A possible decline or even lack in nutrients is compensated through fertilizer application or other soil fertility management practices. The virgin soil might also be influenced by irrigation through capillary rise of the groundwater or surface runoff of the irrigated fields and therefore not be perfectly virgin anymore.

The content of **Calcium** is high and very high in all soil samples, ranging from 18.32 to 40.72 meq/100g soil. The same applies for **Magnesium** ranging from 4.94 to 12.36 meq/100g soil.

The content of **organic carbon** of all soil ranges from 0.76 to 1.88 % and can be rated as very low in all the soil samples. This indicates that without application of fertilizers no adequate yields would be achieved.

Wonji/Shoa Sugar Plantation - Groundwater Hydrology

In Wonji problems due to irrigation are reported with regard to **waterlogging**. The ground water level within the sugar estate shows a rising tendency (observation 1999-2001, fig. 4). However, not only within the sugar cane plantation but in the whole region a rise of the water table has been reported (Teshome, 1999). This might be due to irrigation (seepage losses out of reservoirs and channels, over watering, etc) but also due to seepage losses in a great extent from the Lake Koka reservoir. The water of the Awash River is retained by Koka dam. The dam was built to assure a constant discharge in the Awash River for two hydropower stations, but it also guarantees sufficient irrigation water supply.

What has been reported before and confirmed in the field work are problems with a high water table and waterlogged fields. Especially on fields with heavy clayey soils problems with waterlogging have been discovered during the field study and the analysis in a soil pit (Wallner, 2006). However, the lighter soils – light in relation to the heavy soils of the sugar estate - seem to be of very good quality and not prone to negative impacts of irrigation under the given conditions.

In 2002 a study on groundwater level fluctuation at Wonji/Shoa sugarcane plantation was conducted by Habib D. Investigations showed that on some fields the groundwater table is less than one meter deep (ARS Annual Report, 1994). The same report indicated that in some fields downward percolation of irrigation water below the root zone, especially in soils classified as heavy black soils is so slow that it caused temporary storage within the root zone (in some places up to 10 days after irrigation). These drainage problems have even become one of the major factors in determining the composition of cane variety (Tariku, 2001). In fields located near reservoirs, irrigation canals and drains suppressed cane growth due to seepage and ground water table rise could be observed. Kediru (1997) stated that cane loss due to this problem is economically significant.

In 1998/99 a study was started in Wonji/Shoa Sugar Plantation to measure the groundwater level (GWL) fluctuation with piezometers installed in different plantation fields. Piezometers were installed at different locations near reservoirs, distribution canals and drains. One piezometer was installed in a non-irrigated area as reference (WRS).

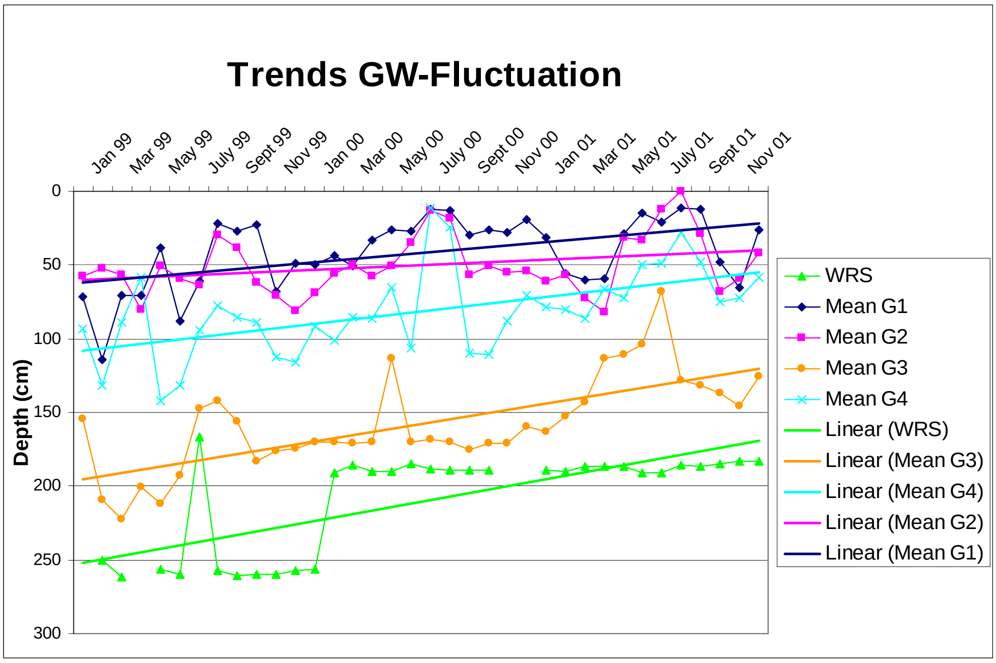
In figure 4 groundwater tables of 4 different fields (G_1, G_2, G_3 and G_4) and the reference field (WRS) are displayed for 3 years (1999-2001). Measurements are given in depth in cm from soil surface. The measurement of groundwater table of the reference area (WRS) shows the maximum water table depth values in all years and months.

The results indicate that fields which are located near reservoirs are affected by rising ground water level more than fields nearby distribution canals and fields nearby drains.

Even this short measurement time series of 1999 to 2001 shows significant increasing trends of rising groundwater table. Fields near reservoirs (G1) are most affected. Habib (2002) concludes that seepage from reservoirs and unlined irrigation canals is the reason for rising groundwater level. Near drains (G3) groundwater levels are significantly lower compared to the measurements near the reservoirs. This result shows that drains if effectively utilized can lower the ground water table. In the reference area GWL was rising the first year but decreasing the second year. Furthermore the GWL is generally at least 50cm deeper compared to the GWL of the irrigated fields.

Three years of GWL measurement reveal that fields near reservoirs are highly affected by waterlogging followed by fields near unlined distribution canals, fields away from water bodies and fields near by drains. The water level is increasing from year to year. Moreover, with the exception of fields near drains the GWL of other fields is less than 60 cm for more than 6 months per year which has a negative effect on sugar production.

Figure 4: Trends in the ground water level at Wonji/Shoa sugar plantation over three years (Habib, 2002)



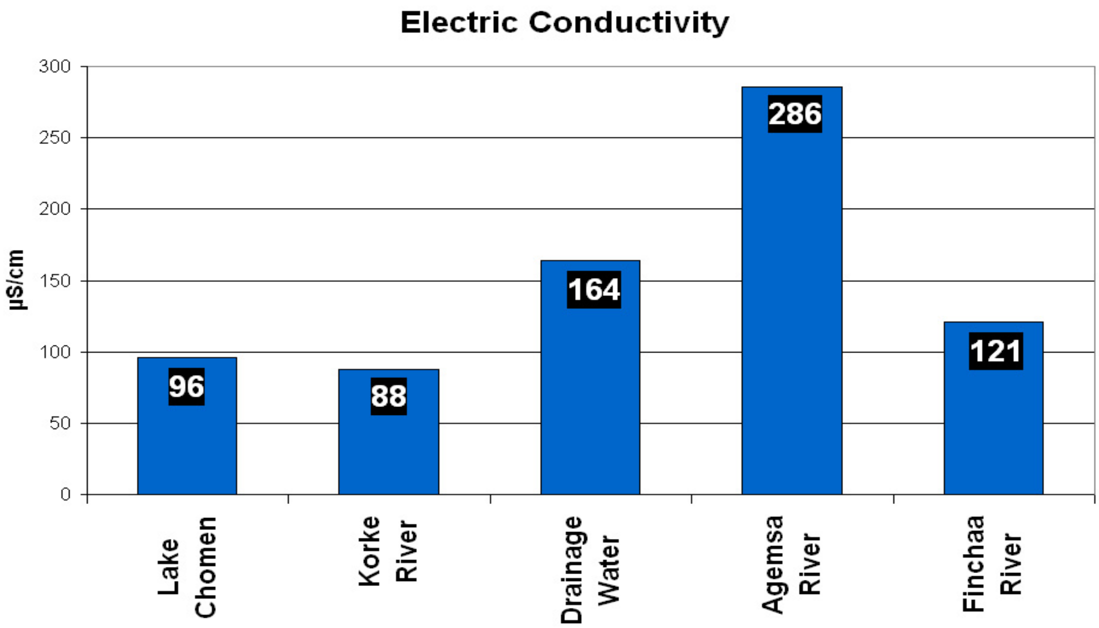
Finchaa Valley Sugar Estate - Water Quality Analysis

Water quality, regarding the physical as well as chemical parameters, of Finchaa Valley Sugar Estate can be rated as very good for irrigation purposes. However, the increase of the **EC** value of Finchaa River from 96 µS/cm measured in the upstream area of the scheme to 121 µS/cm in the downstream area shows the impact of irrigation on the downstream water bodies. This value does not include the indirect impact of irrigation by releasing pollutants by the sugar factory because the outlet of the factory was closed while EC measurements were taken. The observation made during the field visit indicates that the obvious malfunction of the waste water treatment plant of the factory poses a threat to downstream water bodies especially to Finchaa River and its ecosystem. Further investigations are necessary to investigate into the potential impact of the factory and the scheme on downstream users. Additionally an improvement or at least maintenance of the waste water treatment plant is required.

The values of the EC measurement in the field are all below the threshold value of non saline to slightly and moderate saline of 700µS/cm given by FAO (1989). This indicates no problems with salinity caused by the available water source. A detailed analysis of the EC Values of different water bodies in the adjacent area of the estate provides a deeper insight in the hydrological system of the irrigation scheme (fig. 5). The EC value of Lake Chomen (Finchaa Dam) is 96 µS/cm. The groundwater samples show slightly increased EC values of 352 and 477 µS/cm due to accumulation of salts in the aquifer. Fig. 5 shows the EC values of different water bodies within the irrigation scheme from upstream to downstream area of Finchaa Sugar Estate. As mentioned before the EC value of the reservoir is 96µS/cm and 88µS/cm for Korke River one of the tributaries of Finchaa River in the far upstream area of the scheme. Finchaa River drains Lake Chomen to the Blue Nile Basin and therefore has the same EC values. The assumption can be made that the natural EC value of surface water bodies in Finchaa Valley Area is below 100 µS/cm. The EC values of the drainage water (164µS/cm) and of tributaries of Finchaa River, e.g.

Agemsa River (286µS/cm) which are located further downstream of the estate are much higher compared to the values in the upstream area. This fact together with the increased EC value of Finchaa River (121µS/cm) measured at a location downstream of the irrigated fields indicates that the tributaries of Finchaa River crossing the irrigated area serve as the natural drainage system of the sugar farm. The increasing EC value of Finchaa River makes the impact of irrigation on downstream water bodies clearly visible. Drainage waters as well as surface run-off water possibly mixed with agrochemicals affect the water quality of the natural water resources in the adjacent area of the scheme.

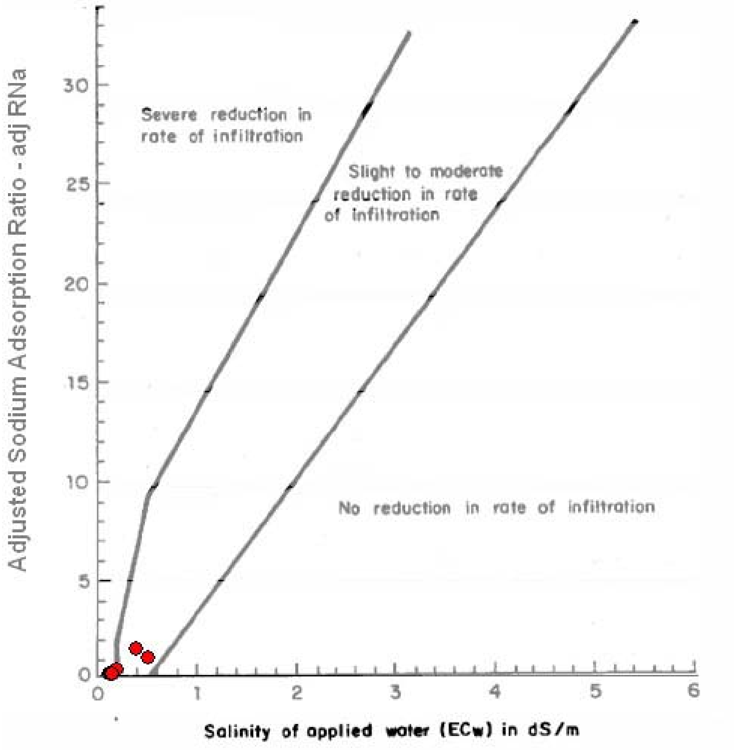
Figure 5: EC values of different water bodies from upstream to downstream areas at Finchaa Valley Sugar Estate



The ratio of adj R_{Na} to EC (fig. 6) of the irrigation water source indicates a risk of severe reduction of the infiltration rate over time. This imposed sodicity has the potential to destroy the soil structure and lead to soil crusting of the affected soil especially when EC value is low (96 µS/cm). The dispersive effects adversely influence the physical properties, e.g. infiltration rate, aggregate stability of the soil (FAO, 1989). The extent of the impact highly depends on the texture and clay-sized particles of the soil.

Since the filling of smaller pore space, sealing the soil surface and therefore reduces infiltration rates, by dispersion of finer soil particles is more likely to happen in soils with high clay content impact on Luvisols which can be classified as sandy loam to sandy clay loam with sand content over 60 % might prove to be less severe compared to the impact on Vertisols with clay content up to 60 %.

Figure 6: Effect on Infiltration rate due to Sodicity of sampled water sources (Finchaa Valley Sugar Estate)



As salinity of both applied water and the soil solution is relatively low no further swelling and dispersion of clay minerals are to be expected caused by the water source.

The threshold values for **chloride** from no restriction on use to slight to moderate restriction on use of 4meq/l are not obtained by any of the water samples. The **SAR** rating for slight to moderate restriction on use ranging from 3 to 9 neither is obtained using the SAR values nor the values for **adj** $\mathbf{R_{Na}}$. Therefore no toxic effects on plants due to irrigation are to be expected.

Finchaa Valley Sugar Estate - Soil Quality Analysis

The comparison of the collected primary and secondary **soil texture** data for Luvisols show differences related to the proportion of sand, silt and clay content. The primary data show a lower sand content for the upper soil and a higher sand content for the lower soil part and vice versa for the clay content which indicates a shifting and relocation of soil particles especially of the sand fraction. A possible reason could be found in mechanized soil tillage. The silt content of the primary data sample is twice as low as it is for the secondary data sample. This ongoing process might lead to accumulation of clay particles in the topsoil layers and therefore aggravate the gradual degradation of the soil structure by induced sodicity.

The **EC** values of all analysed soils range from 10 to 60 µS/cm which is far below the threshold value of 4 dS/m (= 4000 µS/cm). Therefore they are not affected by salinisation. According to the Eth. Ministry of Water Resources (2002) the samples can be rated as non saline. The EC value of the reference soil of the upper 30 cm is double of the value of the irrigated plots. This could be an indication for an ongoing leaching process caused by the application of water.

Secondary EC values of all analysed soil types are far below the threshold value of 4 dS/m (= 4000 µS/cm). The EC value of during the state farm cultivated Vertisols in the East Bank area is significantly higher than the uncultivated Vertisols of the West Bank. This might indicate an accumulation of salts in the rain fed cultivated soil with insufficient leaching by precipitation.

In general **pH** values of sampled irrigated Luvisols are very acidic to moderately acidic with values ranging from 4.89 to 5.62 from deeper to shallower soil depths respectively. The pH value of non-irrigated reference soils ranges from 4.56 to 4.86. Significant changes in soil pH values comparing secondary and primary data for Luvisols could not be observed. All measured values show slightly acidic tendencies, which is common for soils developed under these climatic conditions. Secondary data show that the pH of Vertisols in Finchaa Valley is higher compared to Luvisols. The measurements however show lower values for the uncultivated Vertisols (pH 6.13 - 6.5) than for the during the state farm period cultivated Vertisols (pH 6.9 - 7.37) with increasing trend for increasing soil depths. This difference between secondary and primary data might be an indicator for ongoing decline of soil pH due to irrigation and agrochemical use within the sugar estate. Washed-out-soils tend to acidification. Water dominated soils (soils of humid regions) have low values of pH, because their content of organic and carbonic acids is often subject to replenishing and recharge by rainfall. Under these conditions, the acids attack minerals, producing more acidity (Mirsal, 2004). Therefore washed-out-soils tend to acidification. According to the rating of pH values given by the Ethiopian Ministry of Water Resources Al and Mn will be toxic if present in very acidic soils. Ca, Mg and Mb may be deficient and the availability of phosphorus is low in the presence of free Al and Fe. Nitrification of organic matter is taking place. In moderately acidic soils P, Ca, Mg and Mb may be deficient. Fertilizers (ammonium sulphate and triple super phosphate) which may increase the acidity should be avoided (MoWR, 2002).

The **CEC** values of the tested Luvisols (14.02 to 14.56 meq/100g) indicate low to medium response to fertilizer application which is typical for soils with low clay content. Low CEC values can be caused by losses resulting from leaching-out, especially sodium (Na) is highly exposed to this process (MoWR, 2002). The CEC of Vertisols (23.95 and 26.54 meq/100g) however shows a different picture. The CEC shows an increasing trend with increasing soil depths. As the clay content of this soil type is significantly higher, the response to fertilizer application is more effective. This makes it even more important to plan agrochemical management for each soil type differently. The reference soil however shows a contrariwise tendency with a CEC value of 24.87 meq/100g in the upper 30 cm of soil depth and 15.52 meq/100g below 60 cm. The primary data of the year 2006 confirm the findings of the feasibility study conducted in the pre-design phase of the irrigation scheme. Proper management of agrochemicals is indispensable to avoid contamination of Finchaa valley aquifers.

The **BSP** of the two sampling spots ranging from 55.0 to 74.0 % and from 51.0 to 67.0 % respectively can be rated as medium to high. This fact indicates a medium to high fertility of the soil. The reference soils BSP values are between 37.0 to 56.0 %. Therefore the soil can be rated as medium fertile with lower values compared to the other tested soils and increasing values with depth.

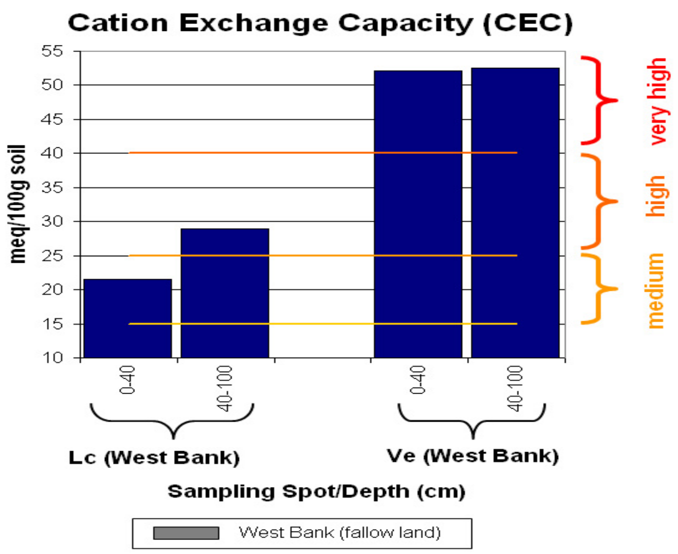
None of the measured **ESP** values of the tested soils exceeds the threshold value of 15 % and can therefore be rated as none sodic soil (FAO, 1988).

With regard to **CEC** and **ESP** only **secondary data** of Finchaa West Bank area were available. From the CEC values the difference in soil fertility of Luvisols and Vertisols can be clearly seen (fig. 7). With a CEC value higher than 52 meq/100g the Vertisols are in the range of very high CEC according to the ratings of the Ethiopian Ministry of Water Resources (2002). The data for Luvisols however show medium to high CEC values ranging between 21.55 and 28.99 meq/100g. The areas where the field work in 2006 was conducted show CEC values ranging from approximately 25.0 meq/100g for the Luvisols cultivated and irrigated since the establishment of the Finchaa Sugar Estate, which is comparable to values of the uncultivated Luvisols, and below 15.0 meq/100g for the Luvisols which have been cultivated since 1975 and irrigated since 1998. This makes the long-term process of soil degradation visible induced by agriculture and especially by irrigation. Minor to major amendments might be required for the Luvisols, however the soil might show only moderate to poor response to fertilizer application (MoWR, 2002).

None of the measured **ESP** values of the tested soils neither for Luvisols nor for Vertisols exceeds the threshold value of 15 % and can

therefore be rated as none-sodic soil (FAO 1988).
The **BSP** ranging from 36.36 to 50.16 % (Lc West Bank), 40.67 to 57.38 % (Lc East Bank) and from 42.98 to 52.55 % (Ve West Bank) can be rated as medium. Only the BSP from the Vertisols which can be found on the East Bank can be classified as high with values ranging from 59.47 to 67.02 %. This fact indicates a medium fertility of the Luvisols in general and the Vertisols of the West Bank. The Vertisols of the East Bank are however characterised by high soil fertility related to the measured **BSP** values.
The content of **total Nitrogen** of the tested soils can be rated as high for all tested soils (ranging from 0.05 to 0.14%). The total nitrogen content of the uncultivated reference soil is significantly lower compared to the irrigated plots.
The rating for **Potassium** is low for all samples ranging from 0.2 to 0.27 meq/100g soil except the value of the topsoil of the non-irrigated plot which shows a medium content of Potassium (0.48 meq/100g soil).
The content of **Calcium** is medium (5.18 to 9.5 meq/100g soil) for the irrigated soil and low (3.36 to 4.99 meq/100g soil) for the non irrigated plot.
The tested soils show a high content of **Magnesium**.
The results show very clearly the naturally low content of **available phosphorus** in the reference soil (fig. 8) which makes the application of agrochemicals necessary in order to achieve high crop yields. It is stated that in moderately acidic soils P may be deficient which is true in this case, nevertheless fertilizers (ammonium sulphate and triple super phosphate) which may increase the acidity should be avoided (MoWR, 2002). The content of available P (29.2 mg/kg) is only high within the first 30 cm of soil depth for sampling point F 1. According to the statement of a staff member of the Sugar Estate DAP had been applied to plot F 1 shortly before the field work was conducted. Obviously phosphorus is not leached to lower soil depth as its content in 30-90 cm is significantly lower.

Figure 7: Cation Exchange Capacity of soil samples of Finchaa Valley Sugar Estate – Secondary Data



The secondary data show that the content of **total Nitrogen** of the Luvisols and Vertisols of West and East Bank can be rated as high for all soils (ranging from 0.05 to 0.27%). The content of total nitrogen in the cultivated Vertisols is significantly higher (0.27%) compared to the other tested soils. The content of total nitrogen in the uncultivated Luvisols (West and East Bank) is similar compared to the content of the irrigated soils.
The rating for **Potassium** of the Luvisols is medium (West Bank and East Bank; lower soil parts) to high (East Bank; upper soil parts) whereas the rating for K of irrigated Luvisols is low. The tested Vertisols in both areas show higher contents of K and can be rated as high. The formerly cultivated Vertisols of the East Bank have a significantly higher K content

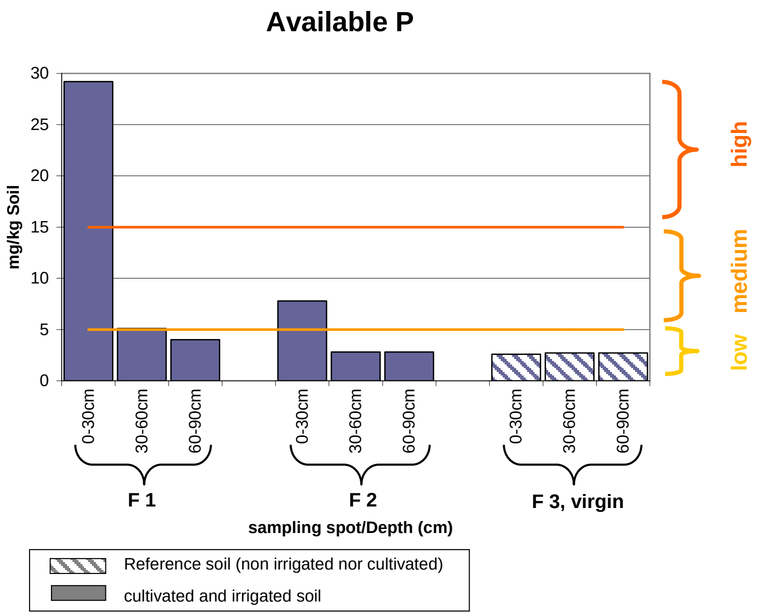
compared to the uncultivated Vertisols of the West Bank.

The content of **Calcium** is medium for the tested Luvisols and high to very high for the Vertisols in both areas. The Ca values of the formerly cultivated Luvisols of the East bank are higher compared to the Luvisols of the West Bank which were uncultivated at that point of time. The Ca content of the tested Vertisols of the West and the East Bank are more or less similar ranging from 18.3 to 21.8 meq/100g but are higher compared to the highest Ca content of tested Luvisols (10.15 meq/100g; Luvisols, East Bank; topsoil).

The **Magnesium** content ranges from 2.32 to 4.36 meq/100g for Luvisols of East and West Bank and East Bank Vertisols. The Mg value for Vertisols of the East Bank is slightly higher with a content of 6.12 meq/100g in the topsoil. The content of Mg in all soils can be rated as high, except the content in the topsoil of the West Bank Vertisols which can be rated as medium. The analysis results of the primary and secondary data show similar Mg contents for irrigated and non-irrigated Luvisols.

The analysis of **organic content** and comparison of primary and secondary data reveals an ongoing soil degradation process caused by intensive sugar cane monoculture. The comparison of the organic carbon content of uncultivated, cultivated and irrigated areas shows a decreasing trend of naturally low organic carbon content of the tested soil types. Two reasons can be spotted as potential causes for this trend. Soil degradation which is caused by intensive agricultural production of sugar cane monoculture might be one reason. The low content of organic carbon can also be explained by the low natural pH value of the soil. The nitrification process of organic carbon which is typical for these soils and climatic conditions could be the direct cause for the very low organic carbon content of the tested soils. However, this makes fertilizers application necessary to achieve adequate yields which additionally spells the risk of groundwater pollution by agrochemicals.

Figure 8: Content of available Phosphorus of soil samples of Finchaa Valley Sugar Estate



Finchaa Valley Sugar Estate – Erosion

Two major types of soil erosion could be identified for the Finchaa Valley cases study. The effect of hinterland erosion and infield erosion jeopardizes the fertility status of the whole region and the Sugar Estate in particular. Deforestation of the highland regions caused by cutting trees for fire wood exposes the highland soils to erosive processes and contributes to high surface runoff. Population pressure aggravates this problem even more. The eroded material from the steep escarpments which is deposited on the irrigated areas of the valley bottom can lead to soil degradation. Run off estimation of the valley bottom indicates loss of eroded fertile soils due to sheet erosion estimated in the range of 5 to 10 mm/y or equivalent to approximately 100ton/ha^{-y} (Girma T., 1995). The eroded soil is deposited to the tributaries of Finchaa River which finally drain to Abay (Blue Nile) River. Considering the high content of available phosphorous which tends to be fixed to soil particles in the topsoil layer, erosion of these soil particles causes an additional threat to downstream water courses. Assuming that these present trends continue the problem of soil and land degradation induced by soil erosion may threaten the sustainability of the irrigation project.

Finchaa Valley Sugar Estate - Impact on Ecosystem

In 1975 the state farm was established which mainly produced food and commercial crops until 1991. About 3500 ha of valuable ecosystems have been cleared and destroyed for agricultural activities. Before that the valley was under natural vegetation cover and very few agricultural plots could be observed. The valley area was a sanctuary for wild animals. Tall savanna grass mixed with trees which occupied most of the valley floor created favorable conditions for a large numbers of wild animals like carnivores, browsers, grazers and other small animals. The natural vegetation in the area was dense and with full canopy during the wet season.

Starting from 1991 up to now more than 8064 ha of land has been cleared and irrigated for sugar production (Ahmed Amdihun, 2006). From 1975 to 1991 these parts of Finchaa Valley area have changed from primary to tertiary economic production; from traditional agricultural to industrial and commercial production respectively. The dominant land use classes are irrigation agriculture and agro-pastoral within the valley area and rain fed agriculture mainly in the high land area. In addition to the land clearing tree and grass species are exposed to extensive and severe bush fires (Ahmed, 2006). Two major reasons could be identified. In addition to natural factors inhabitants of the region earn their subsistence by collecting wild honey and crop cultivation. To clear their land farmers burn the forest. Since the establishment of the irrigation scheme and the beginning of sugar cane production also sugar cane burning for harvesting can be identified as a major cause for forest fires. Furthermore migration tendencies triggered by the attraction and employment options of the sugar estate increase the pressure on the ecosystem.

In developing countries like Ethiopia the GDP of a country highly depends on agricultural production. Priorities have to be outweighed between conservation of valuable ecosystems and important contribution to a country's economy. In order to justify clearance of large natural forest areas agricultural production needs to be sustainable to avoid large scale land degradation and further adverse environmental impacts.

Conclusions

The main goal of this report was to assess the pertinent environmental implications of two selected large scale irrigation schemes in Ethiopia. For this purpose two large scale schemes in different regions were selected Wonji/Shoa and Finchaa Valley. The main focus was put on impact on natural resources like water, soil and ecosystems. Based on the pertinent environmental checklists of FAOs, World Banks and MoWRs EIA procedures, data sheets and guidelines for primary and secondary data collection were designed (Wallner, 2006) and used during the assessment. The water sources of the schemes were sampled and analyzed against FAOs standards and threshold for water used in agriculture. Additionally water samples of downstream water bodies were tested to assess potential adverse impacts. Physical and chemical soil parameters of primary and secondary data were analyzed for possible changes.

In general, the study conducted shows that the irrigation water used in the investigated case studies is of good quality with regard to FAOs standards for water used in agriculture and does not spell any risk for irrigation purposes. The irrigation water sources used in the three case study sites have low EC values ranging from 96 µS/cm (Finchaa Valley) to 293 µS/cm (Wonji/Shoa) and therefore no primary salinisation is to be expected.

With regard to impact of the used water source on the soil quality EC to SAR ratio however indicates potential negative long-term effects on infiltration rates due to damage of the soil structure and soil crusting through induced sodicity especially in case of Wonji/Shoa and Finchaa Sugar Plantation.

The most crucial environmental impacts of large scale irrigation in Ethiopia which could be identified are related to improper irrigation management and development of irrigation project on saline and saline-sodic soils. Inefficient application of water and seepage of water from reservoirs and unlined distribution canals lead to rising of groundwater table at Wonji/Shoa. Investigations showed that on some fields of the Wonji/Shoa Plantation the groundwater table is less than one meter below soil surface (Habib D., 2002). This tendency has mainly two adverse effects. The rise of the groundwater table up to the root zone interferes with the proper development of the planted crop, leads to damage of the soil structure and insufficient soil ventilation. Secondly it induces secondary salinisation due to capillary rising. Improper irrigation management and attempts to leach the accumulated salt by additional application of water, which leads to rising groundwater table, has even aggravated this effect (Tena, 2002). Besides installation of drainage systems to intercept deep percolation of the excess water, other in the long run more cost-effective measures need to be considered. Installation of drip systems could avoid excessively use of irrigation water and make the application of water more efficient and therefore increase the overall water productivity of the schemes.

According to the Ethiopian Irrigation Development Program 26 medium and large-scale irrigation projects are planned to be implemented. Due to topographic reasons most of these already established or proposed large-scale irrigation schemes can be found in the lowlands of Ethiopians major river basins such as Awash, Blue Nile and Wabe Shebelle river basin. Over 11 million ha of land in the arid, semi-arid and desert parts of Ethiopia are known to be salt affected. Large areas of the Awash River Basin especially the middle and lower parts of the basin are saline or sodic or in saline or sodic phase and thus potentially exposed to salinisation and sodicity (EIAR 2006).

Development of large scale irrigation, political decision making and investment strategies are often oriented on short-term profit maximisation whereby environmental sustainability is neglected. Due to the fact that environmental sustainability of irrigation projects is rather on the low end of the policy priority list, adverse and irreversible environmental impacts are bound to happen in the contrary nexus of profit maximisation, short-term benefits and environmental sustainability.

In order to avoid possible negative impacts of the expansion of irrigated agriculture in causing deterioration of land and soil quality, proper understanding of the quality of soil and irrigation water and implementation of appropriate measures have paramount importance for sustainable development. There is no doubt that irrigation can increase intensification and productivity, can help to limit the size of cultivated areas, can provide ample labour and agro-industrialization opportunities and other potentially positive benefits. On the other hand it can also cause negative impacts such as deterioration of soil and water quality, impact on eco-system, health and other negative externalities. It is important to support such endeavours through proper study and continuous research, so that the positive roles could be enhanced with timely mitigation measures for the negative impacts.

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