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Impact of irrigation with Lake Abaya water on soil quality – southern Rift Valley, Ethiopia

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ABSTRACT

The study's aim was to assess the impact of using water from Lake Abaya for irrigation and its impact on soil quality at Mirab Abaya, Ethiopia. Six water samples from the edge of Lake Abaya and 30 (18 irrigated and 12 rain-fed) composite soil samples from farm lands in Wajifo, Fura and Algae were collected. Analyses showed that the use of water from Lake Abaya will bring a soil salinity hazard in future. The soil analyses showed variations in space and time in the physico-chemical components in the study area. The highest salinity was reported from Algae, the closest site to the Lake. The highest soil alkalinity was reported from Wajifo, which has a long irrigation history. The irrigated soils reported higher salinity than the rain-fed soils, indicating that water from Lake Abaya can affect irrigated soil quality. In general, Lake Abaya water is not suitable for salt-sensitive crops and caution is required in using it for irrigation.

Key words: irrigation water quality, Lake Abaya, Mirab Abaya, salinity, sodicity, soil quality

HIGHLIGHTS

- Irrigation water quality is equally important as drinking water quality for sustainable and efficient irrigation project implementation.
- If the irrigation water quality deteriorates it has its own impact on soil quality.
- Due to that, irrigation water quality assessments will be mandatory for the implementation of efficient irrigation projects.

INTRODUCTION

In Ethiopia, agriculture accounted for 42% of GDP in 2014 and about 85% of export earnings in 2010. It employs 83% of the active population (MoA 2011). Smallholders dominate the sector and the landholdings are increasingly fragmented. In 2015, there were 15.6 million agricultural households with an average farm size of 0.95 ha (CSA 2015). Ethiopian agriculture is primarily rain-fed and, as rainfall is highly erratic, there is a high risk of intra-seasonal dry spells and annual droughts. The government, therefore, promotes irrigation at the large, medium and small scale in its strategic plans.

The water management of small-scale irrigation schemes is the responsibility of the farmers themselves, mainly through informal/traditional community groups. Apart from the provision of extension and training services to the water user associations by the Ministry of Agriculture (MoA), no institution is directly involved in water management in small holder-irrigated agriculture. The absence of any appropriate local-level organs catering for small-scale irrigation has led to a lack of formal support to guide irrigation operation and maintenance at the community level. With irrigated areas and user numbers increasing, irrigation water management and water allocation rules are becoming more complex and problematic. The problems of smallholder irrigation farmers include loss of farmland, wastage of water and random water use without checking its suitability for irrigation. Good-quality crops can be produced by applying high-quality irrigation water if other inputs are optimal (Kitila *et al.* 2014). Likewise, irrigation with water of marginal quality could lead to the buildup of new soil characteristics that affect its fertility and lead to lower productivity (Belic *et al.* 2013). These impacts are commonly described in terms of salinity, sodicity, infiltration rate and toxicity (Ayers & Westcot 1985).

Salt accumulates in the soil when water evaporates from the soil surface, affecting crop growth adversely (Al-Rashdi & Sulaiman 2015). Salinity problems are found in and around irrigation projects. For example in the Awash Rift Valley, in central-eastern Ethiopia, some 4,114 ha (40%) of productive agricultural land was abandoned due to salinity between five and eight years after irrigation began (Taddese & Abegaz 2003).

The recent extensive use of Lake Abaya water for irrigation in the southern Rift Valley in Mirab Abaya district, Ethiopia, worries many stakeholders. Since about 2010, the western part of the Lake has been widely used for vegetable and fruit irrigation where the wetlands and bush have been cleared, using water pumped from Lake Abaya to supplement low rainfall (Abebe & Shewa 2017; Agidew & Amanuel 2018). Currently, farmers have no information about Lake Abaya water quality, and the local agricultural office only supplies pumps, not help with water quality analysis, irrigation operations or further soil impacts of the particular irrigation water. The short- and long-term effects of lake water use on soil quality are not good under such farming practices. Therefore, this study aimed to evaluate the impacts of using Lake Abaya water for irrigation on soil quality and sustainability. The specific goals were to (1) evaluate current soil salinity/sodicity and investigate changes after harvesting; (2) study lake water quality and soil water characteristics in the context of salt and nutrient loading to soils; (3) compare the soil quality changes in rain-fed and irrigated land; and (4) determine the suitability of Lake Abaya water for irrigation.

MATERIALS AND METHODS

Locations and site description

The study was carried out in Mirab Abaya District, Southern Rift Valley, Southern Ethiopia, about 455 km from Addis Ababa. The district is bordered by Lake Abaya and has an elevation range between 1,170 and 2,700 m.a.s.l. The district covers about 1,405 km^2, of which 17,437 ha are used for farming. Currently around 7,000 ha of the land are suitable for irrigation. Figure 1 shows the study area and sampling sites.

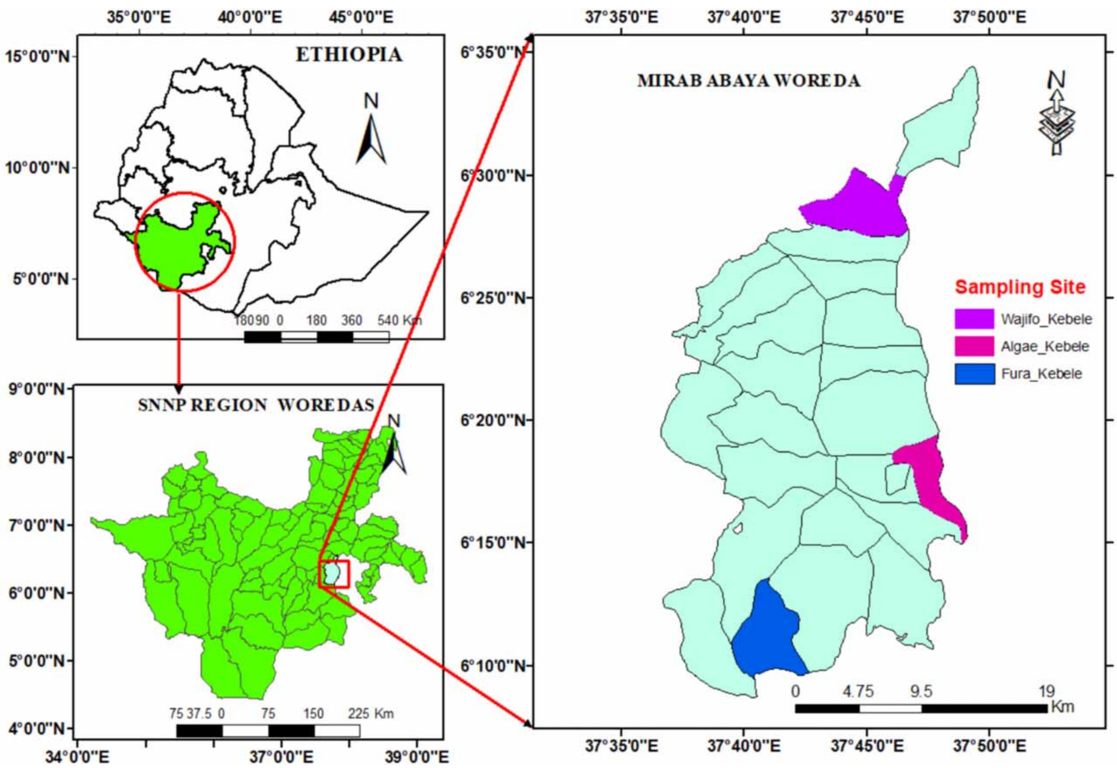

Figure 1 | Study area and soil sampling sites.

Since about 2012, 10 of the 23 'Kebeles' (smallest administrative structure) in the district have started using lake water for irrigation. The irrigated area has increased gradually by clearing the bushes around the lake buffer zone. It has been observed that some farmers have been forced, at the same time, to change crop type and abandon some of their land because of the soil quality deterioration.

Climate and agro-ecology

Mirab Abaya is characterized by moderately hot and dry climatic conditions with low and variable precipitation (Agidew & Amanuel 2018). The study area covers 62% of the district. Rainfall is bimodal, the highest occurring in April–May and September–October (rainy season). The rainy season is followed by the dry season from December to February, and it is sometimes dry in July and August (Abebe & Zeit 2015). The study area is characterized as arid and semi-arid, with mean annual rainfall of 863.7 mm. The minimum and maximum average air temperatures are 17.4 and 30.5 °C.

Farming

Both rain-fed and irrigation agriculture are practised. The irrigated crops include banana, pepper (capsicum), tomato, onion, potato and cabbage.

Sample collection

Water samples were collected at the point where irrigation water is withdrawn. Collection was done in 2 L plastic bottles from 20 cm below the water surface. The samples were stored in an icebox and transferred to Arba Minch University water quality laboratory for analysis. A total of six samples was collected from three sample stations during the study.

Soil samples were collected with an auger, pre- and post-harvest from Wajifo, Fura and Algae sites (all irrigated from Lake Abaya). Thirty composite soil samples were collected for analysis – see Table 1. At Wajifo and Fura both irrigated and rain-fed samples were taken, but only irrigated soil samples were collected at Algae. Each soil sample was collected from a depth of 0 to 20 cm. The sampling locations were determined using a Garmin GPS 60.

Table 1 | Soil sample locations, etc

				Number of samples			
				Irrigated		Rain-fed	
Site	Latitude, m	Longitude, m	Altitude, m.a.s.l.	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Wajifo	716,634.4	364,144.2	1,181	3	3	3	3
Fura	681,899.6	354,660.1	1,185	3	3	3	3
Algae	695,067.6	367,526.9	1,183	3	3	-	-

Water quality analysis

The water quality parameters were determined on the day of sampling. In case of delay, samples were stored at 4 °C. All analyses were conducted according to APHA (1999) unless otherwise stated.

Water temperature, electrical conductivity (EC), total dissolved solids (TDS) and pH were measured using a portable HQ40d meter (HACH) on-site and in the laboratory, consulting the manufacturer's manual. In the laboratory, the samples were filtered through 0.45 μm pore membranes to remove suspended solids before SO_4^{-2}, PO_4^{-3}, NO_3^-, Na^+ and K^+ determination. Nitrate and phosphate were determined by UV-spectrophotometry at 420 and 690 nm respectively, and Na^+ and K^+ were determined by flame photometry (Olubanjo & Alade 2018). Total hardness, Ca^{2+} and Mg^{2+} were determined using standard ethylenediaminetetraacetic acid (EDTA) titration (Dinka 2016). Sample chloride content was determined by standard silver nitrate titration, while CO_3^{-2} and HCO_3^- were determined by titration with 0.02 N H_2SO_4 and an appropriate indicator. Sulfate was determined by turbidity meter.

Soil quality analyses

Soil samples were air-dried, crushed and sieved (2 mm) for physico-chemical analyses. The soil quality parameters determined and methods employed are given in Table 2.

Irrigation water suitability evaluation

The suitability of Lake Abaya water for irrigation was evaluated on the basis of pH, EC, and major cation and anion concentrations, as well as salinity indices (RSC, SAR, SSP, KR, PI, PS, and MAR) – Table 3 shows the relevant equations used in this study. Piper and Wilcox diagrams were also used to evaluate the lake water.

Table 2 | Soil quality determinations

Parameter	Method(s)
pH	Potentiometric (1:2.5 H_2O, v/v)
EC	Conductometry (1:2.5 H_2O, v/v)
Soil texture	Hydrometer
Organic carbon (OC)	Walkley Black
Total nitrogen (TN)	Kjeldahl
Av. phosphorus (AvP)	Olsen
Cation exchange capacity (CEC)	Ammonium acetate (1M NH_4AC)
Soluble sodium (Na^+)	Flame photometry
Soluble potassium (K^+)	Volumetric and instrumental
Soluble calcium (Ca^{2+})	EDTA (0.05 N) titrimetric
Soluble magnesium (Mg^{2+})	
Carbonate (CO_3^{-2})	Volumetric and instrumental
Bicarbonate (HCO_3^-)	Titration with 0.01 N H_2SO_4
Chloride (Cl^-)	Titration using 0.05 N $AgNO_3$
Sulfate (SO_4^{-2})	Volumetric and instrumental

Table 3 | Salinity index equations

Index and Equation	Definition	Reference
$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	Sodium adsorption ratio	Ayers & Westcot (1985)
$ESP = \frac{(1.00(-0.0126 + 0.01475(SAR))}{1 + (-0.0126 + 0.01475(SAR))} \times 100$	Exchangeable sodium percentage	Shainberg & Letey (1984)
$SSP = \frac{Na^+ + K^+}{Mg^{2+} + Ca^{2+} + Na^+ + K^+} \times 100$	Soluble sodium percentage	
$MAR = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} * 100$	Magnesium adsorption ratio	
$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	Kelly ratio	Hwang *et al.* (2017)
$RSC = (CO_3^{-2} + HCO_3^{-2}) - (Ca^{2+} + Mg^{2+})$	Residual sodium carbonate	
$RSBC = HCO_3^{-2} - Ca^{2+}$	Residual sodium bicarbonate	
$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Na^+ + Ca^{2+} + Mg^{2+}} \times 100$	Permeability index	
$PS = Cl^- + \frac{SO_4^{2-}}{2}$	Potential salinity	

Key informant interviews

Key informant interviews about the irrigated farms and the advice offered to farmers were held at the local government agricultural offices when the study started. Interviews were also held with farm owners and workers during data collection. Field visits were conducted during the soil and water sampling to find out about salinity, type of crop, abandoned farms, etc.

Data analysis

The soil physico-chemical data obtained were analyzed statistically using SPSS version 21 (Getintopc 2013). Mean comparisons of soil properties were done before and after harvest using ANOVA at 95% confidence interval. The physico-chemical data for the water were subjected to descriptive statistics using MS Excel 2016, and the Piper and Wilcox diagrams using Aqua Chem 2014.2 (Getintopc 2013).

RESULTS AND DISCUSSION

Lake Abaya water quality

The minima, maxima and means of the physico-chemical parameters of the Lake Abaya water and the recommended values of FAO for irrigation purpose are shown in Table 4.

Table 4 | Lake Abaya water quality at Mirab Abaya

Parameter	Units	Minimum	Maximum	Mean ± SD	FAO Value
EC	dS/m	1.13	1.73	1.4 ± 0.1	0–3
TDS	mg/L	578.00	911.00	703.8 ± 57.8	0–2000
pH		7.90	9.30	8.5 ± 0.2	6–8.4
Total hardness	mg-$CaCO_3$/L	66.00	180.00	126.0 ± 18.1	–
Calcium (Ca^{2+})	meq/L	1.56	2.20	1.8 ± 0.1	0–20
Magnesium (Mg^{2+})	meq/L	0.44	2.80	1.8 ± 0.4	0–5
Sodium (Na^{+})	meq/L	13.27	44.28	22.4 ± 4.8	0–40
Potassium (K^{+})	meq/L	0.48	0.89	0.6 ± 0.1	0–0.1
Sulfate (SO_4^{3-})	meq/L	0.81	5.16	2.4 ± 0.7	0–20
Carbonate (CO_3^{2-})	meq/L	0.33	1.67	1.2 ± 0.2	0–1
Bicarbonate (HCO_3^{-})	meq/L	6.36	10.50	7.9 ± 0.6	0–10
Chloride (Cl^{-})	meq/L	3.16	7.19	5.2 ± 0.7	0–30
Phosphate (PO_4^{3-}-P)	meq/L	<LoD	<LoD	<LoD	0–0.02
Nitrate (NO_3^{-})	meq/L	<LoD	0.01	<LoD	0–0.16
Total alkalinity	mg-$CaCO_3$/L	474.00	716.00	551.3 ± 34.5	–

LoD = Limit of detection.

EC and TDS are important parameters in determining the salinity effects of irrigation water in agriculture (Laze *et al.* 2016). The minimum and maximum values of EC and TDS for Lake Abaya water were within the FAO's recommended range, showing that the water meets the minimum requirements for irrigation. It is classified as slightly to moderately saline water (0.7 to 3.0 dS/m), which can be used for salt-tolerant crops (Ayers & Westcot 1985).

Sodium is highly soluble and usually present in water. It is frequently associated with salinity problems when linked to chloride and sulfate ions (Ogunfowokan *et al.* 2013). The sodium concentration in Lake Abaya water was within the recommended limit. The vegetables grown in the study sites are classified as moderately sensitive and can tolerate 5 to 10 meq-Na/L (CCME 2008). However, the maximum concentration found exceeds the recommended limit, indicating that use of this water may pose a soil sodicity hazard at times. The water's potassium content exceeds the limits suggested by Ayers & Westcot (1985), perhaps due to the potassium-based fertilizer residues in the agricultural runoff. This may also have caused the rise in potassium content in the lake (Kitila *et al.* 2014).

Figure 2 is a Piper diagram of Lake Abaya water.

Figure 2 shows that 5 of the 6 samples were dominated by bicarbonate, in terms of anions; with no dominant anionic type in the sixth. All samples were dominated by sodium and potassium in terms of cations. The upper part of the figure shows that all samples are of sodium bicarbonate type, i.e., the water is alkaline. Lake Abaya water is therefore slightly unsuitable for irrigation and long-term use of it may cause soil salinity.

Salinity indices of Lake Abaya water for irrigation

The suitability of Lake Abaya water for irrigation was determined using various indices – Table 5.

SAR is an estimate of the degree to which sodium is absorbed by the soil concerned (Bauder *et al.* 2008). High SAR values suggest a sodium hazard, by the replacement of soil Ca and Mg with Na by cation exchange (Laze *et al.* 2016). This is undesirable because it can damage the soil structure, affect its fertility and lower crop yields (Marchuk 2013).

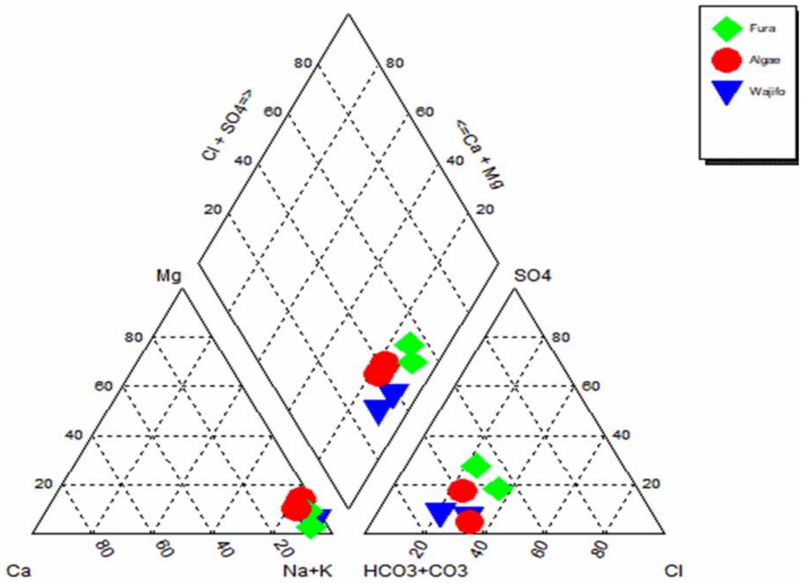

Figure 2 | Piper diagram of Lake Abaya waters.

Table 5 | Lake Abaya water salinity indices for irrigation

Irrigation WQI	Mean ± Std	Ayers & Westcot (1985)	Suitability for irrigation
SAR	16.8 ± 3.3	0–26	Fair
SSP (%)	85.0 ± 2.1	0–60	Poor
MAR (%)	47.6 ± 7.0	0–50	Suitable
KR	6.3 ± 1.2	0–1	Unsuitable
RSC (meq/L)	5.4 ± 0.5	0–2.5	Unsuitable
PI (%)	96.7 ± 1.2	25–75	Class I (Good)
PS	6.4 ± 0.8	0–10	Good

NOTE: SAR=sodium absorption ratio, *SSP*=soluble sodium percentage, KR=kelly ratio, RSC=residual sodium carbonate, PI=permeability index, PS=potential salinity.

Lake Abaya water is classified with high salinity and sodium hazard (C3-S4) according to the Wilcox Diagram (Figure 3). The water is sodic-saline and may affect soil properties. Its SSP value also exceeds the FAO recommended level for irrigation. SSP exceeding 60% can cause sodium accumulation in soil (Kadyampakeni *et al.* 2018).

Lake Abaya water's mean KR value was 6.3 ± 1.2, implying that it is not suitable for irrigation because of excess sodium content. This is in line with an earlier study by Talabi *et al.* (2017). RSC is also used to estimate the carbonate content's potential hazardous effect in irrigation (Kadyampakeni *et al.* 2018), and Lake Abaya water is unsafe as its RSC exceeds 2.5 meq/L. The high concentration of bicarbonate indicates a tendency for Ca^{2+} and Mg^{2+} to precipitate in the soil (Laze *et al.* 2016; Husien *et al.* 2017).

In general, Lake Abaya water has moderate alkalinity and salinity hazards, so effective drainage is required to make its use sustainable in irrigation. The crops grown currently in the Mirab Abaya area are salt-sensitive. Therefore, consideration should be given to growing salt-tolerant crops, to use Lake Abaya water for irrigation.

Soil quality

Soil texture

The soil texture classes in the study area are shown in Figure 4.

The soil textural classes pre- and post-harvest at Wajifo, Fura and Algae were silty clay, silty clay loam and clay loam, respectively. The soil at Fura has the highest silt content of the three. High silt content can increase the probability of major cation and anion accumulation in the soil from lake water.

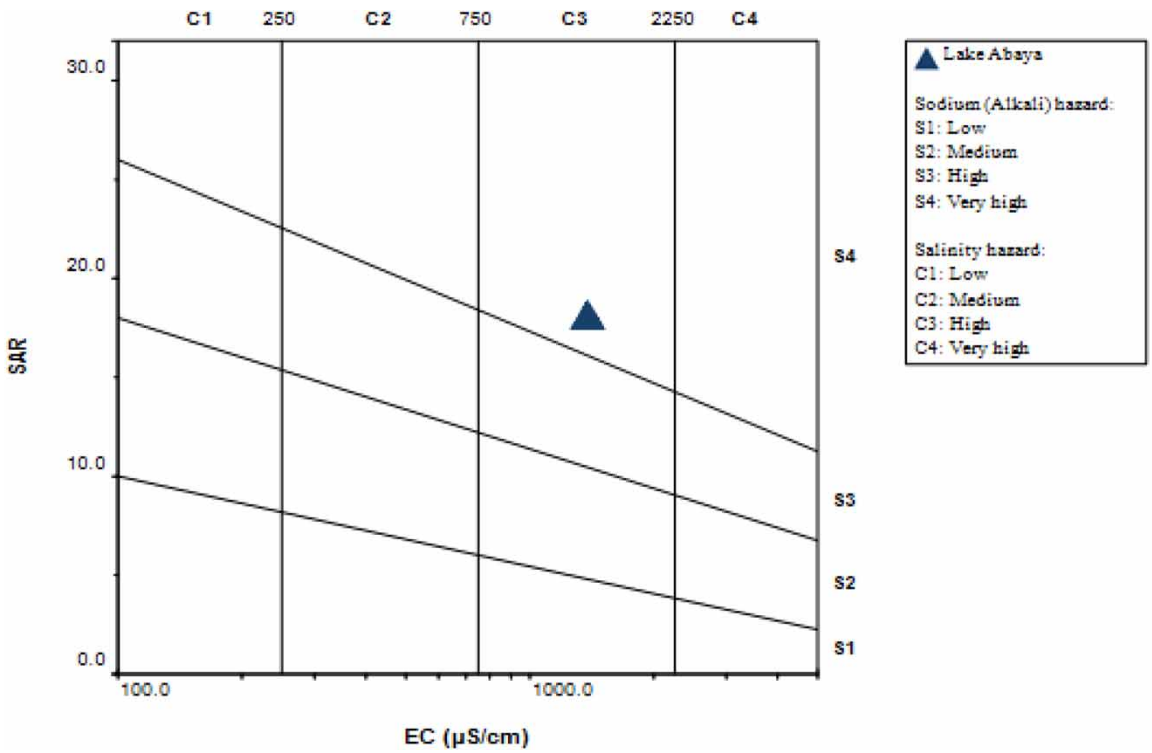

Figure 3 | Wilcox diagram for Lake Abaya.

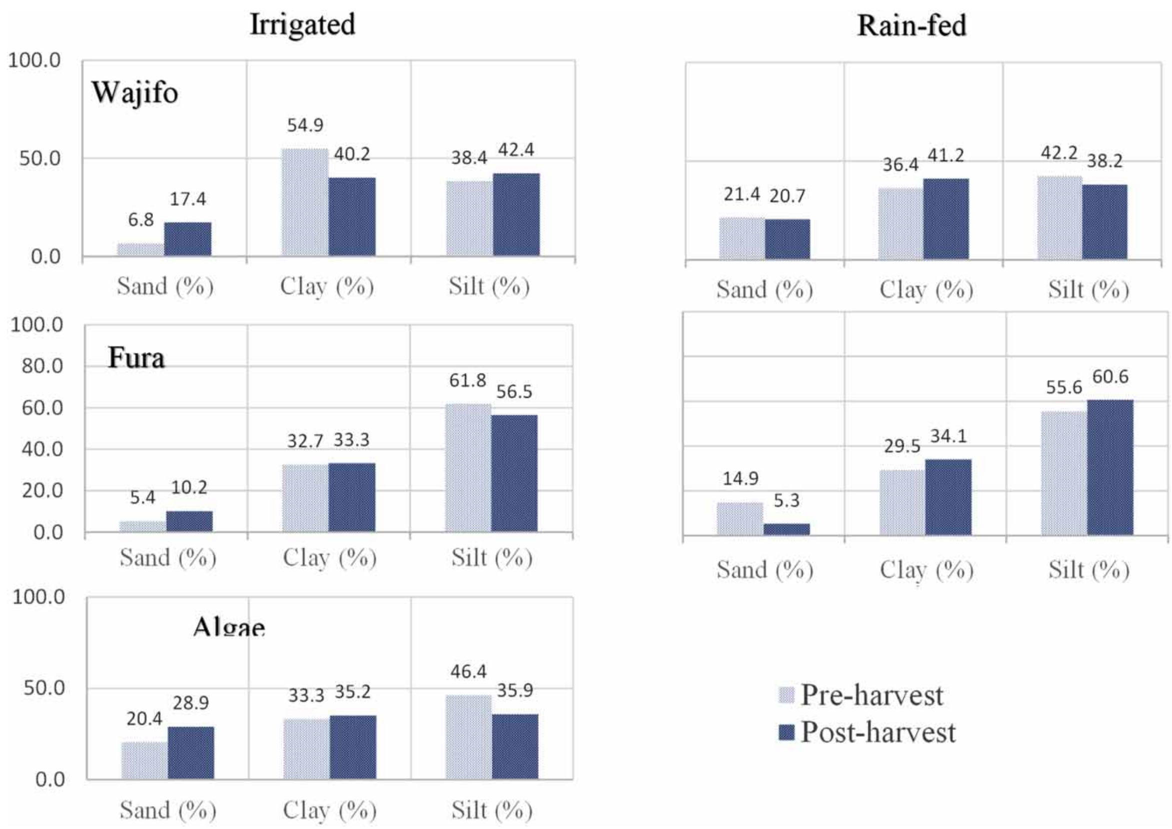

Figure 4 | Soil textures on the farm in the study.

Soil quality irrigated with Lake Abaya water

The soil quality at Wajifo, Fura and Algae is reported in Table 6.

As shown in Table 6, soil pH at Wajifo, Algae and Fura pre- and post-harvest was numerically different, but the differences were statistically insignificant at the 95% confidence interval (p=0.06, 0.88, 0.98, respectively). The soil pH was also similar for irrigated and rain-fed areas. The variation in pH of the irrigated soils is less than that of the rain-fed soils, and statistically insignificant at 95%, however, so Lake Abaya water did not affect soil pH. When the soil pH is below 8.2, the soil is saline; when it exceeds 8.2, it is alkaline (Ayers & Westcot 1985; Lord 2008), so the soil is slightly alkaline.

The soil EC at Wajifo and Fura fell between the pre- and post-harvest seasons, but the changes were insignificant at 95%. The fall in EC might be due to leaching in the rainy season during the observation period. However, the soil EC at Algae rose and the increase was statistically significant.

The changes in OC (p=0.031), ESP (p=0.047), CEC (p=0.003), and sulfate (p=0.031) were all statistically significant (at 95%) in the Wajifo irrigated soil, but were all insignificant in the rain-fed soil.

Soil – major cations and anions

The major soil cations and anions – in both irrigated and rain-fed soils – are shown in Figure 5. Na+ and Cl- report the highest cationic and anionic concentrations, respectively. The differences between them, however, are statistically insignificant, indicating that sodium chloride is the dominant soil salt type.

As shown in Figure 5 there are statistically significant differences (95%) in the Na (p=0.00), Ca (p=0.03), Mg (p=0.00), Cl (p=0.01), and SO_4 (p=0.03) in the irrigated Fura soil, but the differences were insignificant in rain-fed soil. The average soil SAR values at Algae, Wajifo, and Fura are within the FAO recommended range of 0 to 9 (Ayers & Westcot 1985). If a soil's KR is below 1.0, it can be irrigated (Hwang *et al.* 2017). The average KRs for the soils at Algae and Fura both exceeded 1.0, indicating soil sodium hazards. The average RSC values at all irrigation sites are below the 1.25 meq/L recommended maximum (Okubay 2019), indicating that calcium and magnesium are more abundant in the soil than carbonate and bicarbonate, and the soil bicarbonate concentrations are too low to impede crop growth (Okubay 2019).

The value differences of ESP, SSP, and MAR (Table 7) are not statistically significant between pre- and post-harvest. Soil PI and PS differences at Fura, on the other hand, were statistically significant (95%).

The laboratory analyses of soil and irrigation water, on-site observation in April and December 2019, and key informant interviews of farm owners, all show that the major source of solutes in the farm land studied is Lake Abaya water. Although the soil type is important, soil salinization is a combination of solute transport towards the root zone to replenish evaporation and transpiration losses, and limited soil washing by rain or relatively low salt content irrigation water. Nachshon (2018) notes that key factors in soil salinization include climate, soil properties, groundwater level and irrigation water. Thus, more salinized soils are found closer to the lake (shallow groundwater) in the Mirab Abaya district, which is characteristically semi-arid and arid, where precipitation is less than evaporation – a characteristic of the Southern Great Rift Valley in eastern Africa.

A solution could be to irrigate sufficiently to leach the salts contributing to salinity, using the relationship in Equation (1). The excess water that removes salts from the root zone is the 'leaching fraction' (LF), defined as the fraction or proportion of the water penetrating below the root zone to lower the soil salinity below a specified level (Ayres & Westcot 1985; Nachshon 2018).

$$LR = \frac{EC_I}{5EC_T - EC_I} \tag{1}$$

where,

- LR (leaching requirement)=the extra water needed to leach solutes below the root zone:
- EC_I=the electrical conductivity of the irrigation water;
- EC_T=the electrical conductivity of the saturation extract of the irrigation water.

As a mechanism for reducing the salinization of smallholders' agricultural land, the relevant officers working in the sector must support farmers with proper information about leaching requirements, drainage techniques, cultivation practices, available biological solutions and water source blending to ensure sustainable irrigation and income.

Table 6 | Soil quality at the farming areas studied

Parameter	Wajifo						Fura						Algae		
	Irrigated			Rain-fed			Irrigated			Rain-fed			Irrigated		
	Pre-harvest	Post-harvest	Sig.	Pre-harvest	Post-Harvest	Sig.	Pre-harvest	Post-harvest	Sig.	Pre-harvest	Post-harvest	Sig.	Pre-harvest	Post-harvest	Sig.
pH.H_2O (1:2.5)	8.04 ± 0.10	8.46 ± 0.12	0.06	8.02 ± 0.03	8.03 ± 0.06	0.96	7.973 ± 0.03	7.97 ± 0.22	0.98	8.24 ± 0.15	8.25 ± 0.09	0.96	8.22 ± 0.24	8.26 ± 0.14	0.88
EC (dS/m) (1:2.5)	0.33 ± 0.06	0.30 ± 0.00	0.64	0.13 ± 0.03	0.10 ± 0.00	0.37	0.30 ± 0.06	0.20 ± 0.00	0.16	0.47 ± 0.14	0.23 ± 0.03	0.19	0.37 ± 0.09	0.73 ± 0.24	0.23
OC (%)	1.50 ± 0.09	0.96 ± 0.14	0.03	1.13 ± 0.10	1.19 ± 0.03	0.59	0.75 ± 0.08	0.55 ± 0.09	0.18	0.98 ± 0.25	0.54 ± 0.01	0.15	1.55 ± 0.34	1.72 ± 0.04	0.64
TN (%)	0.16 ± 0.00	0.12 ± 0.02	0.17	0.12 ± 0.00	0.16 ± 0.03	0	0.10 ± 0.01	0.07 ± 0.01	0.24	0.12 ± 0.04	0.07 ± 0.00	0.26	0.21 ± 0.05	0.23 ± 0.01	0.64
AvP (mg-P_2O_5/kg)	68.17 ± 2.94	55.92 ± 4.73	0.09	49.77 ± 3.35	51.92 ± 4.56	0.72	53.77 ± 7.84	64.87 ± 10.8	0.45	47.82 ± 4.76	54.91 ± 11.89	0.61	59.25 ± 7.27	78.07 ± 8.68	0.17
CEC (meq/100gm)	71.65 ± 1.12	55.15 ± 2.27	0.01	60.77 ± 0.97	59.48 ± 2.79	0.68	59.36 ± 3.18	58.91 ± 0.17	0.89	61.27 ± 3.73	54.07 ± 0.24	0.13	60.93 ± 2.58	56.73 ± 0.29	0.18

Sig. = significance difference at $p = 0.05$.

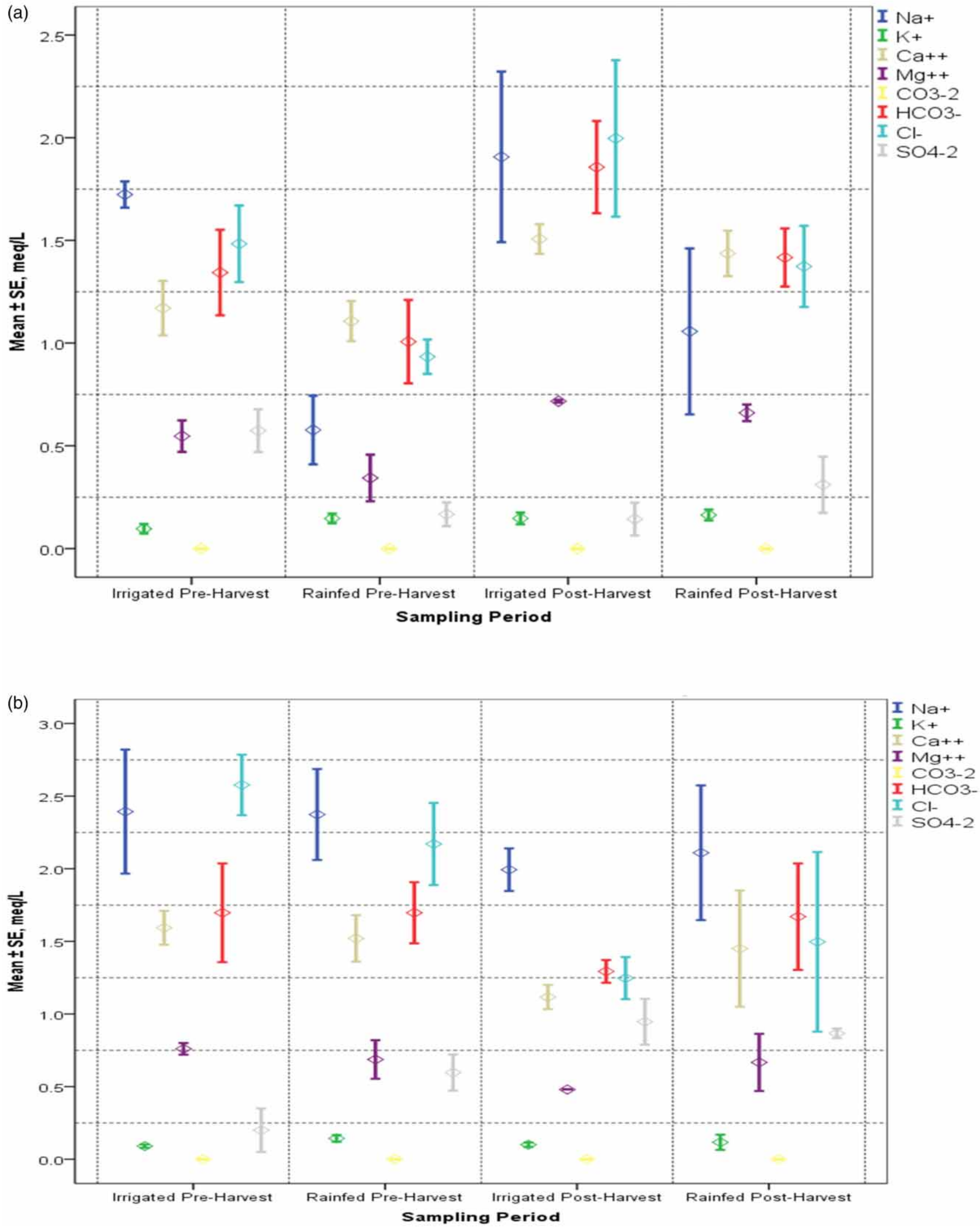

Figure 5 | Major soil cation and anion concentrations. (a) Wajifo. (b) Fura. (c) Algae. *(continued)*.

CONCLUSIONS

The physico-chemical qualities of Lake Abaya water were shown, generally, to be moderately safe for irrigation use. The salinity indices, however, indicated that there might be salinity and alkalinity hazards. Lake Abaya water is, thus, unsuitable for salt-sensitive crops without remedial measures such as leaching and drainage facilities, for sustainable crop production.

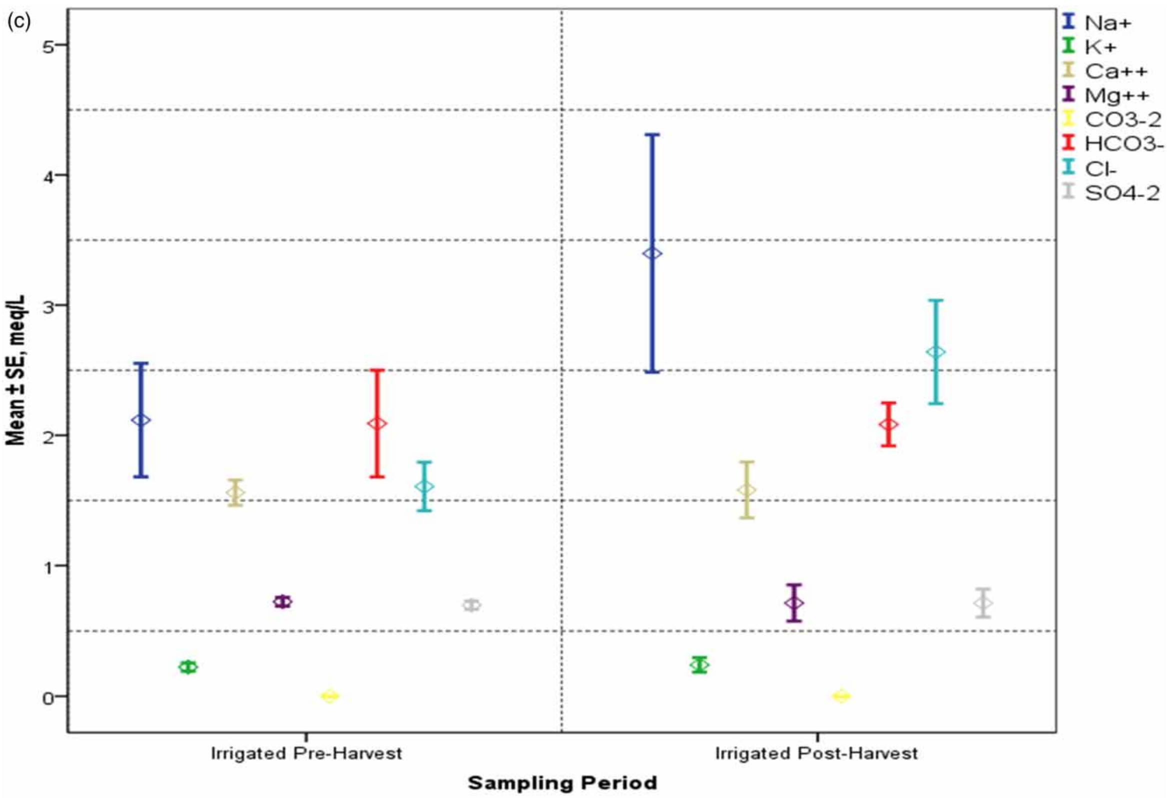

Figure 5 | Continued.

Table 7 | Irrigated soil quality indices for Algae, Wajifo and Fura

	Algae			Wajifo			Fura		
Indices	**Pre-harvest**	**Post-harvest**	***P***	**Pre-harvest**	**Post-harvest**	***P***	**Pre-harvest**	**Post-harvest**	***P***
SAR	2.0 ± 0.5	3.4 ± 1.2	0.34	1.9 ± 0.1	1.8 ± 0.4	0.86	2.2 ± 0.3	2.2 ± 0.1	0.92
KR	1.0 ± 0.2	1.7 ± 0.7	0.39	1.0 ± 0.1	0.8 ± 0.2	0.40	1.0 ± 0.1	1.2 ± 0.1	0.13
RSC (meq/L)	−0.2 ± 0.5	−0.2 ± 0.5	0.98	−0.4 ± 0.2	−0.4 ± 0.2	0.98	−0.7 ± 0.2	−0.3 ± 0.2	0.28
ESP (%)	1.7 ± 0.7	3.5 ± 1.6	0.34	1.5 ± 0.1	1.4 ± 0.5	0.85	1.9 ± 0.5	2.0 ± 0.2	0.91
SSP (%)	49.6 ± 6.7	59.7 ± 8.3	0.39	51.8 ± 2.0	47.1 ± 4.6	0.40	50.6 ± 3.2	56.7 ± 0.6	0.13
MAR (%)	31.7 ± 1.1	30.7 ± 1.3	0.57	31.8 ± 1.6	32.3 ± 1.1	0.80	32.4 ± 0.5	30.2 ± 1.7	0.29
PI	32.9 ± 1.3	26.5 ± 2.3	0.07	84.0 ± 3.7	78.4 ± 3.6	0.34	77.0 ± 2.6	87.5 ± 2.6	0.05
PS	2.0 ± 0.2	3.0 ± 0.4	0.10	1.8 ± 0.2	2.1 ± 0.4	0.50	2.7 ± 0.3	1.7 ± 0.2	0.05

Some statistically significant differences were observed between pre- and post-harvest season soil sample parameters. No such differences were found in the rain-fed soil parameters. This indicates that Lake Abaya water can cause secondary salinity and alkalinity in soil that is irrigated repeatedly for a long period, perhaps leading to non-productive land. Local professionals need, therefore, to support farmers in selecting water and farms for irrigation, and making such operations sustainable.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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