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RESEARCH ARTICLE

CHARACTERIZATION OF SALT AFFECTED SOILS AND IDENTIFICATION OF SALINITY SOURCES IN IRRIGATED SOILS: THE CASE OF SMALL SCALE IRRIGATION SCHEMES IN ADAMI TULU JIDO KOMBOLCHA AND ZIWAY DUGDA DISTRICTS IN THE CENTRAL RIFT VALLEY OF ETHIOPIA

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ABSTRACT: Soil salinity is an environmental threat that impedes productivity of crops particularly in arid and semi-arid areas. This research aimed to assess the status, causes, effects and ameliorative measures of soil salinity in irrigated fields in Central Rift Valley of Ethiopia. A total of 40 composite soil samples were collected from groundwater and river irrigated farm plots and corresponding rain-fed plots, and analyzed for pH, EC, TDS, CEC, ESP, Exchangeable Na, bicarbonate, and sum of anions. Similarly, a total of 12 composite water samples from the groundwater and rivers were collected and analyzed for pH, EC, TDS, Na, K, Ca, Ma, Cl, B, SO_4 and CO_3. In addition, focus group discussion and interviews were conducted with irrigation user farmers. The result showed that farm plots irrigated with groundwater from sodic soil environment with Exchangeable Sodium Percentage (ESP) >15 and areas irrigated with Bulbula River are becoming sodic with an average ESP value of 13.5. Irrigation user farmers who participated in the social survey indicated that soil salinity-sodicity adversely affected growth of vegetables, land productivity and household economy. The social survey also indicated that farmers lack knowledge, skills and capital to apply various ameliorative measures of soil salinity and sodicity. This requires monitoring of irrigation water, planting salt tolerant crops, designing environmentally friendly irrigation practices and empowering farmers on farming practices in order to mitigate and ameliorate soil salinity-sodicity problems, and to enhance sustainability of irrigation farming in the study areas.

Key words/phrases: Exchangeable Sodium Percentage (ESP), Focus group, Sodicity, Soil salinity.

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INTRODUCTION

Soil salinity is one of the serious challenges facing irrigated agriculture, especially in arid agro-ecosystems (Bouksila *et al*., 2013; Valipour, 2014). Globally, about 831 million hectares of land is salt-affected (Martinez-Beltran, 2005). The productivity of nearly 20–30 million hectares of irrigated land has significantly decreased and about 250,000–500,000 hectares of land is lost each year (FAO, 2002). Soils can be saline due to many factors such as weathering of parent materials, irrigation water, fertilizer and shallow groundwater (Shahid, 2013). Salinity severely affects crop production in irrigated regions of the world particularly in arid and semiarid areas where evapotranspiration exceeds annual precipitation (Datta and De Jong, 2002).

Irrigation is a vital tool to improve the subsistence-oriented farm households' economy to assure food security in Ethiopia (Fitsum Hagos *et al*., 2009). In the study area, Central Rift Valley (CRV) of Ethiopia, extreme rainfall variability has a serious impact on food security due to the dependency of the population on climate-sensitive subsistence farming (Pascual-Ferrer *et al*., 2014; Yenesew Mengiste, 2015; Alemayehu Muluneh *et al*., 2017). Irrigation is known to play a crucial role to enhance the adaptive capacity of farmers and expansion of farming areas (Seleshi Bekele *et al*., 2010; Engdasew Feleke *et al*., 2020). For this purpose, different water sources such as lakes, streams and river diversions, groundwater, dams and perennial springs are used for small scale irrigation schemes (SSIS) in the CRV of Ethiopia.

Soil salinization is among the critical environmental effects of irrigation, which impede sustainability of production (Shegena Zewdu *et al*., 2017; Kbrom Ambachew, 2018). The problem is more pronounced in the arid and semi-arid areas like the CRV, especially with the use of groundwater for irrigation (Datta and De Jong, 2002; Shegena Zewdu *et al*., 2017). Over the last 30 years, intensive cultivation has increased land degradation in the CRV (Derege Tsegaye *et al*., 2012). In Ethiopia, 11,033,000 hectares of land are affected by salt. Most of this area is found in the Rift Valley zone where groundwater is used for irrigation (Mohamed Seid and Tessema Genanew, 2013). Mihret Dananto *et al*. (2013) also reported a decline in the quality of the soil in irrigated farm plots at CRV of Ethiopia due to continuous cultivation, and intensification of agricultural production through irrigation.

According to Van Halsema *et al*. (2011), any strategy that targets to increase irrigation efficiency in CRV should include interventions to improve crop productivity and economic returns from small scale irrigation (SSI). Therefore, it is imperative to investigate the status of soil salinity in irrigated farmlands in the CRV area because of the long years of irrigation farming and high prospect of irrigation expansion (Dejene Abera *et al*., 2018). Few studies are already available related to assessing the soil salinity in irrigated plots in Ethiopia (Kefyalew Assefa and Kibebew Kibret, 2016; Shegena Zewdu *et al*., 2017; Kbrom Ambachew, 2018; Mulat Asmamaw *et al*., 2018). Yet, there is a need for more information to address soil salinity problem in irrigated farm plots incorporating laboratory analysis of soils and irrigation water sources in the study sites.

Thus, we believed that understanding about the soil salinity status and irrigation water quality plays a significant role to map the spatial distribution of salt affected soils and to determine the type of salinity. Such information is highly valuable for policy makers and development practitioners to design better policies and development intervention that targets sustainable irrigation based livelihood in drought prone areas, where irrigation is mandatory to overcome the effects of recurrent, chronic drought. Therefore, the aims of this research were to (1) determine the salinity status of the soil; (2) identify the factors that affect soil salinity development; and (3) explore the effects of salinity and ameliorative measures in mitigating the problems of soil salinity.

MATERIALS AND METHODS

Description of the study area

Central Rift Valley (CRV) of Ethiopia is located between, approximately 38°15′E to 39°25′E and 7°10′N to 8° 30′N (Fig. 1) covering an area of approximately 10,000 km^2. The altitude of the area ranges 1,500 m.a.s.l. in the lowest part to about 4,000 m.a.s.l (Mount Kaka) (Fitsum Dechasa *et al*., 2019). It is situated in Oromia regional state and the Southern Nations Nationalities and Peoples Region (SNNPR) as shown in Fig. 1. The mean annual rainfall is 900 mm, however, there is local variability of precipitation depending on altitudinal variation (Bedru Sherefa, 2006; Pascual-Ferrer *et al*., 2014). The rainfall amount varies from 600 mm in the central lowlands to about 1600mm per year in the highlands in the CRV area (Mezegebu Getnet *et al*., 2014). About 70% of the total rainfall is received during the main rainy season (June to September), while the remaining is received during the short rainy season (March to May) (Mezegebu Getnet *et al*., 2014). Most of the lowlands in the CRV is characterized with arid or semi-arid climate situation, erratic rainfall, and frequent drought occurrence (Derege Tsegaye *et al*., 2012).

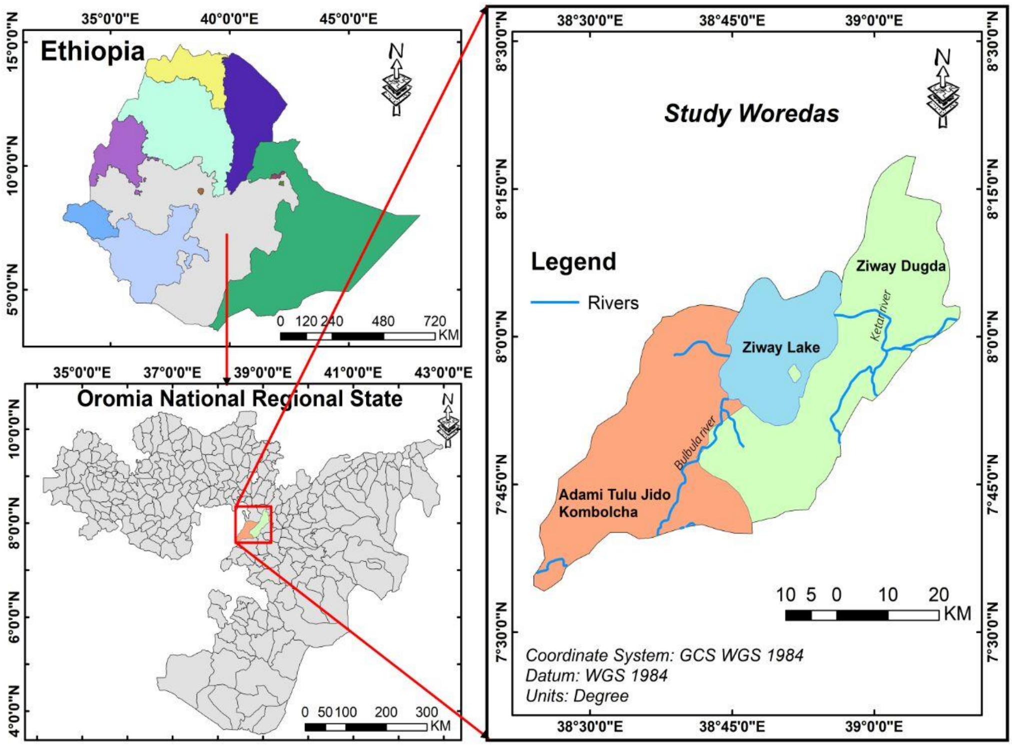

Fig. 1. Map of the study area.

The temperature also varies based on altitude. It ranges from 11.9°C–29.5°C in the lowland of CRV to 4.3°C–26°C in areas above 2500 m (Pascual-Ferrer *et al*., 2014). According to Gizachew Legesse and Andualem Shimeles (2014), all the districts in the CRV experienced severe drought risks at different times in the past.

The CRV of Ethiopia has different soil types with varied infiltration and runoff potential (Mezegebu Getnet *et al*., 2014). Coarse textured soils having high infiltration rates are dominantly found in the eastern and western highlands of the CRV of Ethiopia, and around the lakes in the valley floors. Medium textured soils with moderate infiltration rates dominate the eastern and western mid altitudes. Fine textured black soils (vertisols) with low infiltration dominate the foothills of western highlands and some areas in the central part of eastern CRV (Mezegebu Getnet *et al*., 2014).

The CRV of Ethiopia encompasses a network of rivers and a chain of four lakes (Ziway, Langano, Abyata and Shala), which are subdivided into seven connected sub-basins such as Ketar, Ziway, Meki, Bulbula, Langano, Horakelo and Abyata. The Meki and Ketar sub-basins drain to Lake Ziway through Meki and Ketar rivers respectively. Lake Ziway has natural overflow through the Bulbula River to Lake Abyata (Mezegebu Getnet *et al*., 2014). The lakes are highly productive, harbouring an indigenous population of edible fish and support a wide variety of other aquatic and wildlife. They are globally significant freshwater ecosystems containing important areas of both terrestrial and aquatic biological diversity (Tenalem Ayenew, 2007). Lake Ziway and its tributary rivers are used for irrigation, flower industry, soda abstraction, fish farming, domestic use and recreation (Tenalem Ayenew, 2007; Fitsum Dechasa *et al*., 2019). There is high competition for water resources among large- and small-scale irrigators, commercial farmers, fishery, industrial water use, domestic water use, nature and related eco-tourism (Jansen *et al*., 2007; Pascual-Ferrer *et al*., 2014).

Agricultural production and its related activities are the major bases that sustain the CRV economy; industry and service sectors have low contribution for the economy. Irrigation development in the area is curbed to the Lake Ziway sub-basin along Lake Ziway and between the discharge gauging stations of Meki, Ketar and Bulbula Rivers (Hengsdijk and Jansen, 2006; Pascual-Ferrer *et al*., 2014). Most of the cultivated land is found in the valley floor and the dominant field crops are teff, barley, maize, lentils, horse beans, chickpeas and field peas. Common vegetables are grown under irrigation and include haricot beans, tomato, onion, cabbage and broccoli (Hengsdijk and Jansen, 2006).

The CRV of Ethiopia is a closed basin, thus, relatively small changes in land use and ecosystem has significant adverse effect on the ecosystem (Tenalem Ayenew, 2007). The rate of deforestation is growing every year due to poor land management systems and conversion of naturally vegetated areas to agricultural land as a result of rapidly growing population (Derege Tsegaye *et al*., 2012). *Acacia* woodlands and savannas are the dominant vegetation types in the CRV. Abundant livestock population has played its part in the loss of vegetation and grass cover through overgrazing of range lands (Tenalem Ayenew, 2007).

Study area identification and sites selection

Adami Tulu Jido Kombolcha (ATJK) and Ziway Dugda districts were selected as study sites purposely due to their long-time experience in small scale irrigation (SSI) practices. ATJK and Ziway Dugda (study sites) were two of the districts among the worst hit by chronic drought and experienced the highest frequency of droughts (5 times in 33 years) and had highest probability of severe drought occurrence with 46 to 76% severity level in East Shoa zone of Ethiopia (Gizachew Legesse and Andualem Shimeles, 2014). Such climate risk factors make irrigation essential. Sampling sites were selected using google earth supported with field-based validation, and the land use polygons were created by digitization technique. The polygon of river water irrigated, groundwater irrigated, and rain-fed grid was saved as KML and converted to layer in ArcGIS and then the polygon was exported to shapefile. Soil sampling sites were selected depending on agricultural land uses and farming practices that take place in the area after discussing with the farmers in the study sites supported with GIS based field assessment as shown in Fig. 2. The area irrigated by each water source are 40.2, 222.8, 75 hectares by groundwater at Bochesa, Bulbula river at Bochesa and Dodicha and Ketar river at Sheled, respectively.

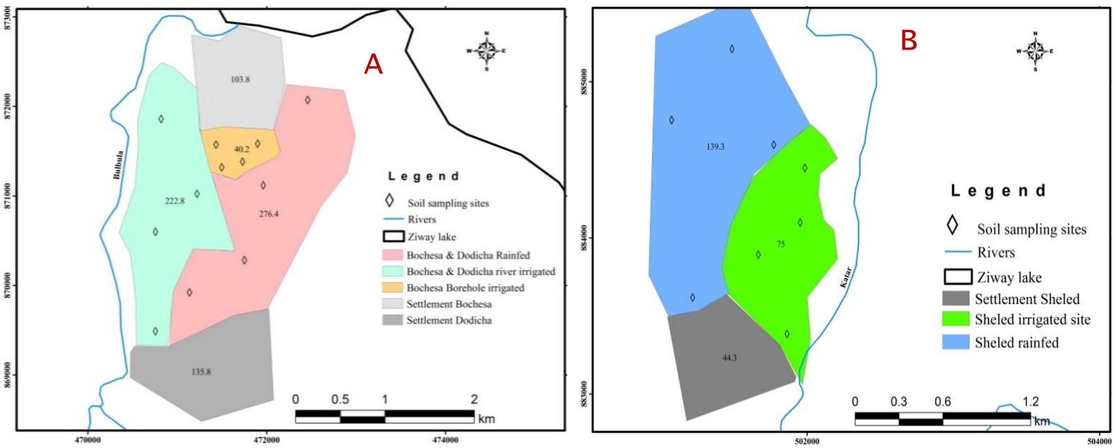

Fig. 2. Soil sampling sites (A[1]and B[2]).

Soil sample collection procedures

Soil samples were collected from the irrigated farms that use water from rivers (Bulbula and Ketar rivers) and groundwater and from farms that has

A[1] is the soil sampling site at Bulbula river and groundwater irrigated sites at Bochessa and Dodicha
B[2] is the soil sampling site at Ketar river irrigated sites at Sheled

grown crops only by rain (Bulbula farm and Ketar farm). They were excavated from 0–15 cm and 15–30 cm (separated by depth) of the top layer, composited and collected in one kilogram plastic bags and triplicated. In general, a total of 40 soil samples were taken for laboratory analysis (from farm plots irrigated using Bulbula river = 14 samples; Ketar River = 8; Groundwater = 11; Rain-fed = 7). Soil samples were collected during dry season after crops were harvested.

Fig. 3. Soil sampling techniques at different depths.

Water sampling sites selection and sampling procedures

GIS-based water sampling sites were selected as shown in Fig. 4 and water samples were collected from two types of sources involving the groundwater and surface water from upper part of Ziway lake (Ketar river) at Sheled and lower portion of the lake (Bulbula river) at Bochesa and Dodicha sites. Groundwater was pumped out to the pond within ten minute at different interval time from which one litre of homogenized sample from each site was collected. River water samples were taken from the source and the canal system. Eight litres of water was taken from each site and one litre was taken from the homogenates. All water samples were collected in clean plastic containers and transported to the laboratory using ice boxes. In general, a total of 12 water samples; four water samples were collected from Ketar river at diversion point and its canal systems, four water samples were collected from Bulbula river at pumping sites and four water samples were collected from groundwater at Bochesa site.

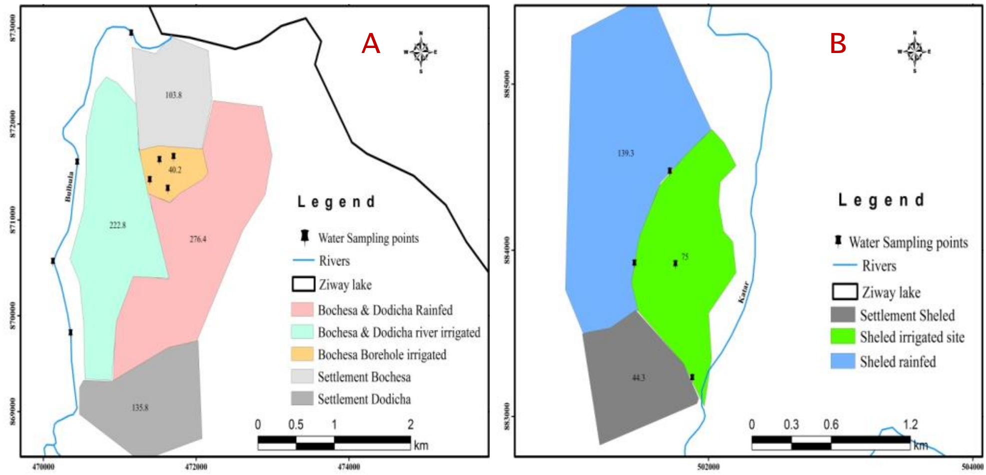

Fig. 4. Surface and ground water sampling sites (A[1]and B[2]).

Soil laboratory analysis methods

The laboratory analysis of soil and water was performed at the Ethiopian Water Works and Supervision soil and water laboratory following all the necessary procedures of standard laboratories and using different testing methods. Prob method was using to test the pH-H_2O and pH-KCL of the soil samples. In testing the chemical characteristics of soil samples ammonium acetate method was used for testing the parameters such as EC, Exch.Na, Exch.Ca, Exch.Ma, CEC, and Exchangeable Sodium. Besides, volumetric and instrumental testing methods were used to test the parameters of soluble salts (Paste Extract) such as ECsat.Ext., Na, K, Ca, Mg, CO-2, HCO_3^{-1} CL-1, SO_4^{-2} and Sodium Adsorption Ratio (SAR).

Irrigation water laboratory analysis methods

In the analysis of the quality of irrigation water, the concentrations of major cations of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Na^+, and K^+ were measured using a direct-current plasma spectrometer (DCP) calibrated using solutions prepared from plasma-grade single-element standards. Major anions of Chloride (Cl^-), and Sulfate (SO_4^{2-}) were analyzed using an ion chromatograph (IC). Total alkalinity (TA) was measured using titration techniques. The concentration of Boron (B) in the irrigation water was tested using ammonium acetate method. Total dissolved solid (TDS) was analyzed using Pocket Pro TDS Tester, low range.

[1] A is water sampling sites at Bulbula river and groundwaters
[2] B is water sampling sites at Ketar river and its canal systems

Statistical analysis methods

SPSS and Excel software were used for analysis of the result such as ANOVA and tested with least significant difference (LSD) test at an alpha (α/2) of 0.05 (95% confidence interval) to differentiate the variables or the parameters significantly different in terms of its composition and effect. After the laboratory analysis of water sample, Sodium adsorption ratio (SAR) and ESP was computed using the following equations:

$$\mathbf{SAR} = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}}$$

Equation 1 (Hanson *et al*., 1993)

$$\mathbf{ESP} = \frac{1.475xSAR}{(1+(0.0147xSAR))}$$

Equation 2 (Hanson *et al*., 1993)

Descriptive statistical techniques were applied to evaluate the relative abundance of the salinity problem due to different irrigation water quality status and between the rain-fed and irrigated component of the study area.

Methods of qualitative data collection

Qualitative data were collected using focus group discussion (FGD), household interview, and key informant interview (KII). FGDs were used to get data from irrigation users in particular about the condition of soil salinity development, its driving forces, effects of salinity, and the types of ameliorative measures practiced by farmers to ameliorate soil salinity. Besides, household interviews were conducted to get deeper insights and understandings of irrigation user farmers about the adverse effects of salinity and soil salinity reclaiming measures practiced by the community. The data collected from the development agents using KII is important to know the situation of irrigation practices and existing soil problems including salinity issues. The KII held with district level irrigation experts and head of agriculture and natural resources offices provided valuable information about irrigation practices and soil salinity. Household interview and KII were conducted in Afan Oromo and Amharic language based on the language skill of the household head, whereas FGDs were conducted in Afan Oromo language. All the FGDs and interviews were recorded using audio recorder and transcribed and translated into English.

Sampling strategy for qualitative data

Purposive sampling techniques such as snowballing and convenience sampling techniques were used to select participants for FGD, household interview, and KII based on a judgmental basis until a saturation point was reached. The farmers who participated in FGDs were irrigation users including both male headed and female headed households, elderly and youth. A total of 8 FGDs were conducted with 8–10 farmers having participated in a single FGD. Four of these FGDs were conducted with farmers from Bulbula river-based irrigation at Dodicha and Bochessa irrigation sites (2 FGDs from each), 2 FGDs from Ketar River based irrigators at Shelad site and 2 FGDs with farmers using groundwater for irrigation at Bochassa site. We conducted household interview with 16 irrigation user farmers including youth, elderly, men, women and farmers using different irrigation water sources. Besides, 10 KII were undertaken with (2 heads of agriculture and natural resources, 4 irrigation experts, and 4 development agents from ATJK and Ziway Dugda districts).

Methods of analysis for the qualitative data

N-vivo11 software was used to analyze FGDs and interviews. The interaction between irrigation water quality, soil situation (comparing irrigated with rain-fed farmland) and their implication for agricultural sustainability in the future in the study area were discussed.

RESULTS AND DISCUSSION

Soil chemical characteristics

Out of the 22 parameters including soil depth (0–15 cm and 15–30 cm), eight parameters were selected based on correlation coefficient analysis. The parameters were; pH-H_2O, Exchangeable Na, EC, CEC, Bicarbonate, the sum of anions, ESP, and SAR (Table 1). The result of the regression analysis showed that that depth of soil did not have significant influence on different parameters of the soil. The analysis of variance (ANOVA) revealed that there was a highly significant difference between the groups of different irrigation water sources and the parameters such as pH, EC, ESP, and Exchangeable Na (Table 1).

Table 1. Chemical composition of soils irrigated with different sources of water.

Sampling site	pH-H2O(1:2.)	EC(ms/cm) (1:2.5)	CEC (meq/100 gm soil)	Exch.Na (meq/100 gm of soil)	ESP	SAR	Bicarbonate	Sum of anions
Soil sampled from irrigated part of the study area								
Ground water	9.3	0.35	56.895	16.845	29.7	3.11	7.03	32.72
Bulbula river	8.515	0.1875	49.2925	6.415	13.5	1.37	7.1275	16.13
Ketar river	7.815	0.2975	67.365	3.25	4.9	2.16	1.5325	7.54
Soil sampled from rain-fed part of the study area								
Bulbula	7.4275	0.0725	54.76	3.787	6.98	0.78	5.6925	13.24
Ketar	7.865	0.345	68.59	3.98	5.82	3.11	2.18	7.27

Based on the ANOVA result the difference in soil parameters was tested with the least significant difference (LSD). With regard to pH-H_2O, Exchangeable Na, ESP and EC, soil samples irrigated with groundwater did not show significant difference among areas irrigated with River Bulbula. This similarity might be due to geographical proximity where the soil samples irrigated by groundwater and Bulbula River found in the Lake Ziway sub-basin. However, there was a highly significant difference in the pH-H_2O, Exchangeable Na, ESP and EC between soil plots irrigated with groundwater and samples irrigated by Ketar and rain-fed farm plots. Yet, no significant difference was found between these parameters among the soils irrigated by Ketar and rain-fed farm plots.

Accordingly, the soils of the area irrigated with groundwater which has ESP of 29.7, as shown in Table 1, is classified as sodic soil while the soil of the area which is irrigated by Bulbula river has also been developing sodicity because its ESP value is nearest to the upper limit (13.515 ≈ nearest to 15). This implies that those areas irrigated by groundwater are sodic (alkaline) soils and show the effect of groundwater on the development of sodicity in the area with high ESP. The study indicated that the sodicity can be expected in the long run in areas irrigated with the Bulbula River unless prevention methods are introduced. According to Horneck *et al*. (2007) and Mulat Asmamaw *et al*. (2018), soils with >15 ESP have a high sodicity risk due to the effects of Na on soil structure and toxicity to crops. Gebremedhin Gebremeskel *et al*. (2018) further noted sodicity problems to be apparent at higher relative Na^+ concentration and lead to degradation of soil structure. Mohamed Seid and Tessema Genanew (2013) have a similar finding and reported the existence of sodicity both in the soil and in irrigation water in the study conducted at the Fursa SSI system in Awash River Basin. This implies those areas with sodic hazards need urgent attention to awareness creation and reclamation interventions.

Understanding the type of sodicity has also a paramount importance for proper reclamation activities. To this effect, the type of sodicity developed due to the irrigation of groundwater was also determined based on Dierickx, (2000). It is found that the type of salinization in the groundwater irrigated portion has a Sodium-Calcium type, which is marked by Na/Mg ratio is >1, Na/Ca ratio is <1 and Mg/Ca ratio is <1, indicating the presence of high exchangeable sodium compared to calcium and magnesium (Horneck *et al*., 2007).

Chemical characteristics of irrigation water sources

The current study revealed that the irrigation water with the value of SAR > 15 and Adjusted ESP >13 at EC< 4ds/m indicated the sodic nature of the water (Table 2). Water with such high SAR of soil water at all sources could create a hazardous condition to the osmotic potential of the plant which influences plant nutrient and water uptake in the soil that in return affects the productivity of the soil that initiates a search for the immediate solution of all stakeholders (Getahun Kitila *et al*., 2014). Our soil and water laboratory analysis showed that groundwater irrigated farm plots were found to be under high risk of soil sodicity (ESP>15) development at Bochessa site as can be seen in Table 3. Among the surface water sources, farm plots irrigated by the Bulbula river showed a risk of sodicity development with higher ESP greater than farm plots irrigated by Ketar and rain-fed plots (having non-salt affected soils) as presented in Table 3. A study by Mihret Dananto *et al*. (2013) showed that the source of salinity is not a natural weathering process but rather soil salinity developed due to irrigation water. Ragab *et al*. (2008) analyzed the effects of irrigation water qualities on chemical properties of soil and identified that there was a significant increase in soil salinity values as the salinity of irrigation water increased.

Table 2. Chemical characteristics of irrigation water sources in the study area.

Source of sample	**Groundwater**	**Bulbula**	**Ketar**
pH	7.92	7.515	6.68
T.Dissolved Solid 105°C (mg/l)	1338	367	132
Sodium(mg/l Na^+)	520	83	20
Potassium (mg/l K^+)	44	36.5	10
Total Hardness (mg/l $CaCO_3$)	124	135	60
Calcium (mg/l Ca^{2+})	25.6	23.2	16
Magnesium (mg/l Mg^{2+})	14.4	18.18	4.8
Alkalinity (mg/l $CaCO_3$)	1035.54	250.27	100.98
Bicarbonate (mg/l Bicarbonate)	1263.36	305.58	123.2
Chloride(mg/l Cl^-)	82.05	17.13	4.69
Sulphate (mg/l Sulphate)	20.87	23.315	8.5
ESP	63.3	21.22	8.4
SAR	116.28	18.255	6.2
Boron (mg/l B)	Trace	Trace	Trace
Carbonate (mg/l Carbonate)	Nil	Nil	Nil
HCO_3/Ca	49.35	13.48	7.7
EC(ds/m)	1.973	0.5305	0.19
Equilibrium Ca concentration	0.22	0.385	0.5
Adjusted SAR	272	38.75	17.4
Adjusted ESP	80.27	37.31	20.41

The salinity status of the soil in the study area is summarized and discussed based on the criteria presented by O'Geen (2015) and Horneck *et al*. (2007) as shown in Table 3. The current study revealed three categories of farm plots irrigated by different water sources based on Exchangeable sodium (Na). In the first category, groundwater irrigated areas showed significant and highly significant differences from other areas irrigated with other water sources. The second category farm plots irrigated by the Bulbula River indicated a significant difference between groundwater irrigated areas and areas irrigated by River Ketar and rain-fed farm plots. In the third case River Ketar, irrigated areas, and areas under rain-fed showed a similar pattern showing a significant difference from the other categories.

Hence, high salinity/sodicity development is expected in those first and second categories for the exchangeable sodium (16.845 meq/100 gm of soil) in areas irrigated with groundwater followed by areas irrigated by Bulbula river with exchangeable sodium (6.735 meq/100 gm of soil) while it is quite low in other sampling areas which are supported by scholars (Edossa Etissa *et al*., 2014). It can be concluded that the main sources of soil salinity and sodicity development are groundwater based irrigation. The driving force for upward movement of water and salts is evaporation from the soil plus plant transpiration (Gebremedhin Gebremeskel *et al*., 2018).

Table 3. Properties used to classify salt-affected soils.

Profile code	Groundwater irrigated	Bulbula river irrigated	Ketar river irrigated	Rain-fed (around Bulbula)	Rain-fed (around Ketar)
pH-H_2O (1:2.5)	>8.5	>8.5	<8.5	<8.5	<8.5
EC(ms/cm) (1:2.5)	<4	<4	<4	<4	<4
ESP	>15	<15	<15	<15	<15
Soil-salinity classification	Sodic soil	Non-ssalt affected	Non-salt affected	Non-salt affected	Non-salt affected

Source: O'Geen (2015) and Horneck *et al.* (2007)

Some previous studies showed the specific limitations of irrigation water quality from various sources in central rift valley (Koka Lake, Groundwater around Ziway, Ziway Lake). Edossa Etissa *et al*. (2014) stated that sample of groundwater from Dugda Borra district was not fit for irrigation as it did not meet water quality standard for irrigation purpose due to high salt contents, chloride toxicity, too high pH, and high content of bicarbonate and calcium ions.

Sources of soil sodicity: Community view

The development agents (DAs) interviewed in the KII at Bochessa site confirmed that the sodicity of the soil has been increasing from time to time due to intensive irrigation. According to the KII with the head of agriculture and rural development office at ATJK district, the sodic nature of groundwater and Bulbula River has been aggravated due to release of wastewater from private large scale floriculture and horticulture irrigation farms that are found around Bulbula and Lake Ziway, and consequently affecting soils irrigated from such water.

On the other hand, the KII conducted with irrigation expert at Ziway Dugda district confirmed that the main cause for waterlogging and soil salinity development is related to the type of the soil being Vertisol. The expert also indicated that irrigation has a long history of more than 44 years in Shelad site. In the area the earthen canal was constructed using soil, which was brought from other areas. So, after a long time the soil was removed from the canal during cleaning the canal and the Vertisol soil appeared. This caused waterlogging due to the swelling and shrinkage nature of the soil which causes the water to percolate under the canal through cracks and returned to the surface through capillary action. The process of returning to the surface during dry season creates unnecessary waterlogging in the farm and causes loss of the land and development of salinity as a leftover when the land is dry as shown in Fig. 5. The KII participant also underlined that the irrigation system is not good in its outlet to return the water into the river and the water remains in the farm field (Fig. 5). Gebremedhin Gebremeskel *et al*. (2018) also reported that the main factors that control sodicity problems are soil type.

Fig. 5. Waterlogged areas, which were previously farm lands at Shelad site.

Effect of soil sodicity

The laboratory result of soil sodicity in groundwater irrigated farm plots were verified by the interview results in which farmers used some indicators to justify sodicity. The indicators include changing in the colour of the soil into a dark, deposition of white salt looking surface on the soil, reduction in water holding capacity of the soil, and increasing demand of irrigated plots for frequent watering. According to farmers' view, sodicity affects yield in irrigated fields through hindering the appropriate growth of vegetables and seedlings, reducing the productivity of land and water and negatively affecting the economy, as farming in lands affected by sodicity demands high human labour, chemical fertilizers and frequent irrigation (Table 4). The result was similar to the finding of Gebremedhin Gebremeskel *et al*. (2018) who showed that high levels of sodium in groundwater result in an increase of soil sodium levels, which affects soil structural stability, infiltration rates, drainage rates, and crop growth potential. In addition, farmers pointed out that cabbage and tomato were less tolerant to the effects of soil sodicity than other plants. Qureshi and Al-Falahi (2015) indicated that farmers perceived the loss of farmland due to salinity as a challenge for their agricultural productivity. The effects of sodicity-salinity on the physical and hydraulic properties of the soil are very complicated processes that can be influenced by many factors (Gebremedhin Gebremeskel *et al*., 2018). The interrelation between sodicity and salinity levels in irrigation water or water coming through capillary flux from groundwater introduces a dual problem in terms of crop response, soil structure degradation, and irrigation management (Gebremedhin Gebremeskel *et al*., 2018).

The current study showed that the adverse effects of sodicity were further aggravated due to declining trend of soil fertility. Household interview participants in all sites indicated in the past they used to apply 25 kg of chemical fertilizer for 0.25 ha of land, but now they are using 100 kg or 150 kg of fertilizer for 0.25 ha of land. Mihret Dananto *et al*. (2013) supported this finding. To this end, Mwamakamba *et al*. (2017) reported the high cost of fertilizer is a challenge of irrigators in Sub-Saharan Africa due to deterioration of soil quality. Besides, based on KII with an agronomist at Shelad site about 12 ha of land, which was the property of 50 households were lost due to water logging and salinity as well. The effects of sodicity in the study area was much diverse and persistent which influenced soil quality, vegetable growth, and maturity (Fig. 6), water quantity, the yield of crops and economic cost (Table 4).

From the information gathered, the irrigated areas showed reduction in yields, early drying of seedlings, an increase in the irrigation water requirement for the same yield, and crop failure due to low salt tolerance. According to Bauder *et al*. (2014), sodicity causes a decrease in the downward movement of water into and through the soil, and actively growing plant roots may not get adequate water, despite pooling of water on the soil surface after irrigation. Sodicity lowers the permeability of the soil to air and water, lowering the availability of some essential plant nutrients due to the osmotic effect of the salt and causes specific ion toxicity (Abrol *et al*., 1988). Soil salinization is one of the major constraints in achieving food security in Ethiopia (Qureshi *et al*., 2018).

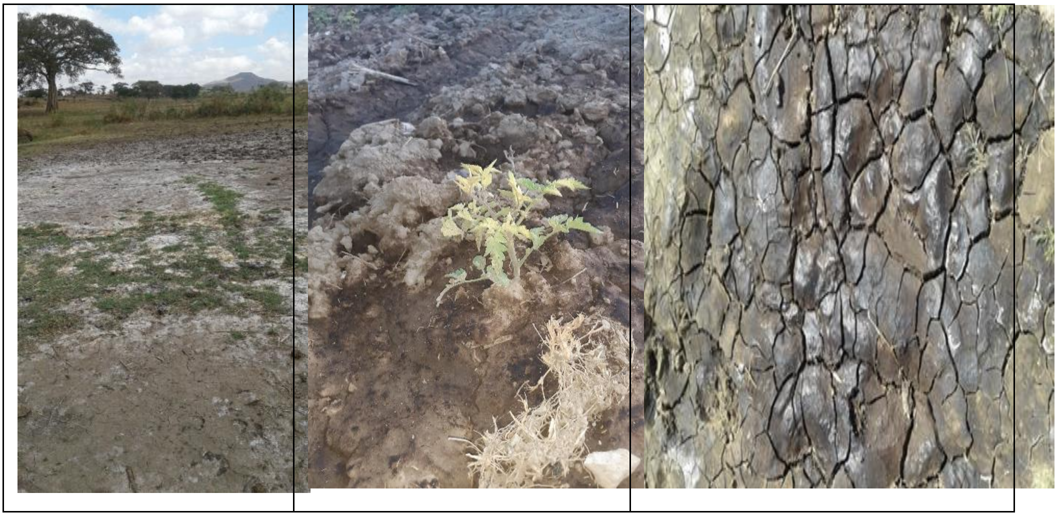

Fig. 6. Effect of sodic water on soil and vegetation growth.

Table 4. Effects of soil sodicity: Farmers' views.

	Effects of salinity	**No. of household interviews**
Soil	The soil gets dry Cracking forms on the farmland The farmland become very black and hard to plow Plowing land affected by salinity is difficult Deposition of ash type of salt looking surface on the soil	12
Vegetables	Seedlings dry Wilting of crops or vegetables before flowering Poor growth of vegetation (yellow color of vegetable leaves like tomato)	15
Water	High irrigation water consumption due to sodicity which increases the frequency of irrigation	8
Agricultural yield	Yield of irrigated vegetables declines though the fertilizer amount applied is increasing from time to time	16
Economic cost rise (Labour demand increase and household economy negatively affected)	Demands much human labor for frequent plowing and irrigation Demands high financial capital for additional chemical fertilizer Needs plowing using a tractor or needs frequent plowing by oxen The land affected by sodicity was left to be open and the farmer rents the land from other farmers whose land is not affected by sodicity	13

Qureshi and Al-Falahi (2015) also emphasized that low land productivity in irrigation fields resulted in low farm income, food insecurity, and the prevalence of poverty. However, according to Mwamakamba *et al*. (2017), low productivity in irrigation fields might be also related to low-quality inputs such as seeds and others. This implies that many factors might impede the productivity of irrigation in addition to the decline in soil fertility due to sodicity. Therefore, considering many factors of production weighs more than focusing on single factors to enhance irrigated agricultural production on a sustainable basis.

Remedial measures to ameliorate soil sodicity

Reclamation of sodic soils is mandatory in the study area which requires removal of the exchangeable sodium and its replacement by calcium ions in the root zone (Abrol *et al*., 1988). Sodic soils usually are the most expensive to reclaim (Horneck *et al*., 2007; O'Geen, 2015). The choice of an amendment and its relative effectiveness is judged from improvement of soil properties and crop growth and the relative costs involved (Abrol *et al*., 1988; Kefyalew Assefa and Kibebew Kibret, 2016). To be successful in the reclamation of sodic soils cropping must be preceded by the application of chemical soil amendments followed by leaching for removal of salts (Abrol *et al*., 1988; Horneck *et al*., 2007; O'Geen, 2015).

Farmers used different land reclamation techniques to recover soils affected by sodicity in the study sites. Some of the techniques include adjusting farming system involving plowing the land using a tractor (applicable for economically better smallholders), apply more irrigation water frequently, use compost, plough the land before the coming of the rainy season, fallow the land, apply chemical fertilizer, crop rotation, use the irrigable land for rain-fed farming and renting another land which is not affected by salinity for irrigation. The KII participants at Shelad site noted the need to use lined canal to overcome waterlogging, salinity and associated loss of farmland. Mohamed Seid and Tessema Genanew (2013) also noted on the need to design appropriate irrigation techniques to overcome the adverse effects of irrigation on soil salinity development. An agronomist who participated in the KII at Shelad site noted gypsum application to reclaim salt-affected soils, however, the interviewee claimed that farmers couldn't afford its cost and some have low awareness about sodicity and its amendment. This implies future research is imperative to examine to what extent gypsum is suitable to ameliorate sodic soils, and to design strategies on how the government can intervene. Mwamakamba *et al*. (2017) underlined the role of national governments to ameliorate soil salinity by supporting farmers to practice basic land reclamation and water monitoring.

Based on FGDs and KIIs there are trials of amendments and improvement of the farm field through the application of compost though farmers have negative attitude towards using compost because of its labour-intensive nature and communities' believe that compost preparation might bring illness (Michi[1]) due to effect of methane gas. This implies that farmers should be technically supported with some trainings and demonstrations at the farm field on how to reclaim soil salinity using indigenous techniques.

CONCLUSION

The result revealed that sodic nature of groundwater in Bochassa SSI site was the main factor for sodic soil development in irrigated plots, and Bulbula River irrigated plots also showed indication of soil sodicity. In the view of the community farming practices, inappropriate drainage system and intensive application of agro-chemicals were also factors for soil salinity in Shelad site. This implies the need to design management options to manage water, land, and irrigation farming practices that are environmentally friendly in an integrated manner to mitigate the adverse effect of sodicity and to enhance agricultural sustainability. Besides, farmers have to be technically supported by well-trained development agents to practice farming techniques that don't harness natural capitals. Future research investigations are worthwhile to quantify the effect of precipitation and evapotranspiration on soil salinity-sodicity development and its effect on crop growth under different seasons.

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REFERENCES

Abrol, I.P., Yadav, J.S.P. and Massoud, F.I. (1988). Salt-affected soils and their management. FAO soils bulletin 39.

Alemayehu Muluneh, Woldeamlak Bewket, Keesstra, S. and Stroosnijder, L. (2017). Searching for evidence of changes in extreme rainfall indices in the Central Rift Valley of Ethiopia. *Theor. Appl. Climatol.* **128**(3–4): 795–809.

Bauder, T.A., Waskom, R.M., Sutherland, P.L. and Davis, J.G. (2014). Irrigation water quality criteria. Fact sheet No. 0.506 pp. 156–182, Colorado State University.

Bedru Sherefa (2006). **Remote Sensing and GIS for Land Cover, Land Use Change Detection and Analysis in the Semi-Natural Ecosystems and Agriculture Landscapes of the Central Ethiopian Rift Valley**. Doctoral dissertation, Techniche Universität Dresden, Dresden.

[1]Amharic term referring illness due to methane effect on eye and respiratory systems

Bouksila, F., Bahri, A., Berndtsson, R., Persson, M., Rozema, J. and Van der Zee, S.E. (2013). Assessment of soil salinization risks under irrigation with brackish water in semiarid Tunisia. *Environ. Exp. Bot*. **92**: 176–185.

Datta, K.K. and De Jong, C. (2002). Adverse effect of waterlogging and soil salinity on crop and land productivity in northwest region of Haryana, India. *Agric. Water Manage*. **57**(3): 223–238.

Dejene Abera, Kibebew Kibret, Sheleme Beyene and Fassil Kebede (2018). Spatial and temporal dynamics of irrigation water quality in Zeway, Ketar, and Bulbula sub-watersheds, Central Rift Valley of Ethiopia. *Ethiop. J. Agric. Sci*. **28**(3): 55–77.

Derege Tsegaye, Tsunekawa, A. and Tsubo, M. (2012). Continuing land degradation: cause–effect in Ethiopia's Central Rift Valley. *Land Degrad. Develop.* **23**(2): 130–143.

Edossa Etissa, Nigussie Dechassa, Tena Alamirew, Yibekal Alemayehu and Lemma Desalegne (2014). Irrigation water management practices in smallholder vegetable crops production: the case of the central Rift Valley of Ethiopia. *Sci. Technol. Arts Res. J.* **3**(1): 74–83.

Engdasew Feleke, Engdawork Assefa and Tesfaye Zeleke (2020). Effects of small scale irrigation on household income and its implication for livelihood sustainability in the drought prone central rift valley of Ethiopia. *J. Sustain. Develop. Africa* **22**(1): 104–131.

Fitsum Dechasa, Feyera Senbeta and Dawit Diriba (2019). Determinants of household wetland resources use and management behavior in the Central Rift Valley of Ethiopia. *Environ. Sustain.* **2**: 355–368.

Fitsum Hagos, Makombe, G., Regassa Namara and Seleshi Bekele (2009). Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation. Vol. 128. IWMI research report 61100, International Water Management Institute.

FAO (Food and Agricultural Organization) (2002). **Handbook for Saline Soil Management**. (Vargas, R., Pankova, E.I., Balyuk, S.A., Krasilnikov, P.V. and Khasankhanova, G.M.) Available online http://www.fao.org/3/i7318en/I7318EN.pdf(accessed on 17 June 2019).

Gebremedhin Gebremeskel, Tesfay Gebretsadkan, Mulubrehan Kifle, Esayas Meresa, Teferi Gebremedhin and Abbadi Girmay (2018). Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis. *Agric. Water Manage*. **206**: 147–157.

Getahun Kitila, Heluf Gebrekidan, and Tena Alamrew (2014). Assessment of irrigation water quality and suitability for irrigation in the Fincha'a Valley Sugar Estate, Nile Basin of Western Ethiopia. *Sci. Technol. Arts Res. J*. **3**(1): 64–73.

Gizachew Legesse and Andualem Shimeles (2014). Analysis and mapping of climate change risk and vulnerability in Central Rift Valley of Ethiopia. *Afr. Crop Sci. J.* **22**: 807–818.

Hanson, B., Grattan, S.R. and Fulton, A. (1993). **Agricultural Salinity and Drainage: A Handbook for Water Managers** No. 93. University of California Irrigation Program, University of California, Davis.

Hengsdijk, H. and Jansen, H. C. (2006). Agricultural development in the Central Ethiopian Rift valley: A desk-study on water-related issues and knowledge to support a policy dialogue. No. 375. Plant Research International.

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M. and Stevens, R.G. (2007).

Managing salt-affected soils for crop production. A Pacific NorthWest Extension Publication: Oregon State University, University of Idaho and Washington State University PNW 601-E.

Jansen, H.C., Hengsdijk, H., Dagnachew Legesse, Tenalem Ayenew, Hellegers, P. and Spliethoff, P.C. (2007). Land and water resources assessment in the Ethiopian Central Rift Valley: Project: Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley. No. 1587. Alterra.

Kbrom Ambachew (2018). A review on waterlogging, salinization and drainage in Ethiopian irrigated agriculture. *Sustain. Water Resour. Manage.* **4**(1): 55–62.

Kefyalew Assefa and Kibebew Kibret (2016). Evaluation of the effect of salt affected soil on selected hydraulic properties of soils in Meki Ogolcha area in East Showa Zone of Oromia Region, Ethiopia. *J. Biol Agric. Healthcare* **6**(21): 64–71.

Martinez-Beltran, J. (2005). Overview of salinity problems in the world and FAO strategies to address the problem. In Managing saline soils and water: science, technology and social issues. Proceedings of the international salinity forum, Riverside, California.

Mezegebu Getnet, Hengsdijk, H. and van Ittersum, M. (2014). Disentangling the impacts of climate change, land use change and irrigation on the Central Rift Valley water system of Ethiopia. *Agric. Water Manage.* **137**: 104–115.

Mihret Dananto, Ermias Alemu, Mekonene Ayana and Adunga Eneyew (2013). Environmental Impacts of small scale irrigation schemes: evidence from Ethiopian Rift Valley Lake Basins. *Environ. Res. Eng. Manage.* **63**(1): 17–29.

Mohamed Seid and Tessema Genanew (2013). Evaluation of soil and water salinity for irrigation in North-eastern Ethiopia: Case study of Fursa small scale irrigation system in Awash River Basin. *Afr. J. Environ. Sci. Technol.* **7**(5): 167–174.

Mulat Asmamaw, Ashenafi Haile and Gezai Abera (2018). Characterization and classification of salt affected soils and irrigation water in Tendaho sugarcane production farm, North-Eastern Rift Valley of Ethiopia. *Afri. J. Agric. Res.* **13**(9): 403–411.

Mwamakamba, S.N., Sibanda, L.M., Pittock, J., Stirzaker, R., Bjornlund, H., van Rooyen, A. and Kashaigili, J.J. (2017). Irrigating Africa: Policy barriers and opportunities for enhanced productivity of smallholder farmers. *Int. J. Water Resour. Develop.* **33**(5): 824–838.

O'Geen, A. (2015). Reclaiming Saline, Sodic, and Saline-Sodic Soils. University of California, Agric. Natural Resour. Publication 8519.

Pascual-Ferrer, J., Pérez-Foguet, A., Codony, J., Raventós, E., and Candela, L. (2014). Assessment of water resources management in the Ethiopian Central Rift Valley: environmental conservation and poverty reduction. *Int. J. Water Resour. Develop.* **30**(3): 572–587.

Qureshi, A.S. and Al-Falahi, A.A. (2015). Extent, characterization and causes of soil salinity in Central and Southern Iraq and possible reclamation strategies. *Int. J. Eng. Res. Appl.* **5**(1): 84–94.

Qureshi, A.S., Ertebo, T. and Mehansiwala, M. (2018). Prospects of alternative copping systems for salt-affected soils in Ethiopia. *J. Soil Sci. Environ. Manage.* **9**(7): 98–107.

Ragab, A.A., Hellal, M., and Abd El-Hady, M. (2008). Water salinity impacts on some soil properties and nutrients uptake by wheat plants in sandy and calcareous soil. *Austral. J. Basic Appl. Sci.* **2**(2): 225–233.

Seleshi Bekele, Merrey, D., Van Koopen, B. and Kamara, A. (2010). Roles, constraints and opportunities of small-scale irrigation and water harvesting in Ethiopian agricultural development: Assessment of existing situation. In ILRI workshop. pp. 14–16.

Shahid, S.A. (2013). Developments in soil salinity assessment, modeling, mapping, and monitoring from regional to submicroscopic scales. In: **Developments in Soil Salinity Assessment and Reclamation**: 3 Innovative Thinking and Use of Marginal Soil and Water Resources in Irrigated Agriculture. Springer, Dordrecht.

Shegena Zewdu, Suryabhagavan, K.V. and Balakrishnan, M. (2017). Geo-spatial approach for soil salinity mapping in Sego Irrigation Farm, South Ethiopia. *J. Saudi Soc. Agric. Sci.* **16**(1): 16–24.

Tenalem Ayenew (2007). Water management problems in the Ethiopian rift: Challenges for development. *J. Afri. Earth Sci*. **48**(2–3): 222–236.

Valipour, M. (2014). Drainage, waterlogging, and salinity. *Arch. Agron. Soil Sci.* **60**(12): 1625–1640.

Van Halsema, G.E., Beshir Keddi, Mengistu Assefa, Hengsdijk, H. and Wesseler, J. (2011). Performance assessment of smallholder irrigation in the Central Rift Valley of Ethiopia. *Irrig. Drain.* **60**(5): 622–634.

Yenesew Mengiste (2015). **Agricultural Water Productivity Optimization for Irrigated Teff (*Eragrostis tef*) in Water Scarce Semi-Arid Region of Ethiopia**. CRC Press, Balkema.