EJRH-D-14-00015: HYDROCHEMICAL CHARACTERIZATION OF VARIOUS SURFACE WATER AND GROUNDWATER RESOURCES AVAILABLE IN MATAHARA AREAS, FANTALLE WOREDA OF OROMIYA REGION

Megersa Olumana Dinka[1]*, Willibald Loiskandl[2] and Julius Musyoka Ndambuki[3]

[1] Department of Civil Engineering Sciences, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
[2]Dep't of Water, Atmosphere and Environment, University of Natural Resources and Applied Life Sciences, Vienna, Austria.
[3] Department of Civil Engineering, Faculty of Engineering and the Built Environment, Tshwanne University of Technology Main Campus, Pretoria, Republic of South Africa.

Abstract

Study Region

The Matahara region is located in the East Showa zone of Oromiya regional state (Ethiopia). Matahra Sugar Estate and Lake Basaka (highly saline, alkaline and sodic lake) are situated within the flat plains of Matahara region. The area is vulnerable to the occurrences of various tectonic and volcanic activities due to its location in the upper most part of the Main Ethiopian Rift Valley region.

Study Focus

In this study, the hydrochemical properties of different surface water and groundwater bodies available at Matahara region have been characterized for quality compositions. Water samples were collected from differ4ent water sources and analyzed for important major quality parameters (pH, EC, cations and anions) following standard test procedures. Other chemical indices were derived from the measured quality parameters. The potential sources of minerals were suggested for each of the considered water sources based on their quality characteristics.

New Hydrological Insights for the region

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*Main/Corresponding author Email: magarsol@yahoo.com or mdinka@uj.ac.za

Overall, the study result elucidates that the chemical composition of different water bodies are due to natural processes and/or anthropogenic activities within the region. The local anthropogenic processes could be discharges from factory, domestic sewage and farming activities. Some of the water types are found to have relatively higher concentration of dissolved constituents. Irrigation waters have almost equal chemical compositions, indicating their hydrochemical sources are almost the same. Most of the concentrations are relatively high in Lake Basaka, groundwater and hot springs. It is easy to imagine the potential damaging effects of such quality waters on crop production, soil properties and environment of the region.

Key words: chemical composition, chemical indices, Lake Basaka, Matahara, natural processes

1. Introduction

Sustainable social and economic developments are largely dependent on water resources. However, securing water (quality and quantity) to satisfy the needs of humans and ecosystems is one of the primary issues challenging the 21st century (Amangabara and Ejenma, 2012). Compounding the problem is the fact that water quality is one of the most sensitive issues worldwide, potentially influenced by many natural and anthropogenic factors. These include (Freeze and Cherry, 1979): source of water, the degree of its evaporation, types of rock and mineral it has encountered (i.e., geology and mineralogy of the watershed), geological processes within the aquifer, velocity and direction of water movement and the time it has been in contact with reactive minerals. It is also affected by external pollution agencies such as effluents from agricultural return flow, industrial and domestic activities (Srinivasamoorthy et al., 2012).

The assessment of water quality has become an important part of water resource studies, planning and management. It is gaining significant importance due to intense urbanization, industrialization and agricultural activities that are increasing the risk of contamination of soil and water (Tiwari, 2011).

Water quality monitoring is important for the protection of public health (*drinking or domestic use*), agriculture, industry, fishing, recreation, tourism and protection of aquatic ecosystems. The knowledge of the water quality status as well as the processes affecting water quality is vital for Integrated Water Resource Management (IWRM) activities within the catchment.

The development of large scale irrigation schemes within Middle Awash Basin of (Ethiopia) in the 1960s coupled with the construction of major highway and railway lines has brought a rapid industrialization and urbanization to the region. These developmental activities, coupled with the expansion of the highly saline and alkaline Lake Basaka (Dinka, 2010, 2012) have increased the risk of contamination of the soils and waters of the area. The area of Lake Basaka increased from about 3 km^2 in 1960 to about 48.5 km^2 in 2010 (Dinka, 2012). The expansion of the lake with such poor quality at a very fast rate in the past five decades is a serious developmental (social, economic and environmental) challenge for the region.

The various developmental activities in Matahara region were generating a variety of effluents and waste products, hence, adding pollutant loads to water resources and environment of the region for an extended period of time. For instance, Matahara Sugar Estate (MSE), one of the important large scale irrigation schemes in the region, is currently affected by various problems associated with environmental degradations (Dinka, 2010). Waterlogging and salinization are threatening the sustainable production and productivity of the sugar estate. Moreover, the sugar estate has been using various agro-chemicals for long period of time. The area is characterized by shallow groundwater, and therefore, groundwater recharge from irrigation and/or rainfall is relatively rapid. This condition facilitates the downward mobility (leaching) of agro-chemicals (herbicides, pesticides, inorganic fertilizers and organic compounds) into the shallow groundwater table and contaminating them quickly.

Due to the changing hydrological conditions and anthropogenic activities in the region in particular and Rift Valley region in general, the hydrochemistry of different water sources, specially groundwater, hot springs and Lake Basaka is expected to change over time. Knowledge and understanding the hydrochemical properties in such semi-arid climate will contribute to sustainable development and effective management of the available water resources. Hence, the characterization of the hydrochemistry of different water sources at the regional scale has paramount importance.

As far as our knowledge is concerned, no comprehensive hydrochemical characterization of the various surface water and groundwater (SW-GW) sources has been carried out in the study region. Most of the previous studies (Halcrow, 1978; Ayenew, 2004; Belay, 2009; Goerner et al., 2009; Dinka, 2010, 2012, 2014) are addressing aspects of the Lake Basaka expansion. In fact, most of the previous research findings are contradicting each other. A study report made by Halcrow (1978) and Ayenew (2004) have suggested that the nearby irrigation farms (Abadir & Nura-Erra) are discharging excess irrigation water into Lake Basaka and are responsible for its expansion. On the contrary, Goerner et al. (2009) and Dinka (2010) reported that Abadir farm has little effect on hydrochemistry of Lake Basaka.

The present study, therefore, initiated with the objective to highlight the hydrochemical compositions of different SW-GW sources available in Matahara plain. Some of the important major water quality parameters were characterized individually. The potential sources of minerals were suggested for each of the considered water sources based on their quality characteristics. This study has an immense contribution for the ongoing management efforts to limit further expansion of the lake.

2. Methodology

2.1. Study Area: Overview

The study was conducted at Matahara Plain, located in the Fentalle Woreda, East Showa zone of Oromiya regional state (Ethiopia). Matahara Plain is situated at about 200 km south-east of Addis Ababa (Fig. 1) and delineated by Fentalle Crater in the north and mountain chains of variable elevation in the south, south-east, north-east, north-west and south-west. MSE, Lake Basaka, Matahara Town, Fantalle

Village and Awash National Park are situated on the flat plain of Matahara area (Dinka, 2012). Lake Basaka is a volcanically dammed terminal lake located at near distance to the Afar Triangle. There is a number of hot springs supplying water to Lake Basaka. The outlets of these springs are currently submerged due to the abrupt rise of lake water. As the area is situated in the upper most part of the Main Ethiopian Rift (MER), central rift valley region of Ethiopia, Lake Basaka is vulnerable to the occurrences of various tectonic and volcanic activities (Belay, 2009; Dinka, 2012).

Matahara plain has a semi-arid climate, characterized by an erratic rainfall distribution. It has a long-term average annual rainfall and evaporation of about 543.7 mm and 2,485 mm, respectively. The average temperature of the area is 26.5 °C. Matahara area is well documented by different research reports (e.g., Alemayehu et al., 2006; Ayenew, 2007; Belay, 2009; Goerner et al., 2009, Dinka, 2012).

Fig. 1 about here

2.2. *Water Sampling and Analysis*

Water samples were collected from eight different water sources (Fig. 1) available in the area, namely Awash River, irrigation canals, reservoirs, drains, factory waste, Lake Basaka, groundwater and hot springs. A total of 64 representative water samples (i.e. 8 samples for each water source) were collected during the months of November and May for two consecutive years (2008 and 2009). In Ethiopia, November represents spring season (just after rainy season) and May represents autumn (just before rainy season). Sampling period takes into account the variation of water quality during wet and dry seasons.

The samples were collected using half liter clean polyethylene bottles. First the bottles were cleaned by acid washing and then labeled with an identification number. Then, the number of the bottle was recorded on the sampling datasheet in line with the sampling location. The location of the sampling area was registered using GPS. All water samplings were completed in the morning (on the same day) and immediately taken to Matahara Breeding Station Laboratory for the analysis of important major cations and anions following standard test methods (UNESCO/WHO/UNEP, 1996; APHA, 1995) (Table 1). Electrical Conductivity (EC) and pH values were measured in situ using a portable conductivity and pH meter, respectively. Other chemical indices were derived from the measured water quality parameters. The formula adopted and sources for the calculated water quality indices are summarized in Table 2.

Tables 1 & 2 about here

3. Results and Discussion

3.1. Hydrochemical Composition

The chemical compositions of different SW-GW sources available in the Matahara area are summarized in Fig. 2 and Table 3. Figure 2 presents the mean value of the measured water quality parameters (pH, EC and major soluble salts); whereas Table 3 presents the mean values of chemical indices derived from the laboratory analyzed water quality parameters. The value of percent analysis (ion-balance) error (%E) was within acceptable range (≤ ±10%) for all water sources (Table 3). The %E was within permissible limit (≤ ±5%) for drains, groundwater (Abadir Extension, AE) and Lake Basaka. This indicates the relatively good ion-balance between cations and anions and, hence, the reliability of the measured values.

3.2. Characterization of Individual Quality Parameters

Some of the major water quality parameters are briefly presented in the subsequent sub-sections.

(a) The pH:

All the water sources of the area are alkaline/basic in nature (pH>7) and showed variability among the different water sources (Table 3). Awash River, irrigation canals, reservoirs, drains and groundwater (North Section, N) are slightly basic (pH = 7.7–8.1). Groundwater (AE), hot spring and Lake Basaka are characterized to be highly alkaline (pH>8.5), indicating the dominance of dissolved HCO_3 rather than

CO_3 ions which are known to affect pH of most waters (Chapman, 1992, cit. Laar et al., 2011). The pH of Awash River is in the recommended range for rivers (6.8–7.8) (Tsytsarin, 1988). However, the pH of irrigation canals and NS reservoirs is slightly above 7.8, but less than 8.2. This may be due to mixing of factory effluent water with Awash River within these water types. The pH of Lake Basaka varies between 8.6 and 10.5 (with average value of 9.6), slightly above the recommended range for fresh lakes (7.3–9.2, Tsytsarin, 1988) and hence, characterized to be a salt (soda) lake, almost similar to sea water. The sources of alkaline pH can be the levels of hard-water minerals and release of basic industrial and agricultural effluents.

Cellular organisms (*except a few tolerant species*) cannot tolerate the high pH level of Lake Basaka, and hence, the release of CO_2 is very high. This premise is based on the fact that dissolved CO_2 forms weak carbonic acid (H_2CO_3), which reduces the pH of natural waters (Hem, 1985). As indicated by Gizaw (1996) and others (Goerner et al., 2009; Dinka, 2010), the MER region including the Matahara area is characterized by high volcanic CO_2 flux.

(b) EC and TDS:

Different water bodies have different EC and TDS values. The measured EC values (dS/m) were in the ranges of 0.3–0.5 for Awash River, irrigation canals, reservoirs and factory waste; 0.7–1.0 for drains; 1.2–1.5 for groundwater (N) and hot spring; 4.0–5.0 for groundwater (AE); and 6.2–15.0 for Lake Basaka (Table 3). Accordingly, TDS values (ppm) were in the range of 192–320 (<500) for Awash River, irrigation canals, reservoirs and factory waste; 500–960 for drains, groundwater (N) and hot spring; 2 500–3 200 for groundwater (AE); and 5 000–1 2000 for Lake Basaka (Table 3). TDS values > 500 ppm indicates the presence of slightly elevated concentrations of salts and is related to the other problems such as hardness (Herojeet et al., 2013). Based on the classification system (Caroll, 1962; Pradhan and Pirasteh, 2011), all the considered water sources (except groundwater (AE) and Lake

Basaka) are generally classified as fresh water (TDS<1 000 ppm). Lake Basaka and groundwater (AE) are classified as brackish water (1 000–10 000). Even, some parts of the lake adjoining Abadir farms have extremely high EC (15 dS/m) and TDS (1 2000 ppm) and, hence classified as salty water, almost similar to sea water, which is in agreement with its pH level discussed above.

Fig. 2 and Table 2 about here

The higher values of EC and TDS for groundwater (AE) and Lake Basaka is indicator of higher ionic concentrations, probably due to the high anthropogenic activities in the region and geological weathering conditions acquiring high concentrations of the dissolved minerals. The local anthropogenic activities could be discharges from intensive and prolonged agricultural activities (*fertigation, chemigation, etc*) and discharges from industrial and domestic wastes. Agricultural activities introduce ions and metals from fertilizers and other agrochemicals (Laar et al., 2011). The principal constituents of TDS are usually major cations and anions. The relatively high value of EC and TDS in groundwater (AE) could be due to the intrusion of lake water in to groundwater system of the area at the Abadir side. This suggestion was emerged based on the fact that the groundwater quality in the other plantation sections is relatively good.

(c) Soluble Cations:

Na concentration is extremely high in Lake Basaka (≅160 meq/L), followed by groundwater (AE), factory waste, hot spring, groundwater (N), drains and water from Awash River (Table 3 and Fig. 2). As indicated by the Na:K ratio (Table 3), the concentration of K << Na (K nearly one-tenth to one-hundredth that of Na) in all water sources. This is expected due to the fact that K minerals have weak migratory ability (Nikanorov and Brazhnikov, 2012) and are resistant to decomposition by weathering (Pradhan and Pirasteh, 2011). Moreover, most salts of Na are not active in chemical reactions even though they are readily soluble in water (Pradhan and Pirasteh, 2011). The highest Na:K ratio obtained in factory waste was due to the use of lime/soda ash ($NaCO_3$) in sugar processing. The concentration of K is relatively abundant in Lake Basaka and hot spring, indicating the K source is sedimentary rocks rather than igneous rocks. The concentration of Na-K ions in groundwater (AE), hot spring and Lake Basaka were relatively higher due to their mineralogical origin. Weathering of Na-K bearing minerals/rocks (such as halite, feldspar and montmorilonite), ion (cation)-exchange process, pollution from industrial effluent and domestic sewage, and/or agricultural activities are responsible for the dominance of Na-K in these water bodies. Halite (NaCl) dissolution can also be the source of Na. The main source of K in the area would be weathering of potash silicate minerals and agro-chemicals (potash fertilizers used in sugar industries and Nura Era farm). The source of Na ion may be due to deposition of rock salts, weathering of rocks (limestone), and its displacement from absorbed complex of rocks and soils by Ca & Mg.

Eventhough Ca and Mg are the 5th and 8th most abundant elements on Earth, respectively, their concentrations in the study area are relatively low. The content of Ca < 0.5 meq/L for hot spring and Lake Basaka; 0.5–1.0 meq/L for groundwater (AE); and 1.5–2.0 meq/L for the other water sources. Mg ion is <0.6 meq/L in all water sources. Calcium plays an important role in the health of water bodies. In natural water bodies, Ca is known to reduce the toxicity of many chemical compounds (e.g. NO_2) on fish and other aquatic life (William et al., 1986). Only few tolerant fish species can survive in Lake Basaka due to its extremely low Ca and high pH.

Lake Basaka has a higher concentration of Na and K ions as compared to others. Conversely to this, it has the lowest concentration of Ca and Mg. This may be due to the precipitation of Ca and Mg ions. Ca occurs usually in the form of calcium salts ($CaCl_2$ or $CaCO_3$). The value of MAR (Table 3) revealed that there are Ca sources other than gypsum (*carbonate, silicates or calcite*) for Awash River, irrigation Canals, NS Reservoirs and Drains. In the case of other water sources, there is Ca removal by either ion exchange or calcite ($CaCO_3$) precipitation. Precipitation of calcite occurs when CO_2 content (in balance) is low, causing chemical reaction process in reverse direction (Nikanorov and Brazhnikov, 2012). The presence of a number of hot springs in the study area favors the precipitation of calcite in Lake Basaka owing to its high temperature. On the other hand, any process that increases CO_2 favors calcite to dissolve in the water solution.

The Mg ion occurs as a result of chemical weathering and dissolution of dolomite, marls, and other rocks. The Mg ion is seldom dominant in natural waters, which is also true for the study area. This is due to the fact that Mg has weak biological activity and the highest solubility. The dissolution of Mg rich minerals is usually a slow process (Ramesh and Jagadeeswari, 2012). The Ca:Mg ratio decreases in waters undergoing a medium to high water mineralization. In the case study area, Mg is dominant as compared to Ca only in hot spring water (Table 3). Thus, it is possible to suggest that hot spring water is undergoing a medium to high mineralization process. Erosion of rocks (*eg. limestone and dolomite*) and minerals (*eg. calcite and magnesite*) are the most common source of Ca and Mg. Leaching of soil by erosion, pollution from sewage and industrial waste can also contribute (Nikanorov and Brazhnikov, 2012).

(d) Soluble Anions:

The dominance of HCO_3 is similar to that of Na. Its content is relatively high in Lake Basaka, followed by groundwater (AE), factory waste, hot spring and groundwater (N). CO_3 content is very high in Lake Basaka, factory waste and groundwater (AE). In other water sources, CO_3 content is low. The concentration of CO_3 ions are negligible compared to HCO_3 ions. The primary source of these ions in groundwater is the dissolved CO_2 in rainwater that on entering in the soil dissolves more CO_2. Both CO_3 and HCO_3 ions occur in the form of carbonate system of chemical equilibrium, usually associated with the alkalinity (pH) and hardness of water which gives an unpleasant taste to water. HCO_3 and CO3 ions are dominant in waters having pH>8.2 (Fig. 2).

The sources of CO_3 and HCO_3 ions are dissolution of carbonate rocks (*eg. limestone, dolomite, magnesites*), which results in precipitation of CO_2 (Nikanorov and Brazhnikov, 2012). Bouwer (1978) indicated that HCO_3 is mainly formed due to the action of CO_2 from the atmosphere and that released from organic decomposition. Dissolution of carbonic acid (H_2CO_3) is also the source of HCO_3 ions (Ramesh and Jagadeeswari, 2012). HCO_3 is dominant anion in factory waste, groundwater, hot spring and Lake Basaka. HCO_3 ions are usually dominant in waters with low mineralization, often in waters with moderate mineralization (Anonymous, 2013). Therefore, it is possible to deduce that groundwater, hot spring and Lake Basaka waters are undergoing low to medium mineralization.

The Cl concentration is low in Awash River, irrigation canals, NS reservoirs and factory waste. It is medium in drains and groundwater; high in hot spring and extremely high in Lake Basaka. SO_4 content is extremely high in Lake Basaka followed by groundwater and hot spring. In other water sources, its concentration is typical of normal/natural water. Cl ion usually exists in the form of chlorine salts (NaCl, CaCl, MgCl) and is extremely soluble in water. Their presence in water is usually associated with leaching from minerals (e.g. gallite, sylvite, carnallite, bischofite), rocks (eg. Nephelines) and saline deposites. It also occurs due to industrial and municipal wastes and irrigated agricultural activities (Anonymous, 2013). The natural sources of Cl ions are sedimentary rocks and other common evaporate minerals (chloride salts) (Pradhan and Pirasteh, 2011; Ramesh and Jagadeeswari, 2012).

The principle natural sources of SO_4 include rock weathering, input from volcanoes and biochemical process (Herojeet et al., 2013). Other factors affecting the concentration of SO_4 are: decomposition and oxidation of substances containing sulfur (*fossil fuels and dissolution of sulfur bearing minerals such as pyrite and gypsum*) and human economic activities (Nikanorov and Brazhnikov, 2012). The sources of SO_4 in Lake Basaka, hot spring and groundwater (AE) may be derived from lithology, industrial effluents, volcanic activities and agricultural activities (*phosphatic fertilizers*). These water types may be enriched by SO_4 by the process of oxidation of sulphide and/or hydrogen sulphide. The first process occurs in the Earth's crust and the later one is created during volcanic eruption and occurrence of atmospheric precipitation. Oxidation of hydrogen sulphide is possible due to the fact that Matahara area is located in MER where there are active tectonic activities.

In general, the potential sources of Cl and SO_4 ions in groundwater, hot spring and Lake Basaka might be the dissolution of halite, pyrite and related mineral salts, leaching of rocks and minerals from (upper) soil layer by weathering or erosion, oxidation processes and anthropogenic activities. Local anthropogenic processes could be industrial effluents, domestic sewage, agro-chemicals (fertilizer inputs) and runoff from surrounding areas.

(e) Hardness:

Most of the water sources are classified from soft (TH<75) to moderately hard (TH=75-100) (Table 3). Accordingly, water from Groundwater (AE), Hot Spring and Lake Basaka are classified as soft and the remaining water sources are moderately hard. Excess hardness is undesirable mostly for economic or aesthetic reasons (Raghunath, 1987). The extremely softness of Basaka Lake is due to very low Ca and Mg values. The water, when touched, is of a considerably soft nature, almost similar to ordinary soaps. The population within the basin uses the water for washing clothes and themselves. Though there is no concrete proof, the people of the area use the water for washing their hair based on the belief that lake water removes dandruff from their hair.

3.3. General Discussion

The findings of this study indicated that all concentrations (except Ca and Mg) are high in Lake Basaka, followed by groundwater (AE), hot spring, drainage and factory waste. Factory waste has excess/high Na due to the use of soda ash in the sugar processing. Water sources from Awash River, irrigation canals and night storage reservoirs have almost the same concentration. This is due to the fact that Awash river is the source of water in irrigation canals and night storage reservoirs.

Table 3 indicates the dominance of alkaline water (RSC > 1, pH > 7) in all water bodies. The pH value exceeds 8.5 and RSC exceeds 40 for Lake Basaka, hot springs and groundwater (AE). But, the pH value is relatively higher in NS reservoirs. This may be due to the presence of aquatic weeds in NS reservoirs, which causes algal blooms. Values of pH >8.4 indicate the predominance of Na, CO_3 and HCO_3 ions. This is true for the case study since Na and HCO_3 ions are excessively high in these water sources. CO_3 content is also high in Lake Basaka. There is a tendency of Na salts to exceed their solubility limit in these water sources, which lead to precipitation of Ca and Mg salts as $CaCO_3$ and $MgCO_3$, respectively.

All the water sources (except Lake Basaka) have normal Cl (<15 meq/L). All water sources have normal HCO_3 (2–7 meq/L), except groundwater (AE) and Lake Basaka. SO_4 content is above normal (>6 meq/L) for factory waste, groundwater (AE), hot spring and Lake Basaka (Table 3). That means Lake Basaka water has above normal concentrations of HCO_3, Cl, and SO_4 ions, indicating the presence of high ionic exchange process in these water types. Water types having a high SAR or %Na (Table 3) damages the soil physical properties due to the fact that the Na ion replaces Ca and Mg ions adsorbed on the soil clays and causes dispersion of soil particles. The dispersion of soil particles further results in the breakdown of soil aggregates, leading to very hard and compact soil when dry and impervious to water penetration (Hergert and Knudsen, 1977). High alkalinity (high CO_3^{2-} + HCO_3^-) in water tends to precipitate Ca and Mg in the form of $CaCO_3$ and $MgCO_3$, respectively due to the chemical reactions. This condition essentially reduces salinity hazard, but increasing the Na hazard to a level greater than that indicated by the SAR (Eaton 1950; Silva, 2004).

The SO_4:Cl ratio is relatively high in factory waste and groundwater (AE) compared to other water sources (Table 3). Higher SO_4:Cl ratio indicates an exchange between upper layer of fresh groundwater and deeper intrusion of modified seawater (Perry et al., 2009). Accordingly, the SO_4:Cl ratio of about 11.9 in groundwater (AE) indicates an exchange between upper layer of fresh groundwater and intrusion of Lake Basaka. This condition further strengthens the intrusion of Lake Basaka in to the groundwater system of Abadir Farm suggested earlier based on the values of EC and TDS. The high Na:Cl ratio in groundwater (AE) indicates that the Na was released from silicate weathering process. The excessively high Na:Ca ratio in Lake Basaka and hot springs (Table 3) may be explained by the high volcanic CO_2 flux throughout MER that has the potential to leach Na and K from the rocks (Gizaw, 1996), causing precipitation of $CaCO_3$ and further increasing the Na:Ca ratio.

The plots of percentage chemical proportions of major ions (based on meq/L) presented in Fig. 3 clearly illustrates the ionic (cationic and anionic) dominance pattern of different water sources. All the water sources are dominated by Na as cation, which accounts about 45% for Awash River and irrigation canals; 50% for NS reservoirs; 70% for drains; and more than 90% for the other water sources. Surprisingly, Na accounts about 99% of the total composition of Lake Basaka. Ca and Mg composition is almost nil in this water type (*0.2% and 0.1 %, respectively*). Most of the water sources are dominated by HCO_3 as anion, which accounts about 55% for Awash River, Irrigation Canals; 50% for NS Reservoirs and drains; 65% for factory waste; 40% for groundwater (AE) and hot spring; and 33% for groundwater (N) and Lake Basaka. As expected, the cationic dominance pattern of Awash River (Na>Ca>Mg>K) is similar to that of irrigation canals and reservoirs. These water types have also similar anionic dominance pattern (HCO_3>SO_4>CO_3>Cl). Drains and groundwater (N) has the similar cationic dominance pattern (Na>Ca>Mg=K). The other water sources have different anionic dominance pattern. Although factory waste, groundwater (AE), hot spring and Lake Basaka have similar cationic dominance pattern (Na>Ca=Mg=K), their anionic dominance pattern is slightly different.

Fig. 3 about here

From the ionic dominance pattern, it is possible to deduce that the anion sources for river Awash, irrigation canals and reservoirs are the same. Even though factory waste water is also added to reservoirs, the cationic dominance pattern of reservoirs is more similar to that of Awash river than that of factory waste due to dilution effect. Drainage water has combined the ionic dominance pattern of Awash river and factory waste. Drainage and groundwater (N) has the same cation sources. Similarly, the cation sources for factory waste, groundwater (AE), hot spring and Lake Basaka are the same. On the other hand, Lake Basaka has distinct ionic dominance pattern from all the other water sources, indicating that it has different sources of soluble salts. This means that Lake Basaka has a combined mineral source from the other water types. This result is interesting since it explains the mineral and water sources for Lake Basaka. This means that the water source for Lake Basaka can be rainfall, irrigation excess, surface runoff from surrounding areas, discharge from sewage and factory waste, groundwater inflow from nearby upstream irrigation schemes and hot spring.

4. Conclusions and/or Recommendations

The hydrochemical composition of different surface water and groundwater sources available at Matahara area has been analysed and characterized based on their chemical compositions. Hydrochemical analysis data has revealed that all concentrations (except Ca and Mg) are high in Lake Basaka, followed by groundwater, hot spring, drainage and factory waste. All the water bodies of the area are dominated by alkaline water (RSC>1, pH>7), with Lake Basaka, hot springs and groundwater (AE) excessively alkaline (pH >8.5; RSC >40). Irrigation waters (water sources from Awash River, irrigation canals and night storage reservoirs) have almost equal chemical compositions, indicating their hydrochemical sources are almost the same. Lake Basaka water has excessively high salinity (EC~6.3 dS/m), alkalinity (RSC~80, pH~9.5) and sodicity (SAR~300). Some of the water types (groundwater, Lake Basaka and hot spring) are found to have relatively higher concentration of major ions (dissolved constituents). It is easy to imagine the potential damaging effects of such quality waters on soil structure, soil fertility and other soil behaviors of the area. The excessively high Na content of Lake Basaka has a potential to destroy soil structure and aggregate stability.

The ionic concentration and other chemical parameters showed variations in different water sources of the area. This may be attributed to variations in natural (geochemical) processes and anthropogenic activities within the region. The anthropogenic processes could include discharges from factory effluents, domestic sewage, and agriculture. Lake Basaka water has the combined characteristics of the other water sources such as direct rainfall falling on the lake surface, irrigation excess, surface runoff from surrounding areas, discharges from sewage and factory waste, groundwater inflow from nearby upstream irrigation schemes and hot springs.

Finally, the authors would like to suggest a comprehensive further investigation for the hydrochemical sources of various water resources of the study area, especially for hot springs, groundwater and Lake Basaka. Long-years detailed study, which includes both dry and wet season data sampling, is re3commended in order to verify this study results and clarify uncertainties associated with few years data. There is an urgent need to identify the alternative sources of water and chemical for Lake Basaka. This plays a significant role for effective management of the available water resources, and hence sustainable socio-economic development of the region. This has an immense contribution for the ongoing management efforts to limit further expansion of the lake and reduce, if not avoid, its damaging effects on crop production, soil quality, water quality and environment of the region.

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List of Tables and Figures

Table 4. Methods adopted for water quality analysis

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 (0.05 N) titrimetric
Magnesium	Mg^{2+}	EDTA (0.05 N) titrimetric
Sodium	Na^{+}	Flame photometric
Potassium	K^{+}	Flame photometric
Chloride	Cl^{-}	Titration using 0.05 N $AgNO_3$
Carbonate	CO_3	Titration (with 0.01 N H_2SO_4)
Bicarbonate	HCO_3	Titration (with 0.01 N H_2SO_4)
Sulphate	SO_4	Spectro Photometric

Table 2. Water quality parameter estimation methods from measured parameters

Quality Parameters	Symbol	Formula Adopted	Reference/Source
Total Dissolved Solids	TDS	TDS = 640*EC (for EC < 5 dS/m) TDS = 800*EC (for EC > 5 dS/m)	*Dinka (2010)**
Sodium Adsorption Ratio	SAR	$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	*USSL (1954)**
Residual Sodium Carbonate	RSC	$RSC = (CO_3^{-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$	*Doneen (1962)***
Permeability Index	PI	$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+}} * 100$	*Doneen (1962)***
Total Hardness	TH	$TH = (Ca^{2+} + Mg^{2+}) * 50$	*Roghunath (1987)***
Sodium Percentage	%Na	$\%Na = \frac{Na^{+} + K^{+}}{Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}} * 100$	*Khodapanahet et al. (2009)*
Magnesium Ratio	MAR	$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100$	*Palliwal (1972)**
% Balance Error	%E	$\%E = 100 * \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions}$	*Fetter (2000)**

All the ionic concentrations are in meq L^{-1}

Source: * Sarker and Hassen (2006); ** Reddy and Kumar (2010)

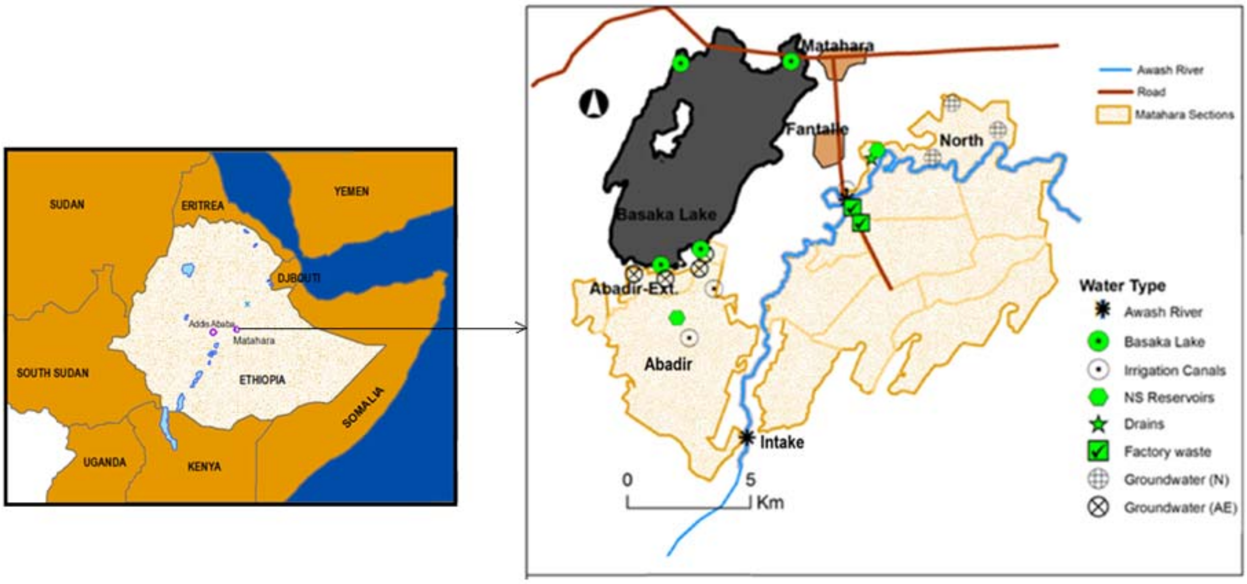
Table 2: Water Quality indices derived from measured values

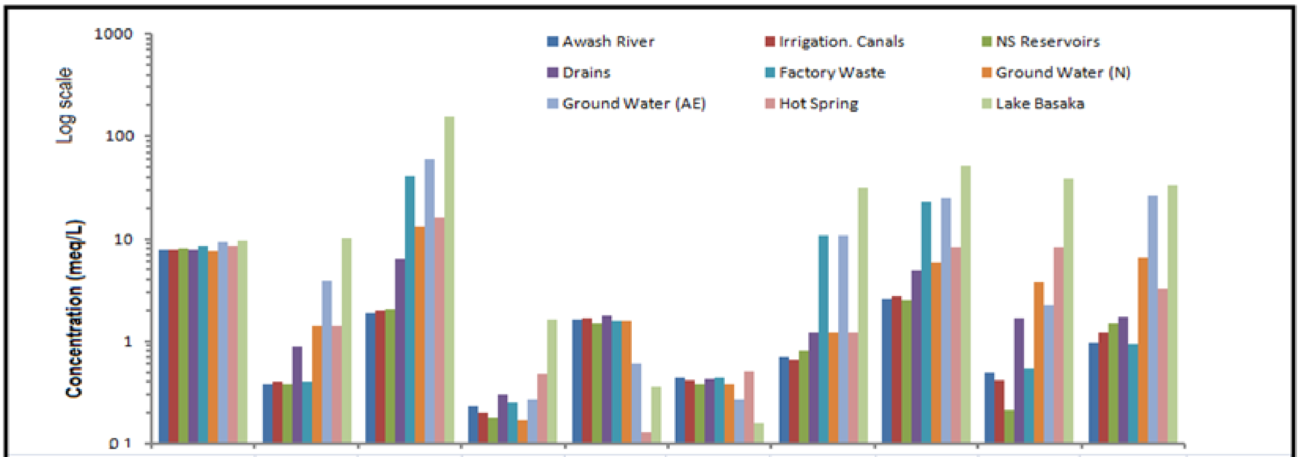
Parameters	Awash River	Irrigation. Canals	NS Reservoirs	Drains	Factory Waste	Ground Water (N)	Ground Water (AE)	Hot Spring	Lake Basaka
% E	-6.87	-8.64	-9.99	1.04	9.70	-7.09	-3.29	-9.50	1.14
SAR	1.1	1.3	1.3	17.5	112.3	11.9	44.0	125.8	304.8
RSC	1.4	1.4	1.6	8.1	1.6	5.2	39.2	8.8	44.1
TDS	243.0	254.0	243.0	258.0	986.0	2461.0	894.0	902.0	8213.0
%Na	1.9	1.9	2.1	38.2	40.1	13.2	89.7	28.7	307.0
PI	1.3	1.3	1.4	28.5	31.6	5.2	34.5	8.8	82.2
TH	103.0	104.0	94.5	94.0	101.5	97.5	43.5	32.0	26.0
Na:K	8.2	9.9	11.3	21.1	161.4	48.3	159.8	33.8	97.2
Na:Cl	3.8	4.7	9.7	3.8	74.7	3.4	26.3	2.0	4.0
Ca:Mg	0.27	0.25	0.25	0.25	0.28	0.24	0.45	3.92	0.44
SO_4:Cl	1.94	2.93	7.00	1.04	1.72	1.70	11.85	0.40	0.85
MAR	21.4	19.7	20.1	19.1	21.7	19.5	31.0	79.7	30.8
TH	99.0	110.0	95.0	123.0	110.5	112.5	50.0	440.0	35.0
MAR	22.7	20.5	23.7	26.8	20.8	20.0	30.0	70.5	28.6
r_1	1.4	1.3	1.2	17.6	42.8	1.4	2.1	2.4	3.5
r_2	1.7	1.4	1.4	17.9	43.1	1.4	2.1	2.6	3.6
Cl<15 meq/L	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
SO_4<6 meq/L	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
HCO_3=2-7 meq/L	Yes	Yes	Yes	Yes	No	Yes	No	No	No
Water class*	C2-S1	C2-S1	C2-S1	C3-S4	C2-S4	C3-S2	C4-S4	C3-S4	C4-S4
Water Type**	g (F)	g (F)	G (F)	F (F)	g (F)	F (F)	F (B)	F (F)	B (B)

Note that Cl<15, SO4<6 and HCO3=2-7 meq/L are considered as normal water type (Soltan, 1998 cit. Singh et al., 2006).

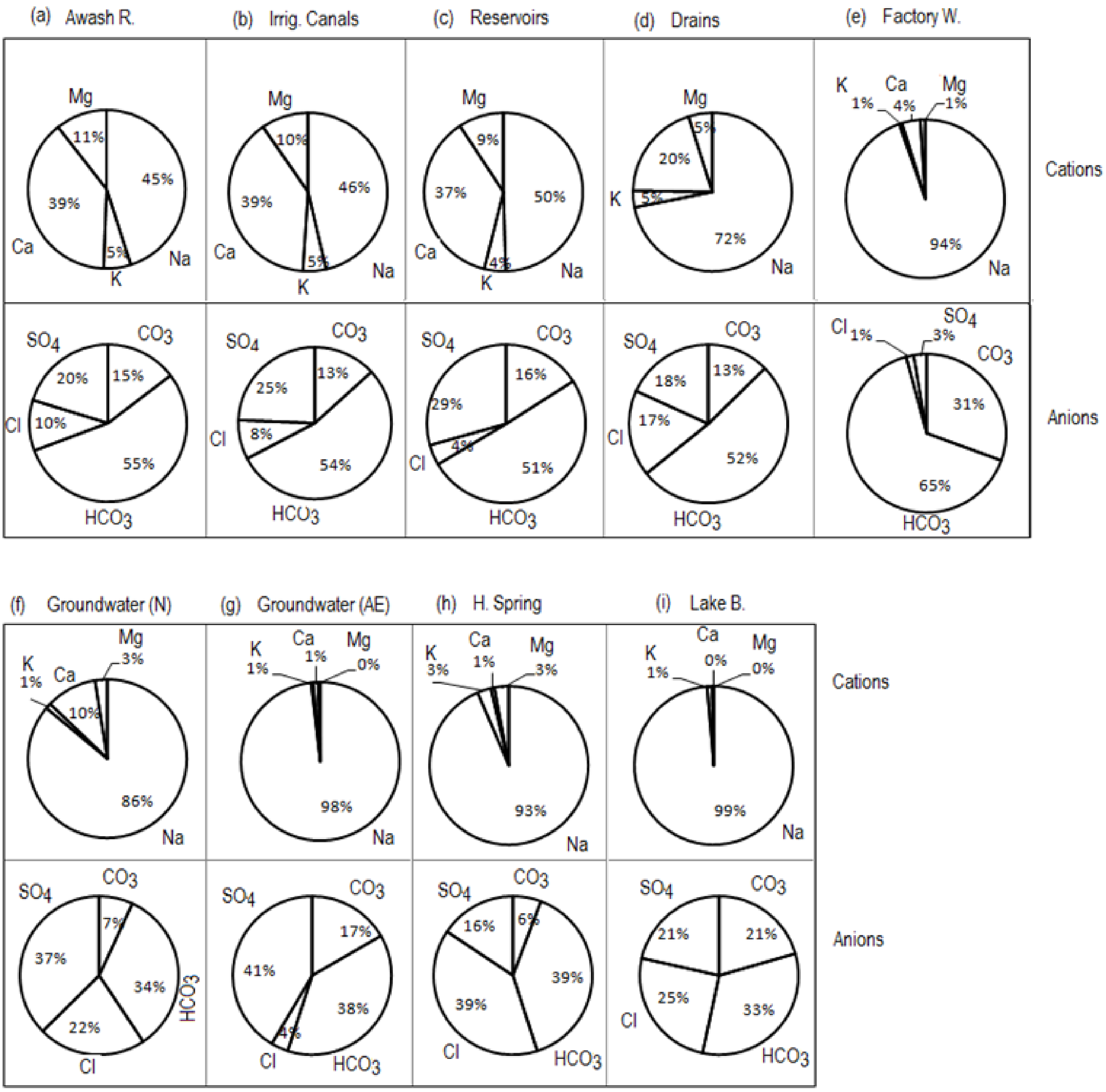
* Based on USSL (1954) classification system.

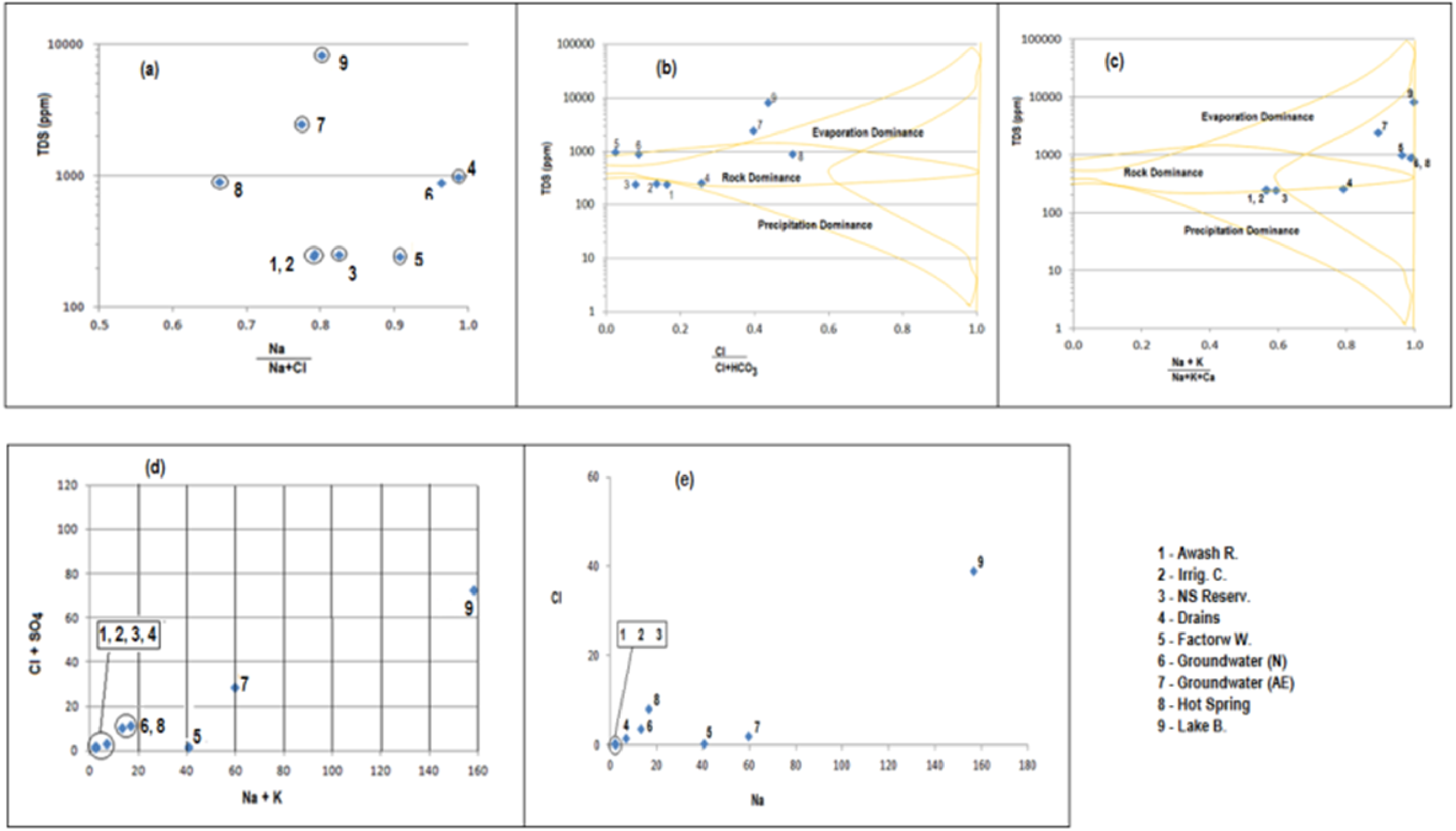
** Water type based on Cl: g – oligohaline, F- Fresh, B- Brackish. The water types in parenthesis are classified based on TDS value (Caroll, 1962, cit. Pradhan and Pirasteh, 2011).





	pH	EC	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	%E
Awash R.	7.73	0.38	1.88	0.23	1.62	0.44	0.7	2.62	0.5	0.97	-6.87
Irrig. Canals	7.83	0.4	1.97	0.2	1.67	0.41	0.67	2.73	0.42	1.23	-8.64
NS Reserv.	8.1	0.38	2.03	0.18	1.51	0.38	0.8	2.53	0.21	1.47	-9.99
Drains	7.75	0.88	6.34	0.3	1.75	0.43	1.2	4.9	1.67	1.73	1.04
Factory W.	8.61	0.4	40.36	0.25	1.59	0.44	10.73	22.9	0.54	0.93	9.7
Ground W. (N)	7.59	1.4	13.04	0.17	1.57	0.38	1.2	5.9	3.83	6.53	-7.09
Ground W. (AE)	9.18	3.85	59.14	0.27	0.6	0.27	10.7	24.65	2.25	26.67	-3.29
H. Spring	8.51	1.41	16.22	0.48	0.13	0.51	1.2	8.25	8.25	3.28	-9.5
Lake B.	9.55	10.27	156.54	1.61	0.36	0.16	31.83	50.93	39.01	33.33	1.14


(a) Awash R.
(b) Irrig. Canals
(c) Reservoirs
(d) Drains
(e) Factory W.
Cations
Anions
Mg 11% Na 45% Ca 39% K 5%
SO4 20% CO3 15% Cl 10% HCO3 55%
Mg 10% Na 46% Ca 39% K 5%
SO4 25% CO3 13% Cl 8% HCO3 54%
Mg 9% Na 50% Ca 37% K 4%
SO4 29% CO3 16% Cl 4% HCO3 51%
Mg 5% Ca 20% K 5% Na 72%
SO4 18% CO3 13% Cl 17% HCO3 52%
K 1% Ca 4% Mg 1% Na 94%
Cl 1% SO4 3% CO3 31% HCO3 65%
(f) Groundwater (N)
(g) Groundwater (AE)
(h) H. Spring
(i) Lake B.
K 1% Ca 10% Mg 3% Na 86%
SO4 37% CO3 7% HCO3 34% Cl 22%
K 1% Ca 1% Mg 0% Na 98%
SO4 41% CO3 17% Cl 4% HCO3 38%
K 3% Ca 1% Mg 3% Na 93%
SO4 16% CO3 6% Cl 39% HCO3 39%
K 1% Ca 0% Mg 0% Na 99%
SO4 21% CO3 21% Cl 25% HCO3 33%


(a)
TDS (ppm)
10000
1000
100
0.5
0.6
0.7
0.8
0.9
1.0
Na / Na+Cl
9
7
8
4
6
1, 2
3
5
(b)
TDS (ppm)
100000
10000
1000
100
10
1
0.0
0.2
0.4
0.6
0.8
1.0
Cl / Cl+HCO3
Evaporation Dominance
Rock Dominance
Precipitation Dominance
(c)
TDS (ppm)
Na + K / Na+K+Ca
Evaporation Dominance
Rock Dominance
Precipitation Dominance
(d)
Cl + SO4
Na + K
1, 2, 3, 4
6, 8
5
7
9
(e)
Cl
Na
1 2 3
4
6
8
5
7
9
1 - Awash R.
2 - Irrig. C.
3 - NS Reserv.
4 - Drains
5 - Factorw W.
6 - Groundwater (N)
7 - Groundwater (AE)
8 - Hot Spring
9 - Lake B.