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Effect of Lake Basaka expansion on the sustainability of Matahara SE in the Awash river basin, Ethiopia

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Matahara Sugar Estate (MSE) establishment nearly 40 years ago is experiencing effects of a rising GW table and salinity in some fields, and as the result the yield of certain fields is decreasing and a significant area of cultivated lands are abandoning The problem is believed to be the result of the expansion of saline Lake Basaka towards the plantation field. The objective of this study was to determine the extent of expansion of the Lake (area & shape) in the past 35 years period from Landsat images and assess its negative effects on the nearby sugarcane plantations' GW dynamics & soil salinity. The result indicates that the lake expanded approximately 34 km^2 in the past 35 years. The GW table is very shallow in the Abadir- extension areas and north section where the GW salinity is under severe condition.

Introduction

Lake Basaka is located in the middle Awash River Basin, Central Rift Valley of Ethiopia at about 200 km South-East of the capital city, Addis Ababa. The lake is expanding as opposed to the other rift valley lakes in Ethiopia, which are shrinking (Alemayehu et al., 2006). Currently the total surface area of the lake is estimated to be 42 km^2, which was about 3 km^2 in the 1960's (Gulilat, 2000; Alemayehu et al., 2006). Before the establishment of the Matahara Sugar Estate(MSE) (in 1970's), according to the information from elders of the indigenous (Karaayyuu) people, the Lake was like a small surface pond created during the rainy season and used as grazing area and watering for their livestock during the dry season. The source of the Lake is not yet fully identified. Some study reports indicate that the Lake expansion is due to the introduction of the Abadir and Nura Era irrigation (Gulilat, 2000) as cited by Eyasu, (2008), which are discharging their irrigation excess directly into the lake. Others believe that it is the result of the geological changes happening in the great African Rift Valley in general, and Ethiopian Rift Valley in particular.

The lake expansion affects the surface - and ground-water dynamics and soil properties of the region and the condition is specifically dangerous for the sustainability of MSE and Matahara town in particular and the Awash basin irrigation in general. For instance, it is evident that Metahara Sugar Estate (MSE) is experiencing signs of a rising ground water table, salinity and alkalinity. In addition, the production & productivity of the Abadir Extension farms are decreasing and a significant number of cultivated fields are abandoned.

To identify the differential vulnerability of the nearby areas to future inundation hazards as a result of the lake expansion, it is necessary that timely actions to be taken by the sugar estates, responsible institutions and the national decision makers. Hence, the quantification of the lake expansion extent in time and space and then evaluation of its effects on the groundwater quality and soil salinization of the area is extremely important.

No profound scientific investigation has been done so far regarding the expansion of the lake and its effects on the groundwater dynamics and soil salinization of the nearby sugarcane plantation. A study made by Girma (1993) on salinity and sodicity status of the Matahara Sugar Estate showed the presence of salinity and sodicity problems in some fields from few soil samples taken across profiles. The study does not indicate the spatial distribution of the soil salinity and sodicity problems and it was done 15 years ago.

Therefore, due to the aforementioned reasons and others, this study was initiated with the objective to determine the surface areal expansion of the Basaka Lake in the past 35 years from satellite images and assess its negative effects on the nearby sugarcane plantation regarding sustainability of production and productivity (in terms of groundwater depth and quality, and soil salinization).

The specific objectives of the study are to:

- determine the expansion (surface area & shape) of the lake in time & space.
- produce a spatial maps of groundwater table depth and salinity in the sugarcane plantation area under current condition.
- determine the trends of the expansion of the lake and predict possible future expansion considering that the past condition will prevail.

Methodology

Description of the study area

Lake Basaka is located in the Middle Awash Basin, central rift-valley of Ethiopia between 8°51.5' N latitude and 39°51.5' E longitude at about 200 km SE of the capital city, Addis Ababa and it has an average elevation of 950m m.a.s.l. The lake formation is very recent (50 years) and salinity level very high, not tolerable by most plants.

Matahara Sugar Estate (MSE) is the second largest irrigation scheme established (in 1965) in the Awash Basin by the Dutch company called Hangler Vonder Amsterdam (HVA) to meet the increase of domestic sugar demand and the suitability of soil & environment for sugarcane crop. Currently the total plantation area of MSE is about 10,200 ha supplying cane to the processing factory with the design crushing capacity of 5,000 tons cane per day (TCD) (Zeleke, 2008). There are ten commercial cane varities being grown on seven soil cycle groups, where the operation period of one crop cycle varies between 4-9 years (Ambachew, 2005). The soil cycle groups were made based on the cane yielding capacity rather than scientific soil classification methods. Figure 1 shows the location of Lake Basaka & Matahara Sugarcane Plantation.

Matahara area is situated on a nearly levelled plain (slope $< 3\%$) stretching along the course of Awash River, surrounded by mountain chains of variable elevation in the south, south east, south west and north west, which are the extensions of Chercher (Hararghe) highlands (Girma , 1993). In the north and north east, the area is delineated by the mount Fentale (volcanic mountain) and undulating plateaus, respectively. Physiographically, the area can be considered as a topographic depression, where runoff from surrounding catchment areas gets overflowed along with alluvial sediments (Girma , 1993).

As Matahara is situated in the central rift valley region, it is vulnerable to the occurrences of different tectonic & volcanic activities. As the result, the area is characterized with features of past & recent volcanic events, which is evident from the observation of vast lava extrusions at the foot slope of mountain Fentale and dots of extensive scoriceous hills in the locality (Mor, 1971) as cited by Girma (1993).

Analysis of the long year's average (LYA) weather data (1966-2008) of the area indicates that the area is characterized by bimodal rainfall distribution pattern with the major rainy season occurring from July to September and the minor, occasional rain occurring between February to April. The LYA mean annual rainfall is about 543.7mm and the mean maximum & minimum temperatures are 32.9 and 17.5 °C, respectively. The long term average pan evaporation of the area is 6.9 mm /day and the reference evapotranspiration between 4-5.5 mm/day (Habib and Girma, 2007). The climate of the area, in general, is classified to be semi-arid.

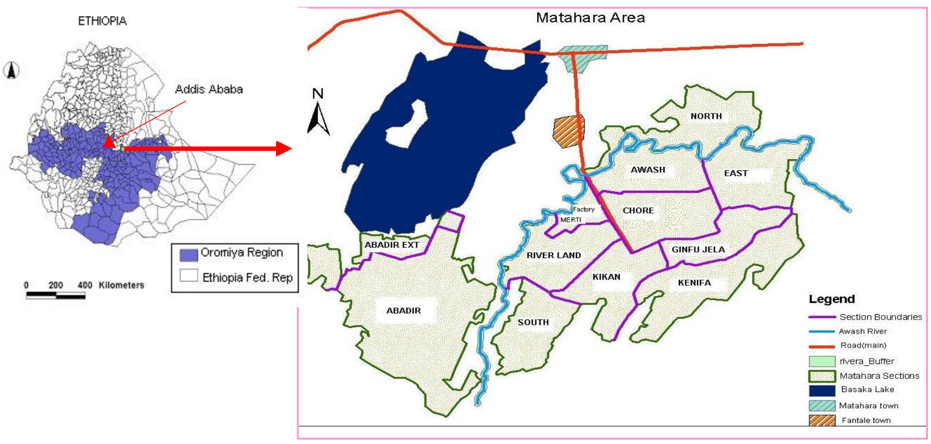

Figure 1. The study area: (a) Location ; (b) Lake Basaka & Matahara Sugar Estate

Data collection

Topographic maps with sufficient accuracy to determine the expansion of Lake Basaka are not available for the past decades. Therefore an attempt is made to use Landsat imagery, which started observation in the early 1970's. Four Landsat images (Jan 1973-MSS, Jan 1986-TM, Dec 2000-ETM & Feb 2008-4ETM+) were acquired from the FREE Global Orthorectified Landsat Data via FTP (http://glovis.usgs.gov). The path/row for the 1973 MSS image was 180/54 and for the other three periods the Path/row was 168/54. The selected images were all cloud free and cover both Matahara & Wonji Sugar Estates. A Digital CAD format Plantation (base) map showing all the roads, irrigation & drainage networks, field plots, Awash river was collected from the Department of Civil Engineering of the Matahara Sugar Estate and the 1975 Matahara topo-sheet (scale 1:50,000) was purchased from the Ethiopian Mapping Agency.

A total of 36 piezometer tubes(Φ=80 mm and Length = 2 to 3m) were installed in October 2007 at different parts of the sugarcane plantation considering the different sources of water such as Lake Basaka, Awash River, Night-storage Reservoirs. Then, the monthly groundwater depth monitoring was carried out (Nov 2007 – April 2008) from the piezometer tubes. The installation of piezometer (PVC) tubes (2-3 m length) was done manually using auger tubes. This is the first attempt for ground water monitoring in the MSE. At the mean time, during the piezometer installation, disturbed soil samples were collected in two profile (0-40 cm & 40 -100 cm) and analysed for electric conductivity (EC) and soluble salts in the Matahara Breeding Station of the Research Directorate. The groundwater quality (EC & soluble salts) analysis was also carried out from few water samples collected from the piezometer tubes and Basaka Lake in the month of May, 2008 and analysed in the same laboratory. The soil & water analysis was done as per the standard test manual prepared by the Ethiopian Agricultural Research Organization (EARO), currently named Ethiopian Institute of Agricultural Research (EIAR). The weather data was collected from the Research Directorate Library and Matahara Breeding Station.

Data processing and analysis

Image processing

The satellite images are registered with the topographic map of the project area by matching some of the identifiable features like crossing of roads, railways, river, irrigation canals, bridges etc. on both the base map as well as on the satellite image. The image was then processed in ERDAS Imagine 8.6 and ILWIS 3.4 softwares. The image geometric correction, layer stacking, sub setting, and image enhancement were carried out. After checking the different enhancement techniques, the spectral enhancement (indices) were adopted. Different Indices such as Time Composite Normalised Difference Vegetation Index (TNDVI), Normalised Difference Salinity Index (NDSI), Normalised Difference Water Index (NDWI), were applied. In this study, the NDWI and NDSI algorithms given by McFeeters (1996) and adopted by GAO (1996) were applied in

ILWIS and the TNDVI was done using the algorithms available in ERDAS. NDSI adopted for the 1973 & 2008 image and NDWI & TNDVI adopted, respectively, for the 1986 & 2000 satellite images.

Data analysis
Average of the six month GW data was considered since there is a great fluctuation in GW depth due to the irrigation system of the area. A regression analysis was carried out between the ground water depth below the ground surface and the ground water quality (EC & SAR) in order to prepare the groundwater quality map. Geostatistical analysis (kriging interpolator) was made in ArcView GIS for the spatial mapping of GW table, GW salinity and soil salinity. The altitude map of the area was made in GIS using the universal kriging with quadratic drift. The soil salinity classification was done as per the FAO (1986) guidelines and the GW water salinity class was made as per the FAO (1976) Water Quality Guidelines (Ayers & Westcot, 1976). The GW water table classes were following the FAO/UNEP (1984) guidelines (Masoudi et al., 2006).

Results and discussion

Spatial and timely expansion of the lake from satellite images

Surface area (size) and shape of the lake
The results of the image analysis using different enhancement techniques for the considered periods are indicated in Figures 2 and 3. Water delineation from the 1973 MSS image was difficult and the NDSI (band3-band4)/(band 3+band4) gave satisfactory results.

Figure 2 shows the individual lake (size & shape) in different periods and Figure 3 indicates the Lake expansion extent in all periods considered. The surface area of the Lake is tabulated in Table 1. From Figure 3, it is obvious that the Lake expansion is very significant and very fast. The significant surface areal expansion of the lake was observed in the period between 1973 to 1986 (about 21 km^2) due to the topographic favour. In the same period, the lake expansion is almost in all direction and mostly towards South (Abadir Farm). In the period between 1986 to 2000 the lake surface area increased by about (11.6 km^2), where the expansion direction is restricted almost towards the South (Abadir farm) and towards the West. In this period the Lake almost established its current shape. Between 2000 – 2008, the expansion of the lake is further restricted towards Abadir Farm in the south and towards Matahara Town in the North East. In general, the recent expansion trend of the lake is in the south, east and north-east directions.

Table 1. Surface area of the lake in different periods

Year	Area (km2)	Incremental area (km2)	Cum. incremental area (km2/yr)
1957*	3.0	0.0	0.0
1973	8.4	5.4	0.3
1975**	10.2	1.8	1.2
1986	29.5	19.3	3.0
2000	41.1	11.6	3.8
2008	42.6	1.5	4.0

Source: *Gulilat, 2000; ** processed from 1975 toposheet

The annual incremental area of the lake (column 4 of Table 1) was determined considering a linear increment for each period. The expansion of the Lake, as table 1 shows, started after the establishment of MSE (1970's) and the probable source of the Lake expansion can be the irrigation excess from the farms (drainage discharge into the Lake and/or the groundwater outflow towards the lake). However, it is difficult to conclude the source of the lake is irrigation excess only since the area is prone to different tectonic activities as it is situated in central rift valley region.

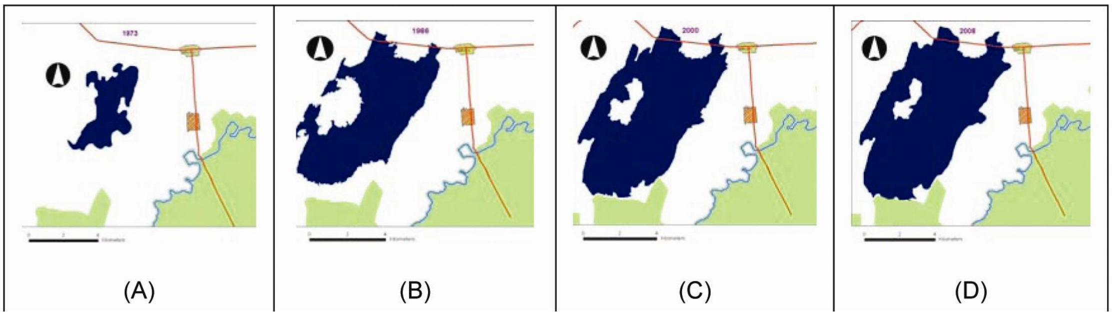

Figure 2. Basaka Lake expansion from 1973-2008: (A) 1973, (B) 1986, (C) 2000, (D) 2008

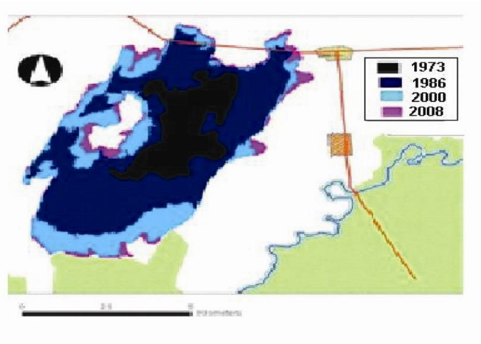

Figure 3. The expansion extent of Basaka Lake in the periods between 1973 - 2008

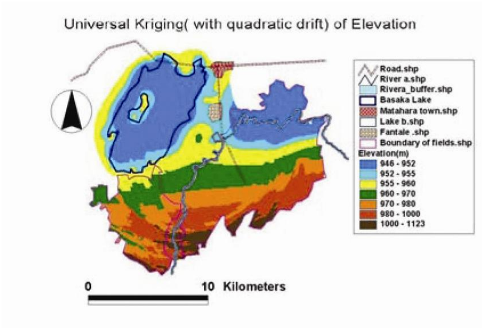

Figure 4. Elevation map of the study area

Projection for the future lake expansion

The recent expansion of the lake towards the south (Abadir farm), east and north-east is in particular agreement with the topography of the area (Figure 4), and it seems the lake is finding a way to further expand in the east and north-east direction. This future expansion extent (depth & direction) was estimated based on the elevation of the lake in 1975 (944 m) and the current average elevation of the lake (950 m). During past 35 years, the depth of the lake has increased – at least – by a depth of 5m, with a current average depth estimated at 8 ± 1 m.

Considering the past expansion trend of the lake (Figure 3) and the topography of the area (Figure 4) and assuming that the past conditions will prevail in the future, it can be expected that the lake will inundate parts of Matahara town and start flowing towards the east, and probably passing through Fantale town towards the plantation in the north within the coming 25 years. The trends in depth increment($\cong$ 0.2 m/year) during the last two years is greater than previously as indicated by field managers of the sugar estate and observed during the field work. Assuming this accelerated trend, we argue that the displacement of nearby towns and the flow towards the north section may even occur during the coming 15 years. Based on this estimate, the Lake will join Awash River either through the north or the Awash section of the plantation, thereby impacting on the sustainability of the nearby sugar plantation, and possible negative impacts on all the downstream irrigation developments of the Awash River Basin more generally.

Effect of the lake expansion on Matahara sugarcane plantation

Spatial dynamics of groundwater (GW) table depth and salinity

The highly saline Lake Basaka expansion is expected to affect the GW dynamics of the sugarcane plantation fields. The maps of GW table depth and salinity presented in Figure 4 and 5 were produced based on the ordinary kriging interpolation ArcView 3.3 from the six month average monthly point measurement piezometer data. As shown in the figure, most of the GW table depth of the area, in general, is categorized as shallow (< 3m). It is under severe condition(< 1 m) at the Abadir extension (South of Lake Basaka), North, East and Awash sections of the plantation and in moderate range (1- 3 m) in the other areas (away from water bodies) according to the FAO/UNEP (1984) guidelines (Masoudi et al.,2006). In general, the GW table depth and salinity is better correlates with the slope of the area (see Figure 4). Lower altitudes with relatively shallower GW table depth have severe salinity than the higher altitudes. Almost all plantation fields have certain amount of GW salinity problem ranging from moderate to severe according to the FAO (1976) guidelines.

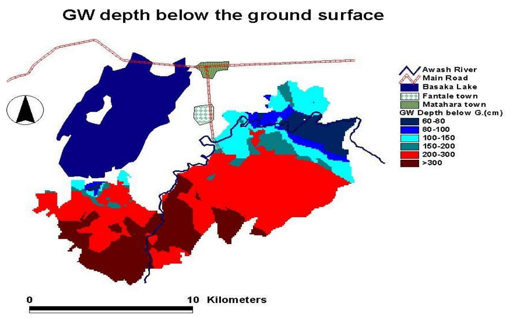

Figure 5. Spatial Map of GW table depth

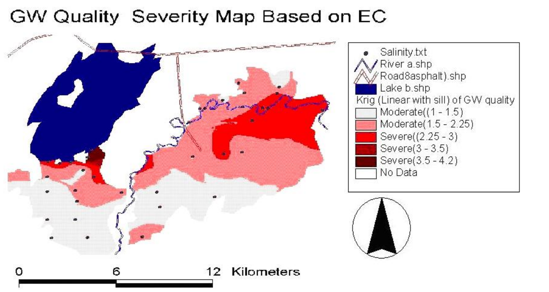

Figure 6. Spatial map of GW salinity

The GW table depth less than 3m is expected to contribute to the crop Evapotranspiration (Kahlown et al., 1998; Kahlown et al., 2005), which is maximum when the depth is less than 1.0 m. For sugarcane crop, the GW contribution increases as function of increment in GW table depth (Kahlown et al., 2005). The saline GW(EC > 4 dS/m) will result in a decrease of sugarcane yield when the GW table depth is less than 2m below the ground (Kahlown and Azam, 2002).This is also true in the Matahara sugarcane plantation, the GW table depth below the soil surface & groundwater electrical conductivity (EC) showed a strong negative correlation (r = - 0.83). That means the contribution of salinity to the crop root zone is significant as the GW table depth become shallower.

The expansion of the lake is interfering with the production & productivity of the sugar plantation. Figure 7 shows the emergence of Lake Basaka in between the Abadir-Extension fields during rainy season. The sugarcane growth is observed to be stunted and out of production. Significant cultivated fields are abandoning in Abadir-ext areas because of salinity and the GW table is coming to the surface.

Soil salinization

The spatial map of the soil salinity based on Sodium Absorption Ratio (SAR) produced using ordinary kriging is shown as in Figure 8. The effect of highly saline Lake Basaka water on the plantation's soil salinity is clearly observable in the Figure 8. It can be shown that the Abadir-extension & section-north are subjected to rising salinity (SAR) value as compared to the other sections of the plantation.

The rise of salinity level may decrease the water availability to crops and may destruct the soil structure & aggregates (Warrence et al., 2003; Hanson et al., 1999). The soil salinity level increased almost as a function of the increase in water-table depth. Most of the of plantation sections (Abadir-extension, Abadir-A, River land, Awash, Chore, East and North) have soil salinity problem ranging from moderate to severe condition.

The increment of soil salinization in the sub-soil (40 -100 cm) indicates that the source of soil salinity is the capillary rise (secondary salinization) from the saline groundwater, which is in agreement with the above argument about the contribution of the saline GW to crop root zone and other works (Kahlown et al., 2005).

Figure 7. Lake emergence in Abadir Extension fields (Photo: Sept 2007)

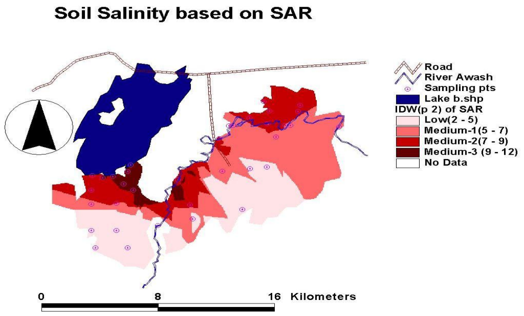

Figure 8. Soil salinity map in the sub-surface (40-100cm)

Change in water quality

The summary of the mean water quality for the different water sources are presented as in Table 2. The effects of the highly saline (EC ~11 dS/m) lake on the different water sources, especially drainage and ground water, in terms of salinity (EC), sodicity (SAR) and specific ion toxicity (Na & Cl) is clearly observable from the table.

Table 2. Mean values for some of the water quality parameters for different water types

Type of water	PH	EC	Na^+	$Ca2^+$	HCO_3^{2-}	Cl^-	SAR
Awash River	7.73	0.38	1.58	1.52	2.70	0.50	*1.6*
Irrigation Canals	7.83	0.40	1.77	1.67	2.83	0.42	*1.7*
Reservoirs	8.10	0.38	1.70	1.41	2.60	0.21	*1.8*
Drainage water	8.10	1.26	24.31	0.36	1.65	0.49	2.5
Factory waste	7.92	0.40	57.03	1.59	2.90	0.54	*57*
Ground water	8.23	2.38	25.09	1.08	15.28	3.04	*30*
Basaka Lake	9.58	10.70	159.7	0.38	20.65	39.42	*307*

** All the units are in meq/L, except EC(dS/m) and pH(-).*

Conclusion

The significant expansion of Lake Basaka during the past 35 years started after the introduction of MSE. The expansion is affecting both the groundwater dynamics and soil salinization of the nearby sugarcane plantation and, if it continuous, the sustainability of the plantation itself is under great risk. The future expansion of the highly saline lake may be aggravated towards the east and north-east direction due to the topography of the area. This has the potential to displace Matahara town and impact the sugar plantation during the next 25-30 years. Assuming the past trends, the lake is expected to join Awash River, thereby impacting all downstream irrigation developments in the Awash Basin, and affecting the livelihood of the people depending on the water resources of this basin.

Recommendations and/or suggestions

Based on the discussion and conclusions made above the following points are recommended and/or suggested:

- The expansion of the lake has already started affecting Matahar Sugar Estate (MSE) and it should be considered seriously before it brings total devastation. Optimum irrigation and appropriate drainage should be adopted, in order to limit the inflow into the lake.
- It is difficult to conclude that the irrigation/rainfall excess from the nearby farms is the only cause for the expansion of the lake. As the area is situated in the rift valley system, where there are active tectonic activities, other factors are expected to aggravate its expansion even in the future. Hence, further and detail investigation that considers all the parameters affecting lake expansion is needed to justify the cause for the expansion.
- The expansion extent of the lake is very terrible and creates a great developmental challenge in the Awash basin. All the beneficiaries of the basin, concerned institutions and the decision-makers of the country should consider the condition seriously and adopt mitigation measures before it brings irreversible damage to the region.

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Keywords

Lake Basaka, Groundwater, Landsat, salinity, spatial mapping

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