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Analysing the temporal water quality dynamics of Lake Basaka, Central Rift Valley of Ethiopia

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Abstract. This study presents the general water quality status and temporal quality dynamics of Lake Basaka water in the past about 5 decades. Water samples were collected and analysed for important physico-chemical quality parameters following standard procedures. The result showed that Lake Basaka water is highly saline and alkaline and experiencing a general reducing trends in ionic concentrations of quality parameters due to the dilution effect. About 10-fold reduction of total ionic concentration occurred in the Lake over the period of 2 decades (1960-1980). There was a sharp and fast decline in EC, Cl, SO_4, Na, and K ions from early 1960s up to the late 1980s, and then became relatively stable. Some ions (eg. Na, Ca, Mg, Cl, SO_4) are showing increment in recent years. This characteristics of the lake water is terrible in relation to its potential to inundate the nearby areas in the near future. The expansion of such quality water has negative effects on the water resources of the region, especially soil quality, drainage and groundwater, in terms of salinity, sodicity and specific ion toxicity. The regimes of soil moisture, solute and groundwater could be affected, concurrently affecting the productivity and sustainability of the sugar estate. Thus, there is an urgent need to identify the potential sources of water and chemicals to the lake and devise an appropriate mitigation and/or remedial measures.

1. Introduction

Lake Basaka, located adjacent to Matahara sugar estate (MSE), Matahara town and Fantalle village (Ethiopia), has been expanding at a very fast and dramatic rate over the last about 5 decades [1-9]). Surface area of the lake was increased from 3 km^2 in 1960s to about 48.5 km^2 in 2010 [8]. Interestingly, the other Ethiopian Rift Valley Lakes are shrinking, except Lake Hawassa [1-2, 6-8]. The expansion of the lake is attracting the attention of the government and other stakeholders, mostly due to its quality. The lake water is saline (EC~6.3 dS/m), sodic (SAR ~300) and alkaline (pH~9.6) and not usable for irrigation and domestic purposes [6, 8]. The expansion of the lake with its poor water quality is expected to create various negative (socio-economic and environmental) impacts to the region, particularly the nearby sugarcane plantationr. The expansion of the lake was started after the establishment of Matahara Sugar Estate (MSE) in the 1960s. Before the establishment of the sugar plantation, the lake was like a small surface pond created during rainy season and used as grazing area [6-7].

A quite different number of studies were conducted on the quality of Lake Basaka for different purposes. The general lake limonology (morphology and chemistry) (including Awassa, Hora Hado, and Shala Lakes) are summarised by different studies [3, 6, 10-13]. This study attempted to present the general water quality status and temporal dynamics of Lake Basaka in the past about 5 decades.

2. Methodology

2.1. Brief Description of the Study Area

Lake Basaka (8°51.5’ N, 39°51.5’ E) is a terminal lake located in the Fentalle Woreda, East Showa Zone of Oromiya regional state at about 200 km southeast of the capital city of Ethiopia, Addis Ababa (Figure 1). It is volcanically dammed, endoheric lake located in the northern part of the Main

Ethiopian Rift (MER), at the near distance to the Afar triangle [3, 6]. According to the catchment delineation made by Dinka [6]. The total surface water catchment of the lake is about 500 km^2. The lake catchment has variable elevation; ranging from 950 m at the lake to over 1700m (m.a.s.l) at Fentalle Crater (Volcanic Mountain) [6-8]. As the area is situated in the upper most part of MER, central rift valley region of Ethiopia, Lake Basaka is vulnerable to the occurrences of different tectonic and volcanic activities. Topographically, the lake is surrounded by various plateus, which are the extensions of Haraghe Highlands. Geologically, the area is characterized with features of past and recent volcanic events. It is bordered by older volcanoes and a rift margin in the eastern side, by young Quaternary complexes of Fantalle crater in the northern part, and by Kone in the western sides [3, 8].

Matahara plain area has semi-arid climate, characterized by bimodal and erratic rainfall distribution. The major rainy season occurs from July to September and the minor/occasional rain occurring from March to April [3, 6-8]. The long-term average annual rainfall, temperature and evaporation of the area are 543.7 mm, 26.5 °C and 2485 mm, respectively [6, 8]. The Lake Basaka catchment have different land use/cover (LUC) (Figure 2) and soil units [6-7]. The soil units include Lepthosols, Cambisols, Podzoluvisols, Luvisols, Podzol, Fluvisols and Solnchaks. The LUC change analysis made by Dinka [7] indicated that Lake Basaka catchment had experienced a drastic change in its LUC conditions over the last 4–5 decades because of the rapid increase in human settlement, deforestation, and the establishment of irrigation schemes and Awash National Park. About 18 924 ha of forest and 4730 ha of grazing lands were devastated from 1973 to 2008; reducing the forest coverage from 42% in 1970s to only 6% in 2000s [7]. The detail description of Matahara Plain and Lake Basaka Catchment can be obtained from different research reports [1-9, 13-14].

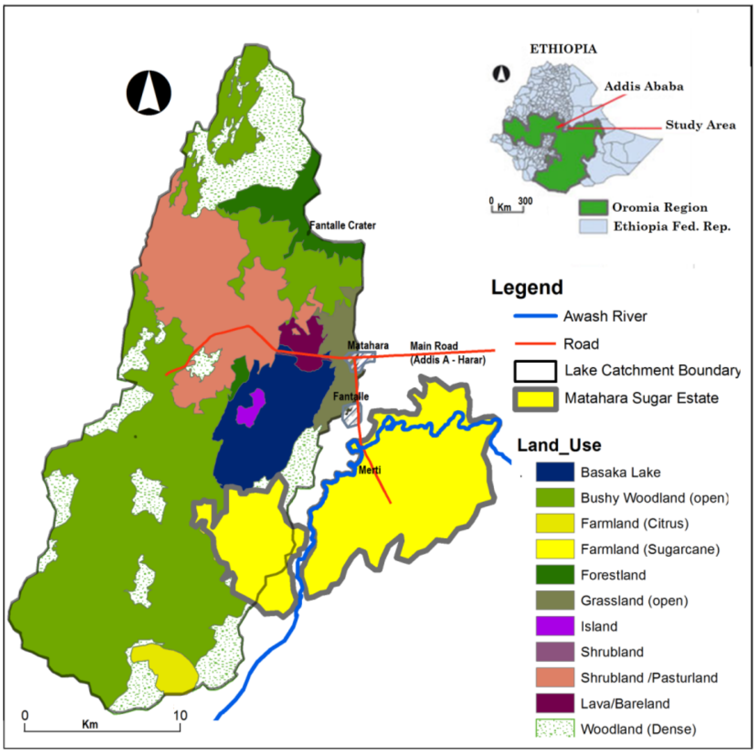

Figure 1. Map showing the location of the study area and the land use-cover for Lake Basaka Catchment and Matahara Sugar Estate (Source: Dinka [6])

2.2. Water sampling and analysis

Water samples were collected in 2015 from Lake Basaka using clean polyethylene bottles (0.5 L). The water pH, EC and temperature were measured actually at field using portable pH and EC meters (Figure 2). All water samples were collected on the same day (morning) and immediately taken to the Matahara Breeding Station Laboratory for important physico-chemical analysis: soluble cations and anions. The water sampling and analysis were done as per the APHA [15] standard test guidelines [13] (Table 1). The previous water quality condition of the lake was taken from previous studies [3, 6-8, 10-11,16, etc].

Photo by MO. Dinka, 2009

Figure 2. Water sampling and measurement of pH, EC and Temperature from Lake Basaka

Table 1. Methods adopted for water quality analysis (Source: Dinka et al. [13]).

Quality Parameter	Symbol	Method Used
pH	pH	Potentiometric (1:2.5 H_2O v/v)
Electrical Conductivity	EC	Conductometery (1:2.5 H_2O v/v)
Calcium	Ca^{2+}	EDTA titrimetric
Magnesium	Mg^{2+}	EDTA titrimetric
Sodium	Na^{+}	Flame photometric
Potassium	K^{+}	Flame photometric
Chloride	Cl^{-}	Titration
Carbonate	CO_3	Titration
Bicarbonate	HCO_3	Titration (with H_2SO_4)
Sulphate	SO_4	Spectro Photometric

3. Results and Discussion

The analytical analysis results for the considered physico-chemical parameters are presented in Table 2 (last two rows). Table 2 also presents the general historic limonology (morphology and chemistry) of Lake Basaka by different studies [3, 6-8, 10-13, 15] and this study. Based on its high salinity and alkalinity levels, the use of Lake Basaka water for irrigation and drinking purpose is impossible. It is easy to deem the potential damaging effects of such quality Lake water on soil structure, soil fertility and other soil behaviors. The excessively high Na content of Lake Basaka has a potential to destroy soil structure and aggregate stability, which can lead to reduced organic matter/carbon content and other problems. There is a tendency of Na salts to exceed above their solubility limit in lake water, which lead to precipitation of Ca salts as $CaCO_3$.

As shown in Table 2 and Figure 3 the salinity (EC) concentrations are exhibiting the reduction trends since 1960s. The reduction in EC is very dramatic until the end of 1970s. Since then, the reduction is gradual and very slow. Salinity level measured by Talling & Talling [19] was about 74.17 dS/m [6] and hence, decreased by about 12-fold (~6.15 dS/m in 2015) in the past about a half-century (1960-2015). This changing property of the lake water quality is of special interest as far as its drastic expansion is concerned. Unfortunately, its decrement in the past 30 years (since 1980s) is not significant in relation to its potential to inundate the nearby areas in the near future [6, 8].

Table 2. Physico-chemical parameters for Lake Basaka water in different periods (1961 -2015)

Year	pH	EC	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	HCO_3^{-2}	CO_3^{-2}
[a] 1961(May)	9.94	74170	17800	406	<3	<7.5	5480	4680	580	-
[b]1971		79230								
[b]1973		25000								
[b]1974		25410								
[c]1978		5620	-	-	26	5.0	-	-	-	-
[d]1991 (Mar)	9.4	7440	1810	67	2.2	0.49	450	600	46	
[e]1993 (Feb)	9.55	-	1900	20	1.0	0.40	572	540	-	-
[b]1996	9.70	6385	882	67.6	4.2	3.7	863	-	515	622
[f]2000	9.71	-	1740	64	3.15	0.70	542	494	-	-
[g]2003 (Jan)	9.54	-	2160	80	2.18	0.38	421	620	-	-
[b]2002 (Jun)	9.6	7335	2449	38	18.2	6.1	1062	1504	2177	385
[b]2003 (Apr)	9.8	7804	1831	15	8.4	12	996	1080	1932	624
[g]2006	9.7	6730	1805	63.8	3.02	1.2	571	540	-	-
[b]2007 (May)	9.57	6280	2583	61.4	7.0	1.7	927	1020	1213	350
[b]2009 (May)	9.52	6170	2579	61.8	4.5	1.1	915	986	1140	340
[h]2010 (May)	9.52	6168	2582	62.1	4.5	1.5	922	987	1174	322
[h]2015 (May)	9.51	6150	2587	62.0	4.2	1.2	937	990	1180	320

All are in units of mg L^{-1}, except EC (μS cm^{-1})
Sources: [a] Talling & Talling [16], [b]Dinka [8], [c] Halcrow [17], [d] Kebede et al. [18], [e] Gizaw [19], [f] Ayenew [11]; [g] Klemperer & Cash [12]; [h] This study
Note that the values provided for the years 2010 and 2015 are average values of measurements made at different sites of the lake. Sampling sites are from the North, West and South.

It is evident from Table 2 that Lake Basaka is experiencing a reducing trend in water quality due to the dilution effect. Interestingly, about 10-fold reduction of total ionic concentration occurred in the Lake Basaka over the period of 2 decades (1960-1980) (Table 2). The other RVLs, except Abiyata with increasing trend [18], have relatively stable quality (with no or little change) [1-2, 6]. Actually, the reduction of ionic concentrations with the increment in lake volumes was expected. The volumetric increment of Lake Basaka has resulted in reduction of ionic concentration and concomitant shift in phytoplankton community [18].

The ionic reduction in most of the ionic concentrations are not significant in recent years (post 2000) and remain almost stable. Even, some parameters (eg. Na, Ca, Mg, Cl, SO_4) are showing increment in recent years. With the incremental trends of lake volume [8-9], the ionic concentrations should have been reduced further [6]. The relatively stable or increasing ionic concentration of some parameters in the past 30 years may indicate there are chemical sources to Lake basaka by natural factors and/or anthropogenic effects. Natural factors could be weathering processes, soil erosion, sediment loading, deposition of animal and plant debris, and solution of minerals in the basin. Geologic condition of Lake Basaka catchment and its high evaporation can be another natural factor. Human activities can accelerate some of the natural factors. Tropical areas are characterized by high rainfall intensity, which can easily wash away debris, top soil and various forms of contaminants through surface runoff [20]. This indicates there are anthropogenic sources of chemicals in to Lake Basaka. As suggested by Dinka et al. [13], the local anthropogenic processes could be discharges from factory, domestic sewage and farming activities. Agricultural activities introduces ions and metals from agro-chemicals such as fertilizers, herbicides, fungicides, etc.

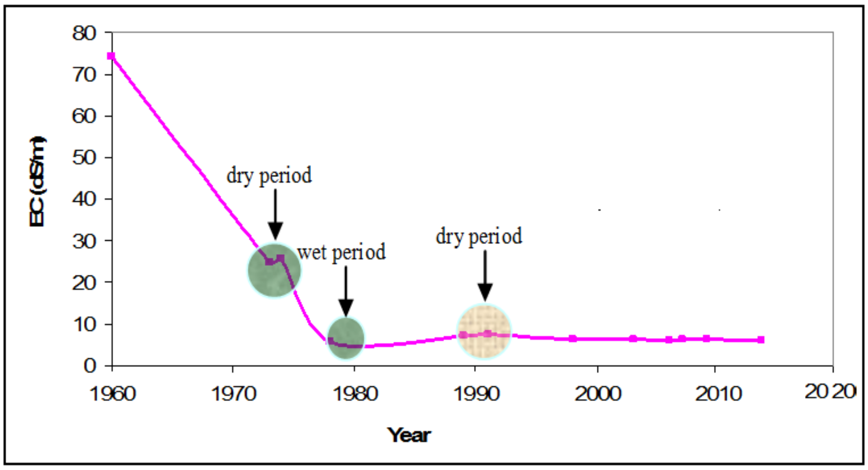

Figure 3. Temporal trend of the salinity (EC) of Lake Basak (data source: from others and this study).

The ionic ratios of ((Ca+Mg)/Na) obtained in this study is about 0.0022. Halcrow [17] reported an ionic ratio for Lake Basaka as 0.028 in 1971 (which was similar to that of hot springs) and 0.01 in 1978 [6, 21]. Hence, the ionic ratios are reduced by approximately 12-fold since 1970s. There was a sharp and fast decline in EC, Cl, SO_4, Na, and K ions from early 1960s up to the late 1980s, and then became relatively stable (Table 2). The sharp decline pre-late 1970s was probably due to the excessively high amount of drainage water discharged into the Lake from flood irrigation from Abadir farm in the period 1964-1978, which was then changed to furrow irrigation. The excess drainage discharge to the Lake was further accelerated by malfunctioning of the gate in Abadir-E side in the period between 1976 and 1978, which was then stopped based on the recommendation made by Halcrow [17].

4. Conclusion

This study result indicated that the use of Lake Basaka for irrigation and drinking purpose is hardly possible. The lake water is saline, alkaline and sodic. It is easy to deem the potential damaging effects of such quality lake water on water resources and soil quality of the region groundwater quality, soil structure, soil fertility and other soil behaviours. The regimes of soil moisture, soil structure and groundwater quality could be affected, concurrently affecting the productivity and sustainability of the nearby sugar estate. The excessively high Na content of Lake Basaka has a potential to destroy soil structure and aggregate stability, which can lead to reduced organic matter/carbon content and other problems. There is a tendency of Na salts to exceed above their solubility limit in lake water, which lead to precipitation of Ca salts as $CaCO_3$. Further, the predominance of Na, K, Cl and HCO_3 in Lake Basaka indicates the recharging water from limestone, sandstone and sand aquifers.

The study result further indicated that Lake Basaka has experienced a reducing trend in ionic concentration in the past about 5 decades due to dilution effect. About 10-fold reduction of total ionic concentration occurred in the period of 2 decades (1960-1980). However, some parameters (eg. Na, Ca, Mg, Cl, SO_4) are showing increment in recent years. The relatively stable or increasing ionic concentration of some parameters in the past 30 years may indicate the potential causes of pollution due to natural and anthropogenic sources. This indicates that there are natural and anthropogenic sources of chemicals in to Lake Basaka. Natural sources could be weathering of rocks, soil erosion, sediment loading, deposition of animal and plant debris, and solution of minerals in the basin, etc. The local anthropogenic processes could be discharges from factory, domestic sewage, and farming activities which introduce ions and metals from agro-chemicals (fertilizers, herbicides, fungicides, etc).

Finally, the author would like to suggest a further detailed study on the potential sources of water and chemicals to Lake Basaka. Identification of the potential sources of water and chemicals plays a great role for understanding the hydrochemical facis and evolution of the lake water, and hence significantly contribute for the sustainable lake water management program in order to limit the further expansion of the lake and its potential damaging effects on the region.

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