

## **Review Article**

# **Overview to Potential Sources, Soil Salinization and Expansion Level of Lake Basaka, Central Rift Valley Region of Ethiopia**

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### **To cite this article:**

Melaku Tafese Awulachew. Overview to Potential Sources, Soil Salinization and Expansion Level of Lake Basaka, Central Rift Valley Region of Ethiopia. *Journal of Water Resources and Ocean Science*. Vol. 9, No. 4, 2020, pp. 71-76. doi: 10.11648/j.wros.20200904.11

**Received:** May 13, 2020; **Accepted:** June 12, 2020; **Published:** September 8, 2020

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**Abstract:** The aim of this overview is extended to indicate the Potential Sources, Soil salinization and expansion level of lake Basaka. 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. Lake Basaka is found to be expanding at an alarming rate. This overview indicates the expansion area/level/ of the lake is challenging the socio-economics and environment of the region significantly. With this point of view the lake's expansion is due to the agricultural sugarcane farm land use type near Beseka Lake and mostly due to the increased ground water flux to the lake. The potential sources or ground water flux to the lake could be an increase of ground water recharge following the establishment of irrigation schemes in the region, subsurface inflow from far away due to rift system influence, and Lake Neotectonism. The significant expansion of Lake Basaka during the past 35 years started after the introduction of Matahara sugar state. The expansion is affecting both the ground water 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 Northeast direction due to the topography of the area. This has the potential to displace Matahara town and impact the sugar Plantation during the next two-three decades 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. Generally, the lake's has poor water quality and its expansion rate damaging effect to the region, and mitigation measures are very important for sustainable lake management.

**Keywords:** Lake Basaka, Potential Source, Expansion Area, Soil Salinization, Ground Water Flux

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## **1. Introduction**

A lake is a large body of water, usually fresh water, which is land locked and commonly formed when natural depressions or basins in the land surface become filled with water over time or inland bodies of water that has no direct exchange with ocean and may contain fresh or saline water with varies depth.

Most of the closed-basin type Main Ethiopian Rift Valley lakes are experiencing water level and salinity fluctuations [1–5], mostly shrinkages in size. Lake Basaka is found to be unique compared to the terminal lakes within the Main Ethiopian Rift Valley region due to the fact that the water is

expanding at a very fast rate and is not usable for irrigation or drinking purposes [2, 3]. Before the establishment of the Matahara Sugar Estate (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 which are discharging their irrigation excess directly into the lake [6, 7]. 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.

This document is prepared to oversee the trends of the expansion of the lake and predict Possible future expansion.

## 2. Material and Methods

This article was formulated through literature searches using Science direct. The following keywords were used: "Lake Basaka; Potential source; expansion area, Soil salinization and Ground water flux".

The section presents a detailed description of the lake's Soil salinization, Expansion rate, Lake water-ground water interaction, Catchment description of Lake basaka, water quality which is very important for future use.

### 2.1. Soil Salinization

The rise of salinity level may decrease the water availability to crops and may destruct the soil structure & aggregates [8, 9]. 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 [10].

### 2.2. Expansion Rate / Surface Area Cover of Lake Basaka

The surface area of the lake increased from 2.7 km<sup>2</sup> in 1957 to more than 50 km<sup>2</sup> in 2015 [5]. The fluctuation of the lake's water is in response to the changes in the surface-and sub-surface components of the lake's water balance. The expansion extent and hydrochemical characteristics of the lake have been well documented by different researchers [11–15].

The expansion of Lake Basaka, owing to its poor water quality, is threatening the socio-economics and environment of the region significantly [5]. The lake's expansion is affecting the irrigation development, pastoralism, infrastructure, and the ecosystem of the region. A study made by Dinka [2, 5] clearly indicated that the expansion of the lake is affecting the regimes of soil and water quality of Matahara Sugar Estate (MSE) and challenging the sustainability of production and productivity significantly. The sugar estate also lost more than 300ha of productive lands due to inundation by lake and salt encroachment [1, 5]. The lake's expansion is also threatening the existence of nearby towns (Matahara and Fantalle) and the sustainability of downstream irrigation developments within the Awash River basin. The lake also inundated the major railway (Addis

Ababa-DireDawa-Djibouti) and highway (Addis Ababa-DireDawa/Harar) lines and caused the reconstruction of new railways and highway lines with a huge investment [2, 3]. The lake has inundated significant grazing lands and hence seriously threatened the existence of the Karayyuu (indigenous) pastoralists. Thus the lake's expansion has created an unstable transitional zone between the wetland and the nearby terrestrial ecosystem; hence she described it as a natural disaster for the ecosystem of the region.

### 2.3. Lake Water-Ground Water Interaction

As a permanent and expanding lake, the interaction of Lake Basaka with the surrounding (surface, atmospheric, and subsurface) water systems is highly expected. Permanent lakes usually interact with the surrounding ground water (GW) system in three main ways [16]: some receive GW inflows, some have seepage loss to the GW, and others receive from and lose to the GW system [4]. The amount of GW contribution in different hydrologic years (1970 up to 2010) using a conceptual water balance model quantified [2, 4]. Based on their finding, GW flux is responsible for the existence and expansion of the lake in recent times. However, the possible sources/causes for GW flux to the lake are not fully identified yet, except for views and suggestions.

### 2.4. Lake Basaka Catchment Description

This section presents a detailed description of the lake's catchment, including its physical characteristics, climate, soils, vegetation, hydrology, geology, and rift structure.

#### 2.4.1. Physical Characteristics

Lake Basaka is a volcanically dammed, endorheic lake located in the Middle Awash River Basin of Ethiopia, in the northern part of the Main Ethiopian Rift Valley, at a close distance to the Afar triangle [1, 2]. It has variable depth, ranging from 1.5 to 13 m (2015 estimate). The deepest part of the lake is located in the north-central part, which is the original lake location, before it started expanding. Then, the lake water expanded to the other areas when the equilibrium of the lake's water balance (i.e., hydrologic cycle) was disturbed by a net influx of water to the lake [1]. The total surface water catchment of the lake is about 500 km<sup>2</sup>, and it receives an annual rainfall of approximately 0.28 billion m<sup>3</sup> (2015 estimate). The lake catchment has variable altitude, ranging from very flat areas (950 m a.s.l.) to undulating plains (1100 m), hills (1500 m) to high mountains (1900 m). The highest altitude (1940) is located at Fantalle Crater, a volcanic mountain located in the northern part of the lake and believed to be created by the recent volcano that occurred in the region at the end of the Eighteenth Century [2]. Topographically, the lake water is located at the lowest elevation, where all the incoming surface runoff and sediment from its catchment are accumulated [2]. That means the sediment trapping efficiency of the lake is 100%.

#### 2.4.2. Climate

The Matahara plain area, including Lake Basaka, has the

characteristics of a semi-arid climate with a bimodal and erratic rainfall distribution pattern [2, 3]. The main rainy season occurs from July to September and accounts for about 70% of the total rainfall of the area. The minor rain season, which accounts for about 30% of the total rainfall, occurs occasionally from February/March to April. The occurrence of occasional minor rainfall in March/April is related to the effect of the Inter Tropical Convergence Zone (ITCZ) or monsoon winds on the Ethiopian climate. The long years' average (1966 to 2015) mean annual rainfall and the temperature of the area are 541.7 mm and 26.3°C, respectively. The average annual pan evaporation and sunshine hours of the area are about 2518 mm and 8.25 h, respectively. The relative humidity of the area is in the range of 29.3% to 82.4%.

#### **2.4.3. Major Soils Types and Vegetation Cover**

The major soil types are Cambisols, Fluvisols, Luvisols, Lepthosols, Podzoluvisols, Solonchak, and mountain soils. Almost half of the soil in the area is covered by Lepthosols and Cambisols. Lepthosols, the predominant soil type in the catchment (33%), are characterised by shallow soil with a weakly developed, coarse textured soil structure, occupying the western part of the catchment and mainly covered by open bushy woodlands. Cambisols are well-drained, deep, and medium-to coarse-textured soils, mainly occupying the northern part of the catchment (west part of the lake) and are mainly covered by open grass and bush lands. Podzoluvisols are well-drained, very deep, medium to coarse textured soils with moderately developed structures, mainly found in the south-eastern part of the catchment. The solon chak soils are poorly drained, deep, have a weak to moderately developed structure, are mainly found along the eastern edge of the lake, and are characterised by salt crust at the surface [1].

Luvisols are soil units mostly occupied by the Abadir farm (south of the lake) and the Nura-Erafarm (south-west of the lake). Then or the part of the lake is covered by basaltic (AA type) lava flow soils, characterized by inverted properties. Most of this lava flow area is currently inundated by the lake.

#### **2.4.4. Hydrogeology and Rift Structure**

As indicated by the United Nations' hydrogeological map of Africa [17], the hydrogeology of the volcanic rocks covering the Great East African Rift Valley (GEARV) region is classified as "the most complex and least understood" [40]. Very few hydrogeological studies [4, 18-21] have been carried out in the Lake Basaka area [6] and the surrounding regions. The lake catchment is located in the active part of the MERV, a geologically unstable area. The MERV is characterized by active volcanic activities and structural deformations, especially along the NNE-SSW belts [22, 23].

The volcano-tectonic belts were formed during the quaternary period by young faults, fractures and volcanic centers on the rift floor [1, 23]. The Lake Basaka catchment aquifers are part of the Fantalle volcano-complex and are mainly alluvial/lacustrine sediments, ignimbrites, and basalts [18]. The Fantalle volcano complex consists of two caldera volcanoes (the older and younger Fantalle) [1]. A substantial portion of the south-western part of the lake's catchment is

covered by undifferentiated lava flow of trachytic to rhyolitic composition with minor ignimbrite intercalations. The area is situated on the axial position of the rift floor in the northern part of the Main Ethiopian Rift Valley, at the junction between the Ethiopian Rift and the Afar triangle. Thus, the region is located at the junction of several faults systems (the NNE, EW, and NS faults) of the Afar depression [18]. Its location within active magmatic segments makes it susceptible to intense volcanic and related tectonic activities.

Furthermore, its position within latitudes at which the EW trending volcano-tectonic structure of the YTVL (Yerer Tullul Wellel Volcano-Tectonic lineament) intersects with the NNE trending fault system of the MERV makes the area an important structural feature [1, 18]. The area was under intensive volcano-tectonic activities during the quaternary period, characterized by several common features of past and recent volcanos and calderas [17]. This is evident from the observation of vast lava extrusions at the foot of the slope of mountain Fantalle, dots of extensive scoriceous hills in the locality [21], lava flows in the northern part of the lake [22], and the availability of a number of hot springs supplying the lake.

#### **2.5. Potential Sources**

GW flux is the main component responsible for the hydrodynamics and existence of Lake Basaka and, hence, responsible for its expansion. As mentioned earlier, the root cause/source of the increment of the GW flux into the lake is not fully identified. Thus, from a water balance study, that the GW flow in the rift is controlled by geologic structures, either via flows in the tensional faults or through fluvial and lacustrine deposits, the occurrence of which is influenced by tectonism.

In addition to lake neotectonism, the author of this study also supports there charge from upstream irrigation schemes (MSE, Nura-Era, and Fantalle) as the cause for the increment of GW flux. The water balance study made by Dinka [2] indicates the existence of an interaction between the lake and groundwater system of the area. MSE has been using an uncontrolled furrow irrigation system for many years (since 1969). Water is also stored in Night Storage Reservoirs (NSR), which are unlined and filled with siltation. The irrigation and drainage canals are also not lined. Hence, significant seepage loss is expected from the NSR and the irrigation and drainage canals. In general, irrigation and drainage water management at MSE is very poor [2, 24]. The infield water application performance evaluation made by Dilsebo [25] showed that the actual field application efficiency is in the range of 12% to 70%. He emphasized the possibility of achieving an application efficiency of about 75% with better water management. Similarly, even the worst irrigation water management is expected in the other irrigation schemes in the region, i.e., Nura-Era and Fantalle. However, it is difficult to conclude that the Fantalle project has significant sub-surface contribution to the lake since the project was under a developmental stage until 2010 and the significant GW flux to the lake started before that time. The effect of the

Fantalle irrigation project has to be justified or verified scientifically and requires due attention.

In addition to the above possible reasons, there are also speculations about the subsurface flow of water from very far distances (like Red Sea) due to rift system influences. Changes are happening within the MER in particular and GEARV in general. The hydrochemical source identification made by Dinka [15] also justifies the above argument. The study concluded that these waters have a chemical composition almost similar to that of seawater, stayed for a very long period of time in the hydrologic cycle, and originated in areas very far distances away. The author of this study would like to suggest the possibility that the seawater is preparing its way underground. The Red Sea is believed to be dividing the African continent into two sub-plates: the Nubian sub-plate and the Somalian/Arabian sub-plate [1, 2]. Based on a visit to the Danakil Depression area in 2005, one online reporter for a German website [25] indicated that the Afar Triangle (where the three sub-plates meet) is moving apart at a staggering speed, more rapidly than the expected geologic time-scale, preparing its way for the red-sea to flow through the rift valley and create an ocean, forcing Africa to lose its horn. The other very interesting information related to the above suggestion is the very shallow groundwater condition in the Matahara plain area, including the Matahara sugarcane planation. The groundwater of the area is very shallow, in the range of 0.5 to 2 m below ground level [4], and its chemical characteristics are more similar to those of the hots springs and Lake Basaka than that of the Awash River [15]. However, the effect of the Red Sea on Lake Basaka and the Matahara region is not scientifically proven and requires due attention.

### 3. Discussion

#### 3.1. Surface Area (Size) and Shape of the Lake

The significant surface areal expansion of the lake was observed in the period between 1973 to 1986 (about 21 km<sup>2</sup>) 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<sup>2</sup>), 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 [6].*

Year	Area (km <sup>2</sup> )	Incremental area (km <sup>2</sup> )	Cum. incremental area (km <sup>2</sup> /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

#### 3.2. Soil Salinization

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.

#### 3.3. Mean Water Quality

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. The summary of the mean water quality for the different water sources are presented as in Table 2.

*Table 2. Mean values for some of the water quality parameters for different water types [26].*

Type of water	PH	EC	Na+	Ca2+	HCO32-	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 (-).

#### 3.4. Water Balance, Ground Water Flux and the Interaction of the Lake

The water balance analysis result indicated that the major fluxes (E, P, Gnet) are showing an increasing annual and decadal trend as a function of the continuous increment of the

lake level and surface area. Lake E and Gnet are the major lake fluxes accounting for (post-2000s) about 93% and 56% of the outflow and inflow components of the lake's water balance, respectively. Hence, GW is mostly responsible for the existence and fluctuation of the lake. The GW flux showed a continuous annual and decadal increment to compensate for the E flux in different time periods. It showed significant inter-decadal

increment from 0.05 m<sup>3</sup>/s (16%) in the 1960s to about 1.6 m<sup>3</sup>/s (56%) in the 2000s. The trend of GW flux is not the same in different periods. The significant increase of GW flux was observed after the mid-1990s, which coincides with the period of significant lake level rise in the area. The increment of net GW flux by 10-fold from the 1960s (0.05 m<sup>3</sup>/s) to the 1970s (0.48 m<sup>3</sup>/s) indicates the possibility of subsurface sources other than the hot springs contributing to the lake.

The likely causes of the increase of GW flux to the lake could be due to one or a combination of the following reasons:

An increase of GW recharge from irrigation schemes (Matahara Sugar Estate, Nura-Era Farm, Fantalle Irrigation Project), which is facilitated by the presence of active terminal faults and the unstable geologic condition of the area;

Lake neotectonism (earth quakes and volcanic eruption), which is continuously affecting the geologic structure and geological setting of rift systems;

Subsurface flow from a nearby surface catchment located on the western side of the lake; and/or

Rift system influence on GEARV.

According to this study, the contribution from the nearby catchment is the main source/cause of GW flux, followed by the recharge from the nearby irrigation schemes. The suggestion related to the moving apart of the great EARV as a preparation for the Red Sea to location. This suggestion is not scientifically proven and, hence, requires due attention.

## 4. Conclusion

The majority of the Ethiopian lake were fluctuating in their level (spatial extent) due to different reasons. Lake Beseka was one top raising lake in Central Rift Valley Region of Ethiopia. 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 two to three decades 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. With this approach an integrated and independent investigation is highly recommended, which requires a multi-disciplinary approach comprised of geologists, hydrologists, hydro geologists, meteorologists, soil scientists, soil and water conservationists, etc. Thus, Management measures for a sustainable lake management strategy, which will be facilitated by the morphometric analysis and aquifer characterization suggested under actions. Accordingly, any of the combination of the following measures are recommended: the diversion of surface runoff to the Awash River, pumping out water accumulated at the pour point of watershed located on the western side of the lake catchment, devising a means to increase the lake's evaporation, mixing the lake water with the Awash River with proper treatment, desalinating the lake water and

using it for different purposes (irrigation, domestic, industry, energy production), and/or improving the vegetation cover of the lake catchment.

## Abbreviations

Great East African Rift Valley; GEARV, Main Ethiopian Rift Valley; MERV, Yerer Tullul Wellel Volcano-Tectonic lineament; YTVL, Matahara Sugar Estate; MSE; Ground water; GW.

## Conflicts of Interest

The authors declare no conflict of interest.

## References

- [1] Belay, A. E. Growing Lake with Growing Problems: Integrated Hydrogeological Investigation non LakeBeseka, Ethiopia. Ph. D. Thesis, Universit  t Bonn, Bonn, Germany, 2009.
- [2] Dinka, M. O. Analyzing the Extents of Basaka Lake Expansion and Soil and Water Quality Status of Matahara Irrigation Scheme, Awash Basin (Ethiopia). Ph. D. Thesis, BOKU University, Vienna, Austria, May 2010.
- [3] Dinka, M. O. Analysing the extents (size and shape) of Lake Basaka Expansion (Main Ethiopian Rift Valley) using Remote Sensing and GIS. Lake Reserv. Res. Manag. 2012, 17, 131–141.
- [4] Dinka, M. O.; Loiskandl, W.; Ndambuki, J. M. Hydrochemical modelling for Lake Basaka: Development and application of a conceptual water budget model. Environ. Monit. Assess. 2014, 186, 5365–5379.
- [5] Dinka, M. O. Lake Basaka Expansion: Challenges for the Sustainability of the Matahara Irrigation Scheme, Awash River Basin (Ethiopia). Irrig. Drain. 2017.
- [6] Gulilat Abebe (2000) Feasibility study on the proposed remedial measures of the Lake Beseka level rise. MSc Thesis submitted to the Graduate School of Alemaya University, Ethiopia.
- [7] Eyasu Elia,(2008) Pastoralists in Southern Ethiopia: Dispossession, access to resources and dialogue with policy makers. DCG Report No. 53.
- [8] Warrence, Nikos, J., Pearson, Krista, E., Bauder, James, W. (2003) The Basics of Salinity and Sodicity Effects on Soil Physical Properties.
- [9] Hanson, B., S. R. Grattan and A. Fulton (1999) "Agricultural Salinity and Drainage." University of California Irrigation Program. University of California, Davis. <http://glovis.usgs.gov>.
- [10] Kahlownd, M. A., Ashraf, M., Haq, Z. (2005) Effect of shallow groundwater table on crop water requirements and crop yields. Agricultural Water Management. 76, 24–35.
- [11] Klemperer, S. L.; Cash, M. D. Temporal geochemical variation in Ethiopian Lakes Shala, Arenguade, Awasa, and Beseka: Possible environmental impacts from underwater and borehole detonations. J. Afr. Earth Sci. 2007, 48, 174–198.

- [12] Goerner, A.; Jolie, E.; Gloaguen, R. Non-climatic growth of the saline Lake Beseka, Main Ethiopian Rift. *J. Arid Environ.* 2009, 73, 287–295.
- [13] Zemed agegnehu, E.; Travi, Y.; Aggarwal, P. Application of environmental isotopes to determine the cause of rising water levels in Lake Beseka, Ethiopia. In *Isotope Techniques in Water Resources, Development and Management, Proceedings of the International Symposium on Isotope Techniques in Water Resources Development and Management, Vienna, Austria, 10–14 May 1999*; International Atomic Energy Agency: Vienna, Austria, 1999.
- [14] Dinka, M. O. Delineate the Hydrochemical Composition and Origin of Various Surface Water and Groundwater Resources in Matahara Area (Ethiopia). *Inland Waters* 2017, in print.
- [15] Winter, T. C.; Harvey, J. W.; Franke, O. L.; Alley, W. M. *Groundwater and Surface Water a Single Resource*; US Geological Survey Circular 1139; DIANE Publishing Inc.: Denver, CO, USA, 1998; p. 87.
- [16] The United Nations Educational, Scientific and Cultural Organization (UNESCO). *Groundwater Resources of the World: Transboundary Aquifer Systems 1: 50,000,000 Scale*; UNESCO: Paris, France, 2006.
- [17] Kebede, S.; Travi, Y.; Asrat, A.; Alemayehu, T.; Ayenew, T.; Tessema, Z. Groundwater origin & flow along selected transects in Ethiopian rift volcanic aquifers. *J. Hydrol.* 2008, 6, 55–73.
- [18] Tessema, Z. *Hydrochemical and Water Balance Approach in the Study of High Water Level Rise of Lake Beseka*. Master's Thesis, University of Birmingham, Birmingham, UK, 1998.
- [19] WWDCE (Water Works and Construction Enterprise). *Study of Lake Beseka (Main Report 1)*; MoWR: Addis Ababa, Ethiopia, 1999; p. 203.
- [20] Mohr, P. A. *The Geology of Ethiopia*; University College of Addis Ababa: Addis Ababa, Ethiopia, 1971.
- [21] Mohr, P. A. Major volcano–tectonic lineament in the Ethiopian rift system. *Nature* 1967, 213, 664–665.
- [22] Mohr, P. A. Patterns of faulting in the Ethiopian rift valley. *Tectonophysics* 1987, 143, 169–179.
- [23] Gizaw, B. The origin of high carbonate and fluoride concentrations in waters of the MER Valley, East African Rift system. *J. Afr. Earth Sci.* 1996, 22, 391–402.
- [24] Dilsebo, H. *Evaluating the Infield Water Application Performance of Furrow Irrigation System at Matahara Sugar Estate*; Research Report submitted to Research and Training Services of the Ethiopian Sugar Industry Support Center; Ethiopian Sugar Industry Support Center: Addis Ababa, Ethiopia, 2004.
- [25] Bojanowski, A. *Africa's New Ocean—A Continent Splits Apart*. Online Report on the Website. Available online: <http://www.spiegel.de/international/spiegel/africa-s-new-ocean-a-continentsplitsapart-a-405947.html> (accessed on 20 July 2010).
- [26] Olumana, Loiskandl & Fürst. Effect of Lake Basaka expansion on the sustainability of Matahara SE in the Awash river basin, Ethiopia. *Water, sanitation and hygiene: sustainable development and multi sectoral approaches*. 34th WEDC International Conference, Addis Ababa, Ethiopia, 2009.