Quality composition and irrigation suitability of various surface water and groundwater sources at Matahara Plain

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Abstract—This study highlights the physico-chemical compositions of different water sources available at Matahara Plain and evaluates their suitability for irrigation purpose. Various surface- and ground-water samples were collected and then analysed for important major physic-chemical quality parameters (pH, EC, cations and anions) following standard procedures. Other chemical indices were derived from the measured quality parameters. The quality rating for each water type was evaluated against the recommended threshold level for irrigation. Each water sources were rated for irrigation suitability following standard FAO guidelines and others. Overall, the findings emphasize the need to avoid the use of poor quality water for irrigation.

Keywords: groundwater, irrigation suitability, Lake Basaka, Matahara, quality parameters

INTRODUCTION

All water sources used in irrigation contain impurities and dissolved mineral salts with changeable concentrations and compositions [1]. Most of these mineral salts are beneficial to crop growth and soil conditioning [3]. However, the use of poor quality irrigation water (beyond the recommended threshold level of concentration) may create a range of impacts on the crop as well as soil quality [3] depending on the water, soil, crop, and environmental conditions [5]. This is due to the fact that most of the mineral salts remain in the soil after the water has been used by the crop. Generally, poor quality irrigation water may lead to the following potential problems [2]: (i) crop yield reduction or even total crop failure (*due to salinity, toxicity and osmotic effects*); (ii) impaired crop quality which may result in inferior products or pose a health risk to consumers; (iii) destruction of soil structure (*as a result of the degradation of soil properties and accumulation of undesirable constituents or toxic constituents*); and (iv) damage to irrigation equipment (*due to corrosion or encrustation*). Some of these problems are not only associated with the presence of a constituent, but also due to the interaction between the constituents [6].

Matahara plain area is an important commercial agricultural area after the establishment of Matahara Sugar Estate (MSE) in the 1965. MSE is the second largest irrigation scheme (*next to Wonji-Shoa Sugar Estate*) within Awash basin of Ethiopia. The sugar estate is located in the Matahara plain, south-east of the Lake Basaka [7]. A large proportion of irrigated land in MSE is affected by waterlogging and salinization [2]. Currently, groundwater (GW) levels are still rising and at some locations they are close to the crop root zone. Due to the changing hydrological conditions, the chemistry of GW is expected to change over time. Groundwater with reduced quality and a rising trend usually results in deterioration of soil quality in irrigated fields [9], which in turn may lead to reduced crop yield and even total failure of irrigated agriculture [2]. Moreover, the highly saline and alkaline Lake Basaka, located adjacent to MSE, has been expanding towards the plantation at a very fast rate over the last about 5 decades [8] [11][12]. The expansion of the lake with poor quality is expected to negatively affect the groundwater dynamics, crop production, and soil properties of the region. Moreover, MSE also uses drainage and factory waste water for irrigation. The use of such water might have negative consequences to the production and productivity of the sugar estate as well as the environment of the region. All the water sources are in contact with the soil, and the sugarcane crop in the study area.

Testing the quality of irrigation water is the first step to assess the suitability of water for irrigation purpose and prevent the irrigation-induced problems. The physico-chemical quality parameters play a significant role in classifying and assessing water quality for irrigation [14]. Many irrigation water quality criteria and guidelines have been already established in the world and published in international and local literatures. Different approaches and methodologies have often been used to derive the criteria and guidelines. The standard criteria developed by USSL [15] still has worldwide acceptance for irrigation water quality evaluation [1]. However, the most internationally acceptable standard guidelines for irrigation water quality evaluation are given by FAO [4]. FAO guideline emphasizes the long-term influence of water quality on crop production, soil conditions, and farm management.

The importance of irrigation water quality assessment and monitoring has been addressed in different parts of the world [3]. In the study area, however, the statuses of different water sources for irrigation purpose were not well documented, except the unpublished scanty reports [18]. The hydrochemical characteristics of the various water sources of the area are recently reported by Dinka et al. [7]. The present study initiated with the objective to highlight the physico-chemical compositions of different water sources and evaluate their suitability for irrigation purpose. This study provides valuable information of the water quality status of the various water sources available within Matahara region. It also contributes to the future developments of irrigation and groundwater resources as well as sustainable management of lake expansion in the region.

METHODOLOGY

Study area: brief description

Matahara Plain is located in the East Showa Zone of Oromiya regional state (Ethiopia); at about 200 km south-east of Addis Ababa. The plain area is delineated by mountain chains of variable elevation [13]. The area is vulnerable to the occurrences of different tectonic and volcanic activities due to the fact that it is situated in the upper most part of Main Ethiopian Rift (MER), central rift valley region of Ethiopia [13]. MSE, Lake Basaka, Matahara town, Fantalle Village and Awash National Park are situated within the flat Plain area.

MSE is the second largest irrigation scheme (next to Wonji-Shoa Sugar Estate) established in 1965 in the Awash Basin by the Dutch company called Hangler Vonder Amsterdam (HVA). Most of the plantation area is covered by sugarcane crop. Matahara plain 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 between February and March [2], [11]. The long-term average values of annual rainfall and temperature and evaporation of the area are 543.7 mm, 26.5 °C and 2485 mm, respectively [11]. Detailed information about Matahara region (*location, climate, soils, hydrology, geology, irrigation practice, land use/cover*) is well documented by different researchers [e.g. [2], [7], [11].

Water sampling and analysis

Different surface- and ground-water samples were collected from Awash River, irrigation canals, night storage reservoirs (*now onwards simply named reservoirs*), drains, factory waste, Lake Basaka, groundwater and hot springs (Fig. 1). *Now onwards, waters from Awash River, irrigation canals and reservoirs are simply called irrigation waters throughout the document.* A total of 44 water samples were collected in 2009 and 2010 during irrigation season. The method used for water sampling and analysis of important physic-chemical parameters is already published by Dinka et al. [7].

From the measured water quality parameters, other chemical indices (SAR, RSC, TH, PI, %Na, MH, TDS) were derived using equations 1 to 8. Sodium Absorption Ratio (SAR) (eq.1) was determined by the methods suggested by USSL [15] and adopted by Sarkar and Hassen [21]. Residual Sodium Carbonate (RSC) (eq. 2) was determined using eq. 2 [22] method; whereas Permeability Index (PI) was calculated using (eq. 3) [23]. Total Hardness (TH) (eq. 4) and Magnesium Adsorption Ratio (MAR) (eq. 5) were calculated using the methods recommended by Raghunath [24] and Palliwal [25], respectively. Percentage Na or soluble-sodium percentage (%Na) was calculated using eq. 6 [26]. The concept developed by Bower and Massland [27] was used to determine adj. SAR (eq. 8) [4].

$$SAR = Na^{+} \Big/ \sqrt{0.5\left(Ca^{2+} + Mg^{2+}\right)} \qquad (1)$$

$$RSC = \left(CO_3^{-} + HCO_3^{-}\right) - \left(Ca^{+2} + Mg^{+2}\right) \quad (2)$$

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Na + Ca^{2+} + Mg^{2+}} * 100 \quad (3)$$

$$TH = \left(Ca^{2+} + Mg^{2+}\right) * 50 \quad (4)$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \quad (5)$$

$$\% Na = \frac{Na^{+} + K^{+}}{Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}} \quad (6)$$

$$TDS = 640 * EC \qquad \text{for EC<5dS/m} \quad (7a)$$

$$TDS = 800 * EC \qquad \text{for EC>5dS/m} \quad (7b)$$

$$adj.SAR = SAR\left[1 + \left(8.4 - pH_c\right)\right] \quad (8)$$

where the concentrations are expressed in meq per liter (me L^{-1}), except TDS (ppm) and EC (dSm^{-1}).

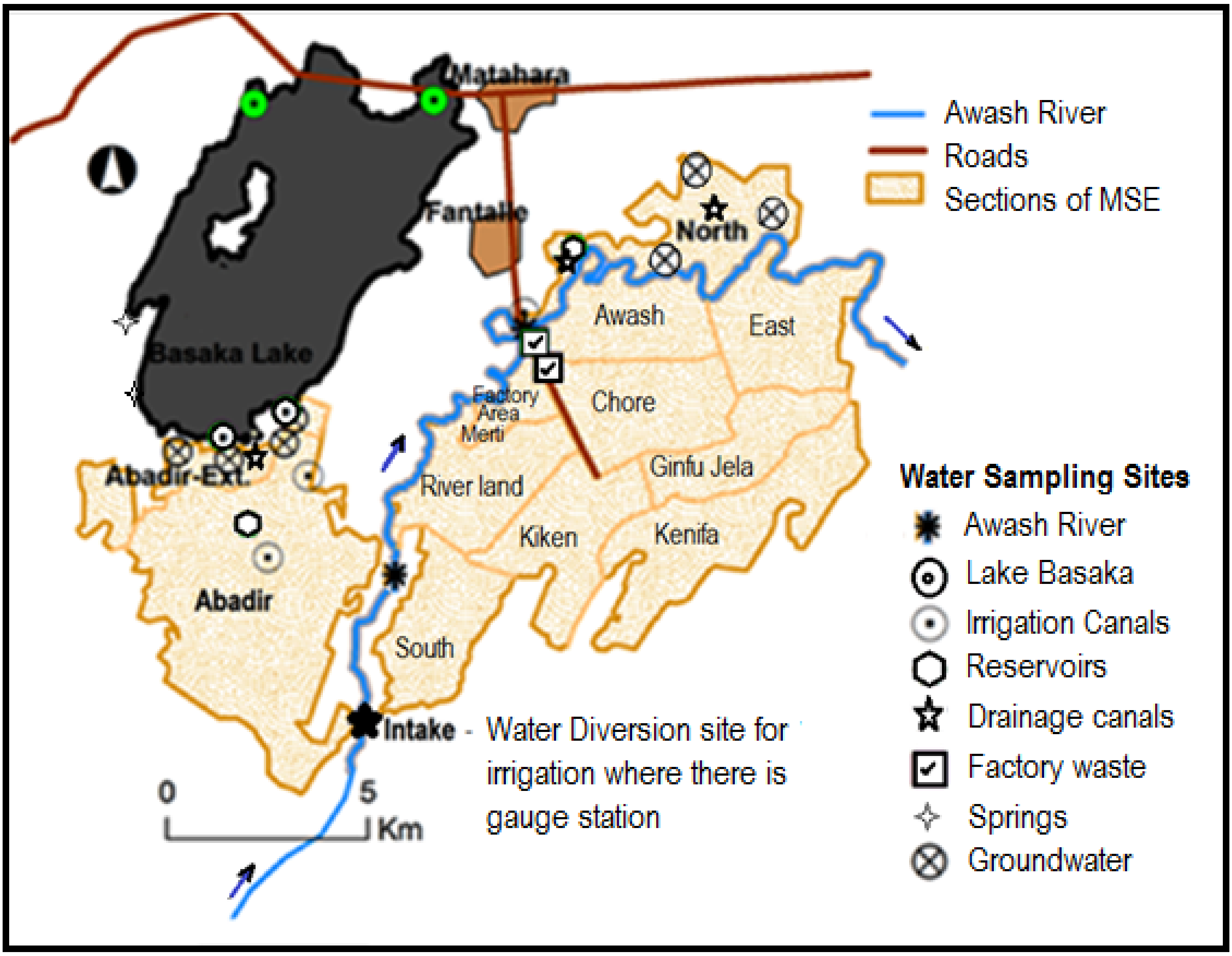

Figure 1. Map showing Lake Basaka, Matahara sugarcane plantation sections and sampling sites for the various water types considered

Irrigation suitability evaluation

In this study, the suitability of different water types for irrigation purpose was mainly evaluated based on the levels of EC, RSC and SAR. Other chemical indices (%Na, PI, TH, MAR) were also used to rate the irrigation suitability. The ratings of EC, SAR and RSC were made following the recommendations made by Bhumbla and Abrol [28], USSL [15] and Bishoni *et al.* [29], respectively and adopted by others [30]. EC <1 dS/m is considered to be low (very good), 1-2 dS/m is medium (good), 2-4 dS/m is high (marginal), 4-6 dS/m is very high (harmful) and >6 dS/m is severe (very harmful) for irrigation [28]. As per USSL [15], SAR ≤10 is considered as fit; 10-18 is marginal, 18-26 is poor and >26 is said to be unfit for irrigation. RSC <0 is very good, 0–2.5 is fit, 2.5– 5.0 is marginal, 5.0–7.5 is poor and >7.5 is unfit for irrigation [29]. Although RSC <2.5 mg/l are generally considered as safe for irrigation, those from 1.25 to 2.5 mg/l are considered to be marginal [22]. MAR greater than 50% [24], [25] and %Na ≤ 60 [26] are generally considered as suitable for irrigation purpose. PI >75 is suitable (CI), 25-75 is marginal (Class-II) and <25 unsuitable (Class-III) for irrigation [23]. TDS <1000 ppm is fresh, 1000–10 000 ppm is brackish, 10 000–1 000 000 ppm is saline, >1 000 000 ppm is brine [31].

Moreover, the general suitability of different water types for irrigation was also evaluated using the Wilcox [32], Thorne and Thorne [33] and USSL [15] diagrams. The relative status of the individual physico-chemical parameters was evaluated following FAO [34] and other standard guidelines [15], [35] -[36]. Finally, the potential hazards (such as salinity, sodicity, permeability, specific ion toxicity, hardness) associated with the use of each water type were evaluated. The probable influence of water quality on physical properties of soils was assessed using PI suggested by Doneen [23].

RESULTS AND DISCUSSION

Water quality composition: comparative analysis

The hydrochemical properties of water samples collected from various water sources are summarized in Table 1 and Fig. 2. Awash River, irrigation canals and reservoirs have very low to medium concentration; whereas drainage, factory waste, groundwater, hot spring and Lake Basaka are within very low to severe condition. Lake Basaka is in the range of highly saline (EC~6.3 dS/m), alkaline (RSC~44, pH~9.6) and sodic (SAR~460). The pH value is greater than 8.4 for groundwater (AE), hot spring and Lake Basaka, indicating the predominance of Na, CO_3 and HCO_3 ions. There is a tendency of Na salts to exceed their solubility limit in these water types, which lead to precipitation of Ca and Mg salts as $CaCO_3$ and $MgCO_3$, respectively. Bicarbonate content is within the recommended range (0-10 meqL^{-1} or 0-610 mgL^{-1}, [4]) for most of the water types, except groundwater (AE) and Lake Basaka. Chloride concentration exceeds the recommended threshold level *(<70 mgL^{-1} for most* crops, [4]) for most of water sources (except Awash River, irrigation canals, reservoirs and factory waste).

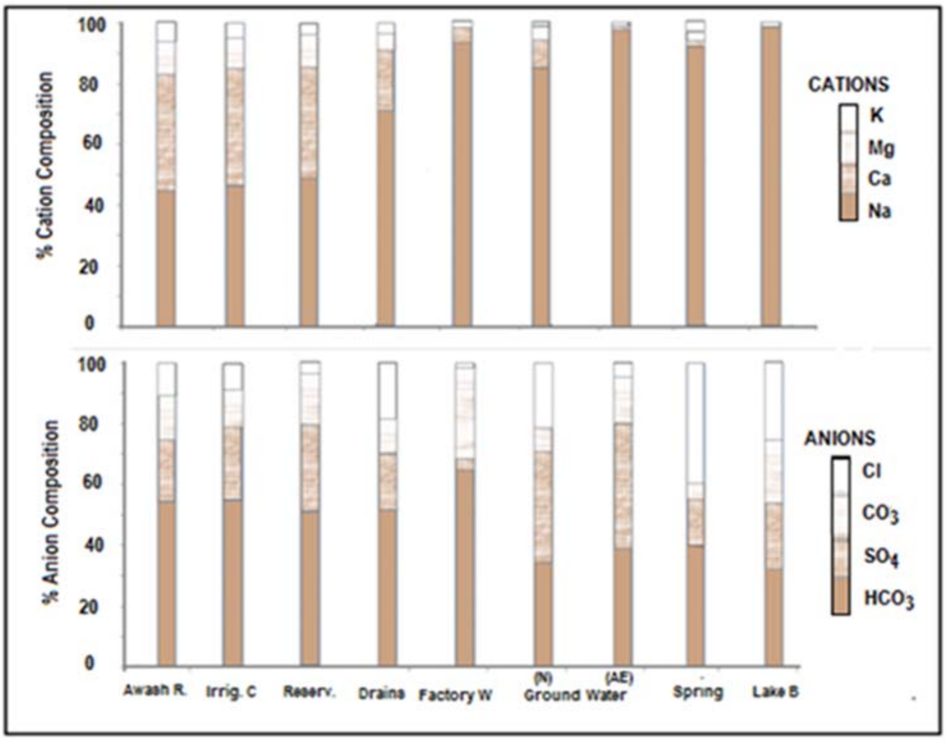

Figure 2. Collins Diagram: Comparison of chemical composition (*in percentage*) of major ions

All the water sources of the area are generally alkaline/basic in nature (pH>7): irrigation waters slightly alkaline; drainage, factory waste and groundwater (N) moderately alkaline; groundwater (AE), hot spring and Lake Basaka highly alkaline (pH>8.5). The pH of Lake Basaka ranges from 8.6 to 10.5, with an average value of 9.6. Based on Doonen [23] chart for PI, only irrigation waters are of good quality for irrigation since they fall within class-I. The Na:Ca ratio is excessively high in factory used water, drainage, groundwater, hot spring and Lake Basaka. Na and Ca are more or less balanced in irrigation waters (Awash River, reservoirs and irrigation canals) (Tables 1, 2). Some of the surface- and ground-water sources in Matahara Area are rich in Na, CO_3, HCO_3, Cl and SO_4 ions (Table 1). Lake Basaka is rich in all concentrations, except Ca and Mg ions. Detailed characterizations of the major ions are presented by Dinka et al. [7].

Suitability for irrigation use and the associated problems

The relative status of the individual physic-chemical parameters for irrigation purpose is presented in Table 2. The quality rating for each water type (Table 2) indicates that most of the individual quality parameters are above the recommended threshold level for irrigation (i.e. high to severe condition). Especially, groundwater (AE), hot spring and Lake Basaka have excessively high concentrations. The high values of TDS and TH of the groundwater of the area indicate the unsuitability of the groundwater for irrigation [38]. Table 3 presents the suitability of different water types for irrigation purpose, which was evaluated based on the levels of salinity, sodicity and alkalinity. The soil degradation problems (such as salinity, sodicity, permeability, specific ion toxicity) related to the use of each water source for irrigation uses are presented in Table 4. The potential for reduction of infiltration rates of the soil was determined from FAO-29 [34] water quality interpretation guideline.

The suitability of various water types for irrigation purposes were evaluated based on the individual limiting factors as presented bellows. The potential problems/hazards of each water type upon the contact with soil and plant are briefly discussed.

(a) The pH

Water quality analysis result (Table 1-3) indicated that the pH of water samples from Awash River, irrigation canals, reservoirs, factory effluent, and groundwater (N) are considered to be within the normal range (6.5–8.5) for most crops [4], including sugarcane. Groundwater (AE), hot spring and Lake Basaka have exceeded the upper limit of threshold value of pH (8.50) proposed for irrigation water. High pH of irrigation water is associated with high concentrations of Na and major anions (HCO_3^-, CO_3^{2-}, *Cl and* SO_4) (Table 2). Water pH does not have direct consequences on crops, except at extremes [36]. The pH >8.2 with excessive HCO_3 significantly affects crop production and create clogging problem, in case of drip and micro-spray irrigation systems. Moreover, high pH water can cause salts to precipitate and can reduce the efficacy of pesticides [39].

(b) Salinity

The salinity hazard (Table 3-4, Fig.2a) was determined based on the value of EC, which is the ability of water to conduct an electric current [4]. Moderate salinity (C2) water types (Awash River, irrigation canals, reservoirs and factory waste) are good and have no restriction for irrigation, except the requirement of moderate leaching. Drainage, hot spring and groundwater (N) have high salinity level (C3) and are doubtful for irrigation; whereas groundwater (AE) and Lake Basaka have very high (C4) salinity hazard which can cause significant yield reduction. As per Rao *et al.* [40] classification system -

Awash River, irrigation canals, reservoirs and factory effluent are classified to be C2 (0.25– 0.75 dS/m); drainage, groundwater (N) and hot spring as C3 (0.75–2.5 dS/m); groundwater (AE) as C4 (2.5–5.0 dS/m); and Lake Basaka as C5 (>5.0 dS/m). C3 waters can be used if accompanied by good drainage and special salt management; whereas C4 types are unsuitable for irrigation, except under special condition of good soil permeability, adequate drainage, excessive leaching and very salt-tolerant crops [4]. Sugarcane crop is moderately sensitive to salinity [41]. Moreover, groundwater table at some sections of the study area are very shallow [2] due to poor surface drainage system. Thus, the use of C4 water types for irrigation purpose is impossible.

Salinity is the accumulation of salts (often dominated by $NaCl_2$) in soil and water to levels that impact on human and natural assets [42] and hence, the wider economy. Different studies clearly indicated that salinity affects both the crop yield and soil physical properties. Irrigation water with high salinity is toxic to plants and poses a salinity hazard [43]. High salt level in irrigation water can significantly reduce crop yield and quality, and can bring total crop failure under extreme condition. Salinity affects the physiological growth of plants due to osmotic stress (*osmotic effect*), specific ion toxicity (e.g. leaf burn) (*toxic effect*), nutritional or hormonal imbalance (due to alteration of nutrient interaction) and/or production of reactive oxygen species and oxidative stress [4]. High salt level in the soil can result in a "*physiological drought*" (i.e., the inability of the plant to compete with ions in the soil solution for water) is the primary effect of high salinity water on crop productivity. This is a condition where plants wilt because the roots unable to absorb the water, though the field appears to have irrigation water [43]. Although increasing salt is beneficial in terms of soil aeration, root penetration, and root growth, high salinity levels is not allowed since it can have negative and potentially lethal effects on plants. Water salinity can affect soil physical properties by causing fine particles to bind together into aggregates [26]. Increased salinity can also result in corrosion of machinery and infrastructures, which can be extremely costly.

Salinity is one of the main factors affecting economic yield of many crops (including sugarcane) in different parts of the world [45]. The reductions of plant growth and yield are mostly proportional to the salt concentration in the soil solution within or around the plant root zone [37]. Irrigation with water containing salt induces salt into the soil profile. Ghassemi *et al.* [46] indicated that the salinity of irrigation water is usually an indicator of soil salinization. The study reports made in the case study area [2] also confirmed there is a strong positive correlation between soil salinity and groundwater salinity. The salinity level at which plant growth starts to decline is defined as the *threshold salinity*. For sugarcane crop, the threshold salinity level is at EC 1.5 dS/m [10] . Accordingly, groundwater (AE) and Lake Basaka can cause relative yield reduction of about 30% and 40%, respectively.

(c) Sodicity

The index of Na hazard (also called '*sodicity*') was evaluated based on the value of SAR or %Na (Table 2-5). In most of water sources (Tables 2, 3), estimated values of SAR or %Na exceeded the recommended threshold values (SAR ≤10, [32] or %Na <60, [26]). Awash River, irrigation canals, reservoirs have low sodicity (S1); groundwater (N) has medium sodicity (S2); and drainage, factory waste, groundwater (AE), hot spring and Lake Basaka are extremely sodic (S4) (Table 3-4 or Fig. 2a). S1 waters especially, Lake Basaka and groundwater (AE) have excessive SAR or %Na. The %Na for the different water sources (except Awash River, irrigation canals and reservoirs) >> 60 (Table 1). Thus, these water types are not suitable for irrigation purpose. This is due to the fact that high %Na can impair soil physical properties and reduce soil infiltration/permeability [47].

Sodium is an alkali metal which reacts with water to form highly soluble positively charged Na ions. For instance, Na along with CO_3 forms alkaline (Na-CO_3) soil and Na with Cl forms saline (Na-Cl) soil; both are not desirable for the growth of plants [48]. Excess Na waters have undesirable effects on soil properties and permeability [43]. High Na irrigation water results in the development of sodic soils. Owing to their poor infiltration and drainage properties, sodic soils impacts cultivation operation and irrigation practices. Thus, irrigation waters containing large amounts of Na/SAR (drainage, factory waste, groundwater (AE), hot spring and Lake Basaka) are of special concern due to sodium's effects on the crop growth as well as soil physical condition. Their excessively high Na content has a potential to destroy soil structure and aggregate stability, which can lead to reduced fertility (Organic Carbon/Matter, OC/OM) and other problems. The reduction of OC/OM was already confirmed by works of Dinka [2] . Dinka [2] reported that OC/OM content at AE fields is extremely low, which is an indicator of the effect of Lake Basaka on soil fertility of the study area.

Extreme SAR (*too much Na relative to Ca and Mg)* in irrigation water significantly affect the crop yield (reduce quality and quantity) and impair soil physical condition (due to reduced soil permeability and increased tendency of hard-setting) [4]. High %Na with respect to Ca^2+Mg^2 in irrigation water causes deflocculating and impairing of soil permeability [40]. Continued use of water having a high SAR or %Na 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 [49]. Fine textured soils, especially those high in clay, are mostly subject to the second effects of Na.

(d) Alkalinity

Alkalinity is defined as the combined effect of HCO_3^- plus CO_3^{-2} as compared to Ca plus Mg ions, measured based on the value of RSC defined by Eaton [22]. It is a measure of water's capacity to neutralize acids. As far as alkalinity hazard is concerned (Tables 3, 4), Awash river, irrigation canals, reservoirs, and factory waste are fit; drainage and groundwater (N) are poor; and groundwater (AE), hot spring and Lake Basaka are unfit for irrigation. Alkaline water increases the pH of the soil or growing media to unacceptable level causing iron deficiency [6].

Moreover, 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 [3]. That is why the value of adj.SAR (Table 2) increased considerably more than that of SAR for waters (groundwater, hot spring and Lake Basaka) highly predominated by Na, CO_3 and HCO_3 ions. Alkaline water could intensify the impact of sodic water (high SAR) on sodic soils [39].

(e) Permeability

The potential for water infiltration problems was evaluated by the combination of EC and SAR of water (Table 3, column 4) or PI class (Table 2). Awash River, irrigation canals, reservoirs and groundwater (N) can cause slight to moderate (PI=Class I) infiltration problems. There is very high risk (PI = Class III) of water infiltration problems if drainage water, factory waste, groundwater (AE), Lake Basaka and hot spring waters are used for irrigation. Water from Lake Basaka has severe infiltration problem if in contact with the soil. Because of its extremely high Na, the lake water has the potential to destroy soil structure. For certain EC and SAR value, water infiltration problems tends to be high for soils having higher clay content. Most of the soils of MSE are heavy clay type; hence, greater infiltration problems are expected. Waters with moderate risk may or may not result in a significant problem with water infiltration. For waters with severe risk of water infiltration, management practices are needed to prevent loss of soil structure [34].

(f) Specific ion toxicity

The specific ion toxicity problem is usually evaluated based on the values of Na, Cl and B ions. The Na and Cl contents in all water types (except Awash River, Irrigation Canals and NS Reservoirs) have been found to be high enough to cause toxicity problems (Tables 1, 3). The presence of high Na^+ creates a disturbance in other nutrients within the soil and plants [50]. Sugarcane genotypes have the capability to absorb more Na under saline condition through their roots and transport it to the shoots [41]. This facilitates the accumulation of Na^+ in roots and shoots of sugarcane, to levels that are toxic to plant growth, and may be the cause of reduced yield or impaired crop quality. Chloride, the anion of the element chlorine commonly constituent in water, is an essential plant micronutrient, highly soluble, and once in solution tends to accumulate. Chlorine does not occur in nature, but is found only as chloride (NaCl, KCl, $CaCl_2$, MgCl salts). The Cl of Na, K, Ca and Mg are all highly soluble in water, and if absorbed through plant roots or foliage can affect crop yield and quality significantly [6]. Excessive Cl deposited on plant leaves causes burning of foliage [36] .

(g) Hardness

The result of water analysis indicated that groundwater (AE), Hot Spring and Basaka Lake are found to be soft water; while the remaining water sources are classified as hard (Table 2). Hard water (high TH and low SAR) will make the ground soft and, hence, maintain good soil structure and good water movement through the soil (infiltration). On the contrary, soft waters (low TH and high SAR) makes the ground hard making dissolution of soil OM and clay dispersion, which results in poor soil structure and low infiltration problems [36] discussed earlier under Na hazard. Soft water can adds salt to the soil, retards plant growth, and removes soil nutrients.

(h) General suitability

The general suitability of the different water types for irrigation purpose was evaluated based on the combined effects of salinity, alkalinity and sodicity (Table 4). Furthermore, the general suitability categorization was evaluated using USSL [15] (Fig. 3a), Wilcox [32] (Fig. 3b) and Thorne and Thorne [33] (Fig. 3c) diagrams.

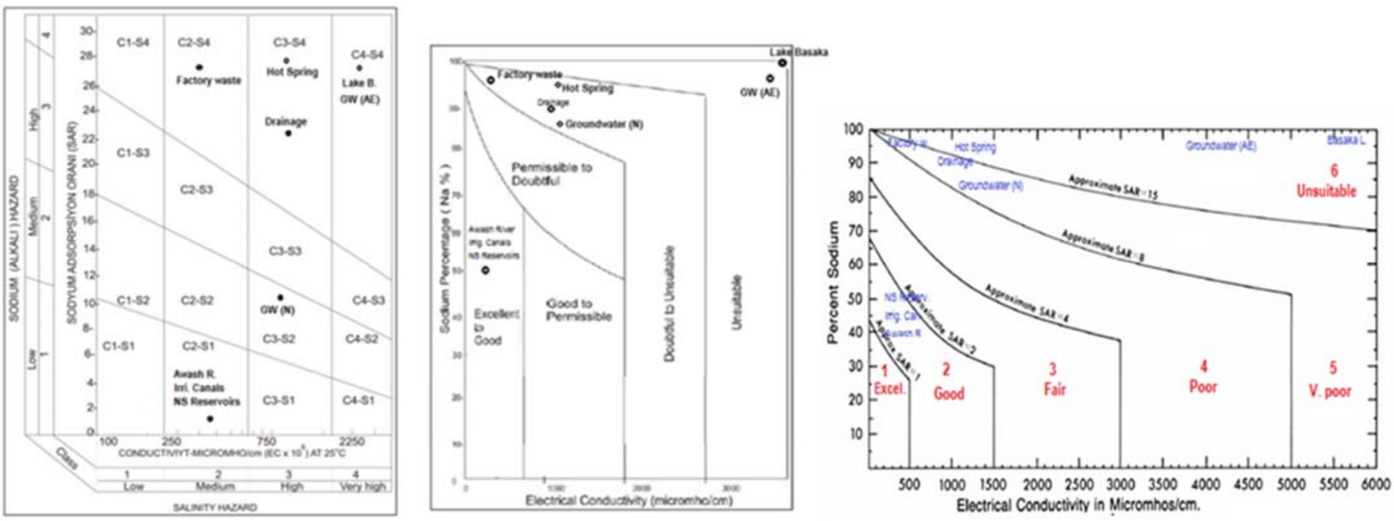

Figure 3. Water distribution for irrigation based on: (a) USSL (1954) diagram; (b) Wilcox (1955) diagram; (c) Thorne and Thorne (1951) diagram

The salinity and sodicity class of different water types are provided on column 5 of Table 4. Medium salinity and low sodium water (class C2-S1) can be used for irrigation on almost all soils with little danger of Na problem, if a moderate amount of leaching occurs. Waters of C4-S4 class generally is not suitable for irrigation. Waters in C2-S4, C3-S2, and C3-S4 classes are marginal/doubtful for irrigation. Such waters have high danger of Na problem in most soils; thus are not suitable for irrigation under ordinary conditions, except under good drainage and crop-tolerance. Sodium in C3-S2 class water is considered medium. Although such waters can create a problem on fine-textured (clay) soils, they can be used on coarse-textured (sandy) soils [15]. Saline-sodic condition requires better fertilizer management practices.

In general, the irrigation suitability classification (Table 4) gives the following categories:

***(i) Awash River, irrigation canals and reservoir waters*:** are suitable (excellent to good) for irrigation without significant problems on crop and soil (class 2). However, lower salinity (EC<0.7 dS/m) and sodicity (SAR<3 √(meqL-1)) indicates that there could be slight to moderate Na hazards on fine textured soils and hence, there could be a possibility of sodicity build-up upon continuous irrigation. Such quality water may have slight to moderate impact on soil physical properties. Extensive and continuous use of these waters (C2) on fine textured (clay) soils where little or no leaching occurs may eventually cause a saline or sodic soil problem [4]. These waters have also slight to moderate specific ion toxicity problems. Some precautions are required under high evaporation and poor drainage conditions.

***(ii) Drainage, factory waste and groundwater* (N):** are marginal (very poor/doubtful to unsuitable) for irrigation (class 5). They can cause moderate to high problems to crop as well as soil structure. The use of such water for irrigation should be with great care since they can cause significant problems upon long term irrigation. These waters can be used successfully for most crops if care is taken to prevent accumulation of soluble salts in the soil. The use of marginal water for irrigation should be accompanied by good management (irrigation and soil) practices.

***(iii) Hot springs, groundwater (AE) and Lake Basaka*:** are not suitable for irrigation (class 6). Lake Basaka is not suitable for irrigation due to the fact that it is extremely saline (EC >6 dS/m), extremely alkaline (RSC >7.5 meqL^{-1}, pH >9.0) and extremely sodic (SAR >26). Though the salinity of hot springs is good, it is not suitable for irrigation due to its pH, SAR and RSC limitation. Groundwater (AE), hot spring and Lake Basaka apply about 902, 2707 and 5040 mg L^{-1} TDS, respectively, to the soil. That means they add a total of about 9.02, 27.07 and 50.4 ton of salt to a hectare of land, respectively. That is why the crop production is almost impossible in areas where the soil is in contact with Lake Basaka.

As opposed to the study made by Abjehu [18] , the use of drainage and factory waste waters is not recommended due to their quality above the limit for crop production and effects on soil quality and environment. Factory waste water is not suitable for irrigation due to Na hazard only. Any treatment that reduces the concentration of Na will make this water type suitable for irrigation. Drainage water is not suitable due to Na and HCO_3 limitations. Abjehu [18] recommended the use of drainage and factory waste waters without significant problems. However, he emphasized their potential damages and greater care and management required in use of such quality water for irrigation.

Status of soil salinization and crop production

Shallow GW with poor quality is expected to affect the soil properties and crop yield because of the significant salt and water contribution [15]. The result obtained for the study area also confirms this argument that most of the soil quality parameters are above the permissible limit in those sections (Abadir-A & -E) with very shallow GW depth (see Fig. 4). Extensive irrigated areas affected by waterlogging are usually also affected by soil salinity and/or sodicity/alkalinity [15]. It is also true for the study area that waterlogged areas (Fig. 4a) are affected by salinity and sodicity (Fig. 4b). This result explains the interaction among the twin major threats (waterlogging and salinization) challenging the sustainability of irrigated agriculture.

The effects of Lake Basaka on the water resources of the region, especially drainage and ground water is clearly observable from Tables 1-4. Furthermore, the effect of highly saline Basaka Lake water intrusion on the plantation's soil salinity can be visualized from Fig. 4b. All Abadir-Ext and parts of Abadir-A fields are subjected to elevated salinity (EC) level compared to the other sections. The works done by Dinka [2] indicated that fields adjoining Lake Basaka at Abadir -Ext side are experiencing soil quality degradation and significant yield reduction. significant fertile lands are abandoned in AE areas The soil salinity level increased almost as a function of the rise in GW table and increased GW salinity; indicating the occurrence of secondary (capillary) soil salinization in the area. In order to reduce the level of SAR and RSC, addition of amendments like acid and gypsum are recommended. Acids react with CO_3 to form CO_2 gas, while gypsum adds Ca to reduce RSC and SAR values [36] .

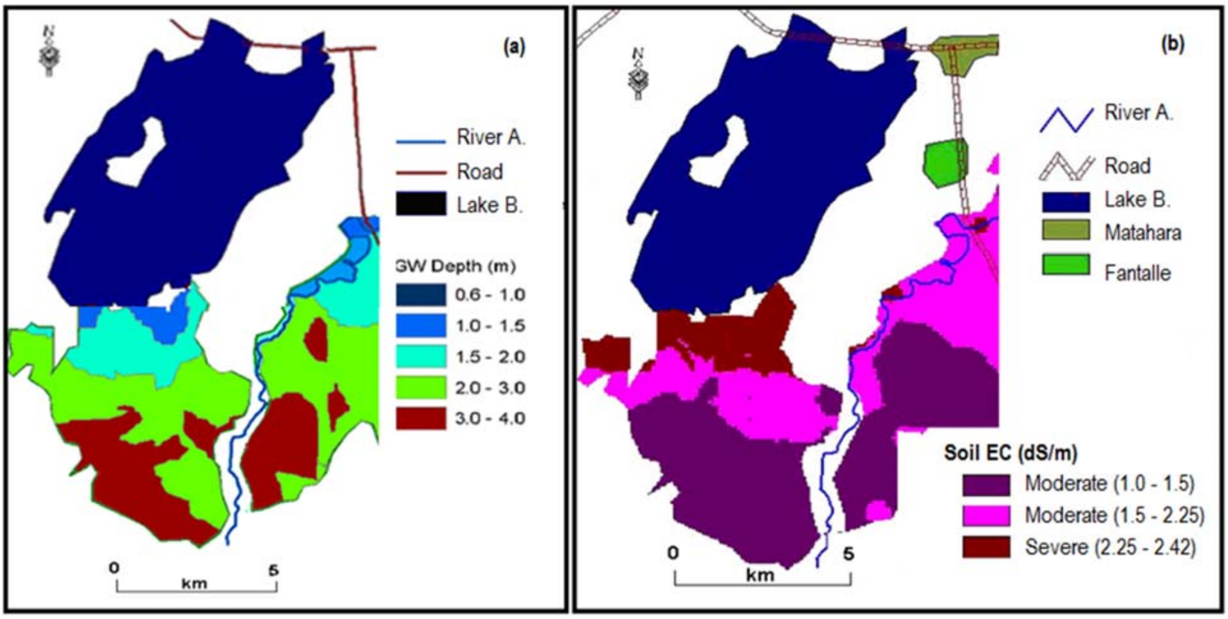

Figure 4. Spatial maps of groundwater depth and soil salinity *(produced based on universal kriging in ArcGIS)*

The status of waterlogging and soil salinization (Fig. 4) reveals the potential yield reduction at MSE. Analysis of sugarcane production (2000-2010) clearly indicates the deterioration of production and productivity in the Abadir and North sections (Fig. 5), where the soil and water quality deteriorations are prevalent. The productivity of certain sugarcane cultivated lands is valued based on the number of successive ratooning. Consequently, the sugar estate is forced to uproot the fields before completing their crop cycle. In recent years (after 2000), almost 50% of the Abadir-Ext fields (where there is very critical waterlogging and severe soil salinization) were uprooted after first-and second-ratoon stages because of their poor performance far below expected. In line with the cane yield, the sugar productivity is also significantly reduced in those fields with problem of waterlogging and salinization. This is not economical as far as ratooning and cane production policy is concerned because of the large cost associated with land preparation. About 70% of the cane production cost is attributed to land preparation. Uprooting below third ratoon (4^{th} Cutting) is usually considered to be not economical [18].

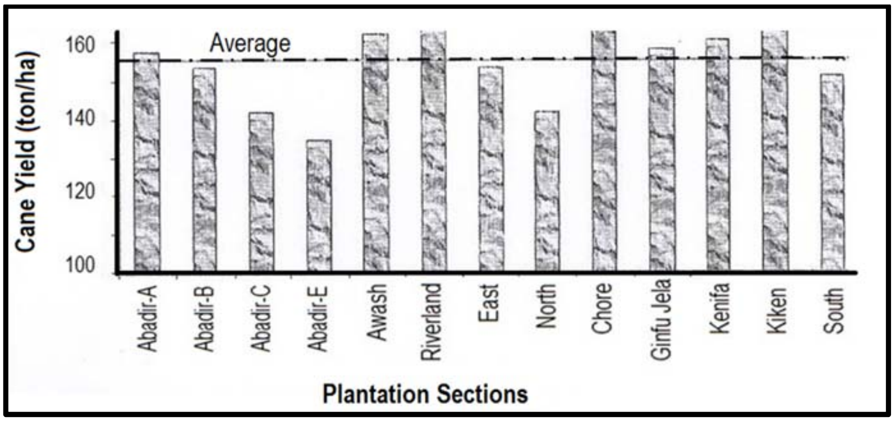

Figure 5. Variability of cane yield at different plantation sections (2000-2010) *(*Refer Fig. 1 for plantation sections)*

CONCLUSION AND/OR RECOMMENDATION

Analysis of water quality of different SW-GW sources in the study area indicated that most of the parameters are above the recommended threshold level. In general, some of the surface and groundwater sources in Matahara Area are rich in Na, CO_3, HCO_3, Cl and SO_4 ions. Lake Basaka is rich in all concentrations, except Ca and Mg ions. Awash River (the source of water in irrigation canals and night storage reservoirs) is suitable for irrigation without major limitation; whereas drainage, factory waste and groundwater (N) are marginally suitable (doubtful to unsuitable). Groundwater (AE), Lake Basaka and springs are found to be unfit for irrigation too, owing to their salinity, sodicity and alkalinity limitations. There is very high risk of water infiltration problems if drainage water, factory waste, groundwater (AE), Lake Basaka and hot springs are used for irrigation. Continuous use of these waters may result in soil quality deteriorations and change of other soil behaviour and performance, which in turn can lead to reduced crop growth, decline in crop yield and total crop failure. Groundwater (AE) and Lake Basaka can cause the respective relative yield reductions of about 30% and 40% due to salinity hazard. Lake Basaka can add a total of about 50.4 ton of salt to a hectare of land, indicating crop production is almost impossible in areas where the soil is in contact with Lake water.

The use of drainage (*especially in Abadir and North sections*), factory waste and groundwater for irrigation is not recommended. This recommendation is based on the known fact that continuous use of these marginal waters can cause significant effect on sugarcane production and productivity, soil quality deterioration and other environment degradations. However, good management practices and proper amendments (such as acid and/or gypsum, mulching) can make some of the marginal waters usable for irrigation. Other management practices such as leaching, pre-planting irrigation, crop variety selection, adequate and improved irrigation and drainage facilities, blending marginal water with Awash River, crop rotation, etc can be practiced. Moreover, modified fertilizer management is required in fields which are in contact with saline-sodic water.

Overall, this study result emphasizes the need to avoid the use of poor quality water for irrigation. The expansion of Lake Basaka with its poor quality is of great developmental challenge in the region, particularly to the sustainability of MSE. As far as possible, the author urges the need to control the contact of Lake Basaka water to crops and productive soil of the region.

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Table 1. Statistical Summary of hydrochemical parameters (measured and derived) for different water sources *(mean value of 2009 – 2010)*

Parameter	Awash River	Irrigation Canals	NS Reservoirs	Drainage Canals	Factory Waste	Groundwater (N)	Groundwater (AE)	Hot Spring	Basaka Lake	Recommended threshold*
					Measured Parameters**, a					
Na^+	1.52 - 1.61 *(1.58)*[a]	1.76 - 1.86 *(1.77)*	1.65 - 1.78 *(1.70)*	1.8 - 27.5 *(24.31)*	1.67 - 2.43 *(57.03)*	4.21 - 17.86 *(11.04)*	34.5 - 43.8 *(43.8)*	12.0 - 25.2 (16.22)	64 - 254 *(112.31)*	0-2.2
K^+	0.21 - 0.24 *(0.23)*	0.16 - 0.23 *(0.20)*	0.16 - 0.21 *(0.18)*	0.23 - 0.6 *(0.36)*	0.22 - 0.26 *(0.25)*	0.16 - 0.18 *(0.17)*	0.10 - 0.23 *(0.11)*	0.31 - 0.56 (0.48)	1.51 - 1.73 *(1.57)*	0.1-0.25
Ca^{2+}	1.50 - 1.53 *(1.52)*	1.41 - 1.72 *(1.67)*	1.40 - 1.42 *(1.41)*	1.08 - 1.74 *(1.65)*	1.52 - 1.74 *(1.59)*	1.40 - 1.72 *(1.57)*	0.54 - 0.67 *(0.65)*	0.10 - 0.16 (0.13)	0.32 - 0.43 *(0.35)*	2- 6
Mg^{2+}	0.43 - 0.45 *(0.44)*	0.33 - 0.45 *(0.41)*	0.23 - 0.45 *(0.38)*	0.22 - 0.65 *(0.49)*	0.43 - 0.45 *(0.44)*	0.31 - 0.42 *(0.38)*	0.21 - 0.33 *(0.22)*	0.50 - 0.53 (0.51)	0.11 - 0.22 *(0.14)*	0.5-2
CO_3^{2-}	0.61 - 0.83 *(0.70)*	0.61 - 0.81 *(0.67)*	0.60 - 0.93 *(0.80)*	0.61 - 7.42 *(2.53)*	0.61 - 1.2 *(0.73)*	1.01 - 1.43 *(1.20)*	9.2 - 12.5 *(9.40)*	1.0 - 1.30 (1.20	17.2 - 47.2 *(24.7)*	<1.0
HCO_3^-	2.51- 2.90 *(2.70)*	2.51 - 3.10 *(2.83)*	2.51 - 2.84 *(2.60)*	3.20 - 18.23 *(7.73)*	2.71 - 3.2 *(2.90)*	4.4 - 7.3 *(5.90)*	18.1 - 31.0 *(30.7)*	7.5 - 9.2 (8.25)	19.1 - 22.2 *(19.88)*	<2.4
Cl^-	0.36 - 0.63 *(0.50)*	0.36 - 0.45 *(0.42)*	0.09 - 0.45 *(0.21)*	0.54 - 4.14 *(2.00)*	0.54 - 0.63 *(0.54)*	0.80 - 6.82 *(1.98)*	1.90 - 2.61 *(3.83)*	7.10 - 9.21 (8.25)	12.5 - 67.2 *(26.1)*	<2.8
SO_4^{2-}	0.82 - 1.41 (1.07)	1.21 - 1.56 (1.33)	1.23 - 1.72 (1.47)	0.6 - 1.3 (0.93)	1.40 - 2.63 (1.73)	5.62 - 7.51 (6.53)	21.3 - 30.2 (26.67)	2.81 - 3.73 (3.28)	26.1 - 36.7 (33.33)	0-20
pH	7.72 - 7.74 *(7.7)*	7.21 - 8.16 *(7.8)*	8.06 - 8.12 *(8.1)*	7.3 - 9.5 *(8.1)*	7.36 - 8.61 *(7.9)*	7.31 - 7.88 *(7.6)*	7.45 - 8.90 *(8.9)*	7.4 - 8.89 (8.5)	8.6 – 10.5 *(9.6)*	6.5-8.5
EC	0.36 - 0.40 *(0.38)*	0.38 - 0.42 *(0.40)*	0.36 - 0.39 *(0.39)*	0.42 - 2.90 *(1.26)*	0.39 - 0.45 *(0.41)*	0.66 - 2.09 *(1.40)*	3.43 - 4.23 *(4.23)*	1.21 - 1.70 (1.41)	5.6 - 14.0 *(6.30)*	0-2
					Indices derived from measured parameters					
SAR[b]	1.6 *(11)*	1.7 *(12)*	1.9 *(13)*	22.7 *(179)*	56.1 *(455)*	11.3*(85)*	100.5*(814)*	50.8*(386)*	459.0*(3810)*	0-10
RSC	1.4	1.4	1.6	8.1	1.6	5.2	39.2	8.8	44	0-2.5[d]
TDS	243	256	246	806	256	896	2707	902	5040	<1000
%Na	48	49	51	92	97	85	98	96	100	≤60
PI	91	90	95	2	99	4	110	13	4	>75
TH	98	104	89	107	102	97	44	32	25	>75
MAR	23	20	21	23	22	19	25	80	28	>50
Na:Ca	1.2	1.2	1.4	16.9	41.2	8.1	77.5	143.5	369	<2

The units for cations, anions, RSC, TH, are in meq/l. Others: EC (dS/m), SAR (√(meqL^{-1})), TDS (ppm), PI & MAR (%) and pH and PI (-)

[*] Ayers and Westcot [4] (1985). [**] Originally the measurement was made in mg/l and then converted to meq/l to derive the other parameters using the conversion factor: meq L^{-1} = mg L^{-1} / equivalent weight

[a] Value in parenthesis are average values; [b] Values in parenthesis are for adj. SAR; [c] 1.5 for fine textured soils and 2.5 for course textured soils (1.5-2.5 ESP is marginal).

Table 2. Relative status/rating/hazard of individual quality parameters for irrigation purpose

Parameters	Awash River	Irrigation Canals	Reservoirs	Drainage Canals	Factory Waste	Groundwater (N)	Groundwater (AE)	Hot Springs	Lake Basaka
Na^+	Medium	Medium	Medium	Severe	Severe	Severe	Severe	Severe	Severe
K^+	High	High	High	V. High	High	High	Low	V. High	V. High
Ca^{2+}	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low
Mg^{2+}	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low	V. Low
CO_3^{2-}	V. Low	V. Low	V. Low	Low	V. Low	V. Low	Severe	V. Low	Severe
HCO_3^-	Medium	Medium	Medium	Severe	Medium	Severe	Severe	Severe	Severe
Cl^-	V. Low	V. Low	V. Low	Medium	V. Low	Severe	Medium	Severe	Severe
SO_4^{2-}	Medium	Medium	Medium	Low	Medium	V. High	V. High	Medium	V. High
pH	Medium	High	V. High	V. High	High	High	V. High	V. High	Severe
EC	Low (C2)	Low (C2)	Low (C2)	Medium (C3)	Low (C2)	Medium (C3)	V. High (C4)	Medium (C3)	Severe (C4)
SAR	Low (S1)	Low (S1)	Low (S1)	Severe (S4)	Severe (S4)	Medium (S2)	Severe (S4)	Severe (S4)	Severe (S4)
RSC	Low	Low	Low	Severe	Low	Severe	Severe	Severe	Severe
[c]PI	CI	CI	CI	CIII	CIII	CIII	CIII	CIII	CIII
TH	Mod. Hard	Mod. Hard	Mod. Hard	Mod. Hard	Mod. Hard	Mod. Hard	Soft	Soft	Soft

[a] pH value is rated for micro irrigation. Otherwise, it is very high for Groundwater (AE), hot spring and Basaka Lake. It is within normal range for other water types.
[b]salinity rating [4, 34] (Ayers & Westcot, 1985): low (<0.7 dS/m), medium (0.7 -1.5 dS/m), high (1.7 – 3 dS/m), very high (3.0 – 6.0 dS/m), severe (> 6.0 dS/m)
[c] PI rating were based on Doneen [23] (1964) chart. PI categorised in class I (>75), class II (25-75) and class III (<25)

Table 3. Degree of restriction for irrigation (based on Ayers & Westcot, 1994)

Water Type	Degree of Restriction/Risk				
	Salinity* (EC)	Sodicity (SAR)	Infiltration (SAR+EC)	Spec. Ion Toxcity (Na, Cl)	Miscelaneous (pH, HCO_3)
Awash River	None	None	None	None	None
Irrigation canals	None	None	Slight to moderate	Slight to moderate	None
Reservoirs	None	None	Slight to moderate	Slight to moderate	None
Drainage Canals	Slight to moderate	Severe	High	Severe	None
Factory waste	None	Severe	High	Severe	None
Groundwater (N)	Slight to moderate	moderate	Moderate to high	High	moderate
Groundwater (AE)	Severe	severe	Severe	Severe	Severe
Hot Spring	Slight to moderate	severe	Severe	Severe	Severe
Basaka Lake	Severe	Severe	Severe	Severe	Severe

Table 4. Irrigation suitability classification for different water sources

Water Type	Salinity[a]	Sodicity[b]	Alkalinity[c]	Suitability Class			General Category[d]
	(EC)	(SAR)	(RSC)	USSL (1954)	Wilcox (1955)	Thorne & Thorne (1951)	
Awash River	V. good	Fit	Fit	C2-S1	Excellent – Good	Good	Suitable
Irrigation Canals	V. good	Fit	Fit	C2-S1	Excellent – Good	Good	Suitable
NS Reservoirs	V. good	Fit	Fit	C2-S1	Excellent – Good	Good	Suitable
Drainage Canals	Good	Poor	Poor	C3-S4	Doutful – unsuitable	V. poor	Marginal
Factory waste	V. good	Unfit	Fit	C2-S4	Doutful – unsuitable	V. Poor	Marginal
Groundwater (N)	Good	Marginal	Poor	C3-S2	Doutful – unsuitable	V. Poor	Marginal
Groundwater (AE)	Harmful	Unfit	Unfit	C4-S4	Unsuitable	Unsuitable	Unsuitable
Hot Spring	Good	Unfit	Unfit	C3-S4	Doutful – unsuitable	Unsuitable	Unsuitable
Basaka Lake	V. harmful	Unfit	Unfit	C4-S4	Unsuitable	Unsuitable	Unsuitable

Suitability class based on: [a] Bhumbla & Abrol (1972); [b]USSL (1954); [c] Bishnoi et al. (1984); [d]made based on the three general classes (salinity, sodicity and alkalinity).
C1- low salinity, C2- medium salinity, C3-high salinity, C4- very high salinity; S1-low Na, S2-medium Na, S3-high Na, S4-very high Na

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Figure 5. Variability of cane yield at different plantation sections (2000-2010) *(*Refer Fig. 1 for plantation sections*)

Figure 4. Spatial maps of groundwater depth and soil salinity *(produced based on universal kriging in ArcGIS)*

Figure 3. Water distribution for irrigation based on: (a) USSL (1954) diagram; (b) Wilcox (1955) diagram; (c) Thorne and Thorne (1951) diagram

Figure 2. Collins Diagram: Comparison of chemical composition (*in percentage*) of major ions

Figure 1. Map showing Lake Basaka, Matahara sugarcane plantation sections and sampling sites for the various water types considered