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, SO₄, Na, and K ions from early 1960s up to the late 1980s, and then became relatively stable. Some ions (eg. Na, Ca, Mg, Cl, SO₄) 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 km² in 1960s to about 48.5 km² 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 plantation. 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 limnology (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, endorheic 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 km². 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 plateaus, 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, Fluvisol, 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](image)

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

| Quality Parameter     | Symbol | Method Used                      |
|-----------------------|--------|----------------------------------|
| pH                    | pH     | Potentiometric (1:2.5 H₂O v/v)   |
| Electrical Conductivity| EC     | Conductometry (1:2.5 H₂O v/v)    |
| Calcium               | Ca²⁺   | EDTA titrimetric                 |
| Magnesium             | Mg²⁺   | EDTA titrimetric                 |
| Sodium                | Na⁺    | Flame photometric                |
| Potassium             | K⁺     | Flame photometric                |
| Chloride              | Cl⁻    | Titration                        |
| Carbonate             | CO₃⁻   | Titration                        |
| Bicarbonate           | HCO₃⁻  | Titration (with H₂SO₄)           |
| Sulphate              | SO₄²⁻  | Spectro Photometric              |

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

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 CaCO₃.

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].
The ionic reduction in most of the ionic concentrations are not significant in recent years (post 2000) and remain almost stable. Even, some parameters (e.g. Na, Ca, Mg, Cl, SO₄) are showing the reduction of ionic concentrations with the increment in lake volumes was expected. The shift in phytoplankton community with increasing trend of lake volume should have been reduced further through surface runoff, rainfall intensity, which can easily wash away debris, top soil and various forms of contaminants. Geologic condition of Lake Basaka catchment and its high evaporation can be another natural factor. Sediment loading, deposition of animal and plant debris, and solution of minerals in the basin. Sources from agro-chemicals such as fertilizers, herbicides, fungicides, etc.

| Year       | pH    | EC   | Na⁺  | K⁺  | Ca²⁺ | Mg²⁺ | Cl⁻  | SO₄²⁻ | HCO₃²⁻ | CO₃²⁻ |
|------------|-------|------|------|-----|------|------|------|-------|--------|-------|
| 1961(May)  | 9.94  | 7417 | 17800| 406 | <3   | <7.5 | 5480 | 4680  | 580    | -     |
| 1971       | 7.923 | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0      | 0     |
| 1973       | 2500  | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0      | 0     |
| 1974       | 2541  | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0      | 0     |
| 1978       | 2541  | 0    | 0    | 0    | 0    | 0    | 0    | 0     | 0      | 0     |
| 1991(Mar)  | 9.4   | 7440 | 18100| 67   | 2.2  | 0.49 | 450  | 600   | 46     | -     |
| 1993(Feb)  | 9.55  | -    | 1900 | 20   | 1.0  | 0.40 | 572  | 540   | -      | -     |
| 1996       | 9.70  | 6385 | 882  | 67.6 | 4.2  | 3.7  | 863  | -     | 515    | 622   |
| 2000       | 9.71  | -    | 1740 | 64   | 3.15 | 0.70 | 542  | 494   | -      | -     |
| 2003(Jan)  | 9.54  | -    | 2160 | 80   | 2.18 | 0.38 | 421  | 620   | -      | -     |
| 2002(Jun)  | 9.6   | 7335 | 2449 | 38   | 18.2 | 6.1  | 1062 | 1504  | 2177   | 385   |
| 2003(Apr)  | 9.8   | 7804 | 1831 | 15   | 8.4  | 12   | 996  | 1080  | 1932   | 624   |
| 2006       | 9.7   | 6730 | 1805 | 63.8 | 3.02 | 1.2  | 571  | 540   | -      | -     |
| 2007(May)  | 9.57  | 6280 | 2583 | 61.4 | 7.0  | 1.7  | 927  | 1020  | 1213   | 350   |
| 2009(May)  | 9.52  | 6170 | 2579 | 61.8 | 4.5  | 1.1  | 915  | 986   | 1140   | 340   |
| 2010(May)  | 9.52  | 6168 | 2582 | 62.1 | 4.5  | 1.5  | 922  | 987   | 1174   | 322   |
| 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], c 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 Abiyat, 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 (e.g. Na, Ca, Mg, Cl, SO₄) 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 introduce ions and metals from agro-chemicals such as fertilizers, herbicides, fungicides, etc.
The ionic ratios of \((\text{Ca} + \text{Mg})/\text{Na}\) 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 sustainabiltiy 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.

References

[1] Ayenew T 2004 Environmental implications of changes in the levels of lakes in the Ethiopian rift since 1970 Regional Environ. Change 4 pp 192–204.

[2] Alemayehu T, Ayenew T and Kebede S 2006 Hydrogeochemical and lake level changes in the Ethiopian Rift J. Hydrology 316 (1-4) pp 290-300.

[3] Belay E A 2009 Growing Lake with Growing Problems: Integrated Hydrological Investigation on Lake Basaka, Ethiopia. PhD Dissertation, online publication. Available form URL: http://hss.ub.uni-bonn.de/diss_online. Accessed 15 January 2010.

[4] Goerner A, Jolie E and Gloaguen R 2009 Non-climatic growth of the saline Lake Beseka, Main Ethiopian Rift J. Arid Environ. 73 pp 287–95.

[5] Dinka M O, Loiskandl W and Furst J 2009 The expansion of highly saline Basaka Lake and its effects on the sustainability of Matahara Sugar Estate. Proceedings of the 34th–WEDC International Conference Referreeed Paper (296), pp 571–9, Addis Ababa, Ethiopia.

[6] Dinka M O 2010 Analyzing the extents of Basaka Lake Expansion and Soil and Water Quality Status of Matahara Irrigation Scheme, Awash Basin (Ethiopia) PhD Thesis submitted to BOKU University (Vienna) Austria.

[7] Dinka M O 2012a Analysing decadal land use/cover dynamics of the Lake Basaka catchment (Main Ethiopian Rift) using LANDSAT imagery and GIS Lake Reserv. Res. Manag. 17 pp 11-24.

[8] Dinka M O 2012b Analysing the extents (size and shape) of Lake Basaka Expansion (Main Ethiopian Rift Valley) using Remote Sensing and GIS Lake Reserv. Res. Manag. 17 pp 131-141.

[9] Dinka M O, Loiskandl W, Ndambuki J M 2014 Hydrochemical modelling for Lake Basaka: development and application of a conceptual water budget model Environ. Monit. Assess. 186 pp 5365–5379.

[10] Baxter R M 2002 Lake morphology and chemistry. In: Tudoranacea, C. and Taylor, W.D. (Eds). Ethiopia Rift Valley Lakes. Backhuys, Leiden pp 45-60.

[11] Ayenew T 2007 Water management problems in the Ethiopian rift: Challenges for development. Afr. J. Earth Sci. 48 pp 222–36.

[12] Klemperer S L and Cash M D 2007 Temporal geochemical variation in Ethiopian Lakes Shala, Arenguarda, Awasa, and Beseka: possible environmental impacts from underwater and borehole detonations J. African Earth Sci. 48 pp 174–98.

[13] Dinka M O, Loiskandl W, Ndambuki J M 2015 Hydrochemical characterization of various surface water and groundwater resources available in Matahara areas, Fantalle Woreda of Oromiya Region Journal of Hydrology: Regional Studies 3 pp 444-456.

[14] Dinka, M O 2016. Quality Composition and Irrigation Suitability of Various Surface Water and Groundwater Sources at Matahara Plain Water Resources 43 (4) pp 677–689.

[15] APHA 2005 Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WPCF, 21st Centennial Edition, Washington DC.

[16] Talling J F and Talling I B 1965 The chemical composition of African lake waters Int. revue. ges. Hydrobiol 50 pp 421 – 463.

[17] Halcrow W 1978 The study of Beseka Lake Levels. Report for the Government of Ethiopia. Awash Valley Development Agency, Addis Ababa. p 83.

[18] Kebede E, Gebramariam Z and Ahlgren A 1994 The Ethiopian rift valley lakes. Chemical characteristics along a salinity-alkalinity series Hydrobiologia 288 pp 1–2.

[19] Gizaw B 1996 The origin of high carbonate and fluoride concentrations in waters of the MER Valley, East African Rift system Journal of African Earth Science 22 (4) pp 391 – 402.

[20] Yilla P T 2009 Linking land use to stream pollutant dynamics and management implications. PhD Thesis submitted to Vienna University of Technology, Austria.
[21] MoWR (Ministry of Water Resources) 1998 Lake Basaka Study and Design Project. Inception Report, Federal Democratic Republic of Ethiopia, MoWR, Addis Ababa.