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Evaluation of soil and water salinity for irrigation in North-eastern Ethiopia: Case study of Fursa small scale irrigation system in Awash River Basin

Mohamed Seid* and Tessema Genanew

Department of Soil and Water Resources Management, Wollo University, Dessie, Ethiopia

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For sound land use and water management in irrigated area, knowledge of the chemical composition of soils, water, climate, drainage condition and irrigation methods before action are crucial for sustainability of irrigation projects. The study aimed to evaluate the physicochemical properties of soils and water for intended irrigation scheme with reference to standard suitability classes. With regard to this, a study was conducted in Awash River Basin at *Fursa* small scale irrigation scheme in Northeastern Ethiopia. Soil samples were collected from bore holes of three soil mapping units of the study site across depth and water samples were taken from irrigation water with plastic bottles for analysis of range of physical and chemical properties. The results of the analysis reveal the existence of potential sodicity not only in the soil but also in the irrigation water. The study underlines the need for selection of salt tolerant crops and good water management by using appropriate irrigation methods to sustain productivity of soil in the proposed irrigation site. This has significant contribution to deciding the type of crop to be produced and appropriate irrigation methods for sustainability of soil productivity.

Key words: Fursa irrigation scheme, salinity, sodicity, soil analysis, water analysis.

INTRODUCTION

Sound irrigation agriculture contributes towards achieving food security and livelihood improvements for the increasing population through enhancement of agricultural productivity. Lessons from the past indicate that the development of a sound irrigated agriculture depends on a catena, or chain of related factors, involving soils, waters, crops and man. Failure of any one of these links can bring hardship or even disaster to an irrigation enterprise (Tessema, 2011). Poor irrigation agriculture in arid and semiarid regions results in land degradation through soil salinity and sodic soil developments in different parts of the world. Hence, the study of arid lands and salt affected soils has been an important topic for modern agricultural management and particularly for poor countries like Ethiopia where agriculture is the backbone of its economy while arid and semi arid climatic zones occupy over 60% of the total land area (Awulachew et al., 2007).

The total land area affected by salinity and sodicity in Ethiopia estimated at about 11 thousand ha and soils have been reported to occur for the most part of the rift valley zone (FAO, 1985a; Tadesse and Bekele, 1996). Nowadays, soil salinity has become important problem in irrigated soils of Awash River basin in central and Eastern Ethiopia. The effect of the quality of irrigation water on soil properties has been discussed by many researchers (Richards, 1954; Westcott and Ayers, 1985; Kinfe, 1999). Water quality related problems in irrigated agriculture are identified as salinity, sodicity, specific-ion toxicity

*Corresponding author. E-mail: tessemagenanew@Gmail.Com. Tel: +251912022161.

and impeded infiltration rate as well as hydraulic conductivity (Ayers and Westcott, 1985; Frenkel, 1984).

For appropriate land use and water management in irrigated area, knowledge of the chemical composition of the soil characteristics, water, climate, drainage condition and irrigation methods should be evaluated before implementation of irrigation projects (Al-Ghobari, 2011). With regards to soil studies, a number of surveys have been carried out for different purposes at different times by different institutions. However, the scale and purpose of the studies allow only planning for development undertakings. A very detailed survey is necessary to characterize soils as well as water to identify the salinity hazard and level of nutrients (major or minor) at each irrigation sites for the proper understanding of the hazard and appropriate mitigation measures. Salt affected soils and the associated poor soil drainage conditions results from poor management of soils and irrigation systems (Tessema, 2011). The Middle and Lower Awash River Basins in Ethiopia appear to be the most recent examples of such a situation (Tadesse and Bekele, 1996). In addition to these, salt affected soils are not only the result of the saline soils but also attributed to application of low quality irrigation water. All waters used for irrigation caries varying amounts of dissolved salts and other constituents. Some dissolved constituents can improve crop growth if present in small to moderate amounts, otherwise can harm soils and restrict plant growth if they are present in excessive amount.

Due to the above facts and indication of salt in the immediate upstream Woreda (district) along the gullies, intermittent streams and deep wells dug for domestic use made us to assess the salinity hazard for soils and water of Fursa irrigation project. Therefore, the objective of this study was to evaluate the soil physicochemical properties of intended irrigation areas and to assess chemical composition (quality) of irrigation water for the project understudy based on the standard suitability classes. This has significant contribution to decide the type of crop to be produced and appropriate irrigation methods for sustainability of soil productivity.

MATERIALS AND METHODS

Study area

The study was conducted in Afar Regional State, Awsi-Resu administration, Ada'Ar Woreda (district) at Fursa River diversion irrigation project in Northeastern Ethiopia. It lies with UTM coordinate of 645,886E and 1,237,969N with altitude of 706 m above sea level (m.a.s.l) where the slope rangefrom 0 to 2%(Figure 1).

Climate

According to the traditional agro-climatic zone classification of Ethiopia and considering the temperature, length growing period (LGP) and elevation (500 to 1500m.a.s.l), the study area lies under *Dry kolla* climatic zone. Records from Elliwuha metrological station showed that the mean annual rainfall was about 458 mm. It receives a bimodal type rainfall pattern with the first peak from February to May and the second from August to September. However, both seasons were not sufficient to support reliable crop growth. The mean annual maximum and minimum temperature was 38and 10.3℃, respectively. December is the coldest month and June is the hottest month of the year. The LGP is less than 90 days which shows that there is no reliable growing period.

Survey methods

Office work

Prior to commencement of the field soil investigation, necessary field materials like GPS, topographic map of scale 1:50,000, knife, hoe, shovel, plastic bags, hard paper or labeling, markers, rope, etc, were collected.

Field work procedure

Profile sampling

During site mapping, altitude and geographic locations of block boundaries and important landmarks were recorded using total station with association of GPS to locate local bench marks. Profile locations were taken by total station along with topographic survey. For further soil characterization, soil profile pits were dug on three representative sites for this irrigation project. The soil profile descriptions made was according to FAO (1990) guidelines for soil profile description. Soil samples were collected from the flat face of each natural soil horizons. The pits were dug with size of one meter width, two meter length and two meter depth of bore hole (1 x 2 x 2 m).

Laboratory analyses

Soil analysis

Soil samples, taken from each pit across depth, were air dried, weighed, and grinded and passed through a 2 mm sieve. Then soil pH was measured by pH meter using suspension of distilled water to soil solution ratio (1:2.5) and EC measurement was performed using saturated paste extracts. Exchangeable bases and cation exchange capacity (CEC) of the soils were determined by the 1 M ammonium acetate (pH 7) method according to the percolation tube procedure (Van Reeuwijk, 1993) while calcium carbonate ($CaCO_3$) was determined by acid neutralization (titration) method using HCl. Available phosphorous content of the soils was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) using the method of Olsen et al., (1954) as outlined by Van Reeuwijk (1993). The total nitrogen content of the soil was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982) and organic carbon content by the wet combustion procedure of Walkley and black (1934). Soil texture was determined by the hydrometer method (Bouyoucos, 1951) and soil color was identified using munsell color chart.

Water quality analysis

As long as the natural replenishment of the aquifer equals the withdrawal of irrigation water, there will be little change with time in the chemical characteristics of water due to sampling problem (FAO, 2000). Thus, samples for irrigation water analysis can be collected in 1- or 2-litre clean glass or polyethylene (plastic) bottles. Based on this principle one liter water sample was taken at the middle of *Fursa River* for analysis of pH, EC, Ca, Mg, Na, K and SAR.

$$\text{SAR (mmoles}_c\text{/L = meq/L)} = \frac{Na^{+}}{[(Ca^{2+}+Mg^{2+})/2]^{0.5}} \quad (1)$$

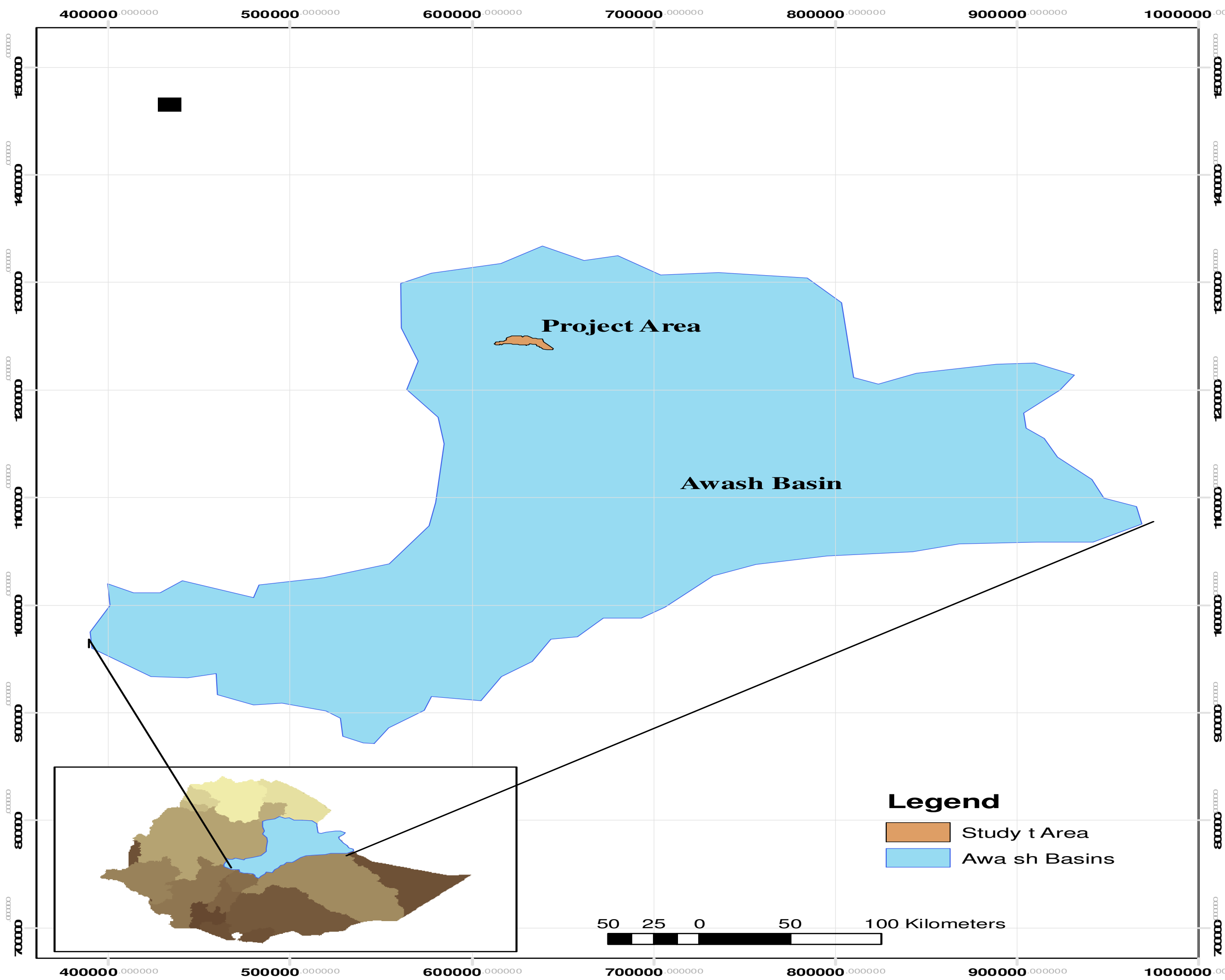

Figure 1. Location map of the study area.

The SAR of a water adjusted for the precipitation or dissolution of Ca^{2+} and Mg^{2+} is expected to occur where water reacts with alkaline earth carbonates within the soil. This was calculated by using FAO Irrigation and Drainage paper No. 29.

Data analysis

The data generated from laboratory analyzed descriptive statistics. One way analysis of variance was used to compare the physical and chemical properties of soil between and within soil mapping units. All the data were edited, coded and analyzed using SPSS software version 16.0.

RESULTS AND DISCUSSION

Soil quality evaluation

For characterizing the physico-chemical properties of soils of intended irrigation area, the catchment were partitioned into three soil mapping units based on uniformity of land attributes. Characteristics of the mapping units and detailed analytical data of the soil profile are given in the subsequent sections.

Soil physical properties

In the soil profile description, the soils of mapping unit one and two were found to be very deep (>150 cm). The texture is clay loam for the first top layer (0 to 35 cm depth) and clay for the next layer (35 to 150 cm depth) (Table 1), whereas clay for the first two top layers (0 to 50 cm depth) and silt-loam for the next layer (50 to 90 cm depth) for site two (Table 1). No sample was taken for the last layer (90 to 200+) due to its gravel layer. A medium soil depth (0 to 87cm) was observed in mapping unit three (site three). The soil texture third site was found to be sandy-clay for the first top layer (0 to 35 cm depth), clay for the next layer (35 to 47 cm depth) and clay loam for the last layer (47 to 87) (Table 1). With regards to soil

Table 1. Some physical characteristics of the studied soils in three mapping units (sites).

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Site one				
0-35	28	30	42	Clay loam
35-80	40	28	32	Clay
80-150	48	40	12	Clay
Site two				
0-30	52	38	10	clay
30-50	44	20	36	clay
50-90	18	58	24	Silt Loam
Site three				
0-35	50	2	48	Sandy clay
35-47	48	36	16	clay
47-87	38	38	24	Clay loam

depth, the texture of the soil in the catchment generally lay clay-loam for the upper layer, clay for the middle and lower layer. The top soil texture is dominantly clay loam for mapping unit one, clay for site two and sandy clay for mapping unit three (site three). All sites have soil color of light brown when moist. This physical property has significant influence on infiltrate rate and hydraulic conductivity of the soil as well as the retention and movement of irrigation water around root zone (FAO, 2000).

Generally, results of the particle size analysis indicate that the majority of the soils are heavily textured. Moreover, mass of surface soil layers have weakly developed platy structure while the subsurface soil layers have developed platy structure with good porosity. These properties have impact on movement of air and water within the soil (Brady and Weil, 2002). Medium infiltration rate was registered in all the sampled sites. However, infiltration rate at the beginning of the test was lower when compared with the theoretical rate that is attributed to platy structure of the soil, that is, it could impede the down ward movement of water. This is in agreement with the findings of Mass and Hoffman (1977). As well, availability of deep soil depths in the study site imply that soil depth is not a limiting factor for the production of most field crops.

Soil chemical properties

Soil reaction

Soil pH is a good indicator of intensity of acidity or alkalinity of the soil. In site one, the pH of surface soil is 8.3 (strongly alkaline); decreasing to 8.0 (strongly alkaline) in surface horizons and it comes back again to 8.3 in the subsurface layer. Similar pattern was observed in the second site, it was 8.3 (strongly alkaline) in surface horizons; decreasing to 7.8 (moderately alkaline) and it comes back again to 8.4 (strongly alkaline) in the last subsurface layer. On the third site, pH of 7.9 (moderately alkaline) was recorded in surface horizons and it decreased from 7.8 to 7.7 (moderately alkaline) subsequently in two subsurface layers (Table 2).

The electrical conductivity (EC) is generally non-saline that ranges between 0.083 dS/m on the surface soil (0 to 35) to 0.319 dS/m in the sub soils of the lower layers (35 to 180 cm) soil depth in the first site (Table 2). EC of the second site ranged from non-saline to moderately saline (0.831 to 7.52 dS/m) on the surface soil (0 to 50) and (0.482 and 5.08 dS/m) subsequent sub surface layer (50 to 200 cm soil depth). Similarly results of EC obtained in the third site that ranges from non-saline to moderately saline (0.63 to 7.75 dS/m) on the surface soil (0 to 50cm) and it is slightly-saline in the next layer (2.76 dS/m).

CEC and exchangeable bases

The cation exchange capacity (CEC) of the soils is high [(31.58 cmol (+)/kg soil), (7.24 to 45.40 cmol (+)/kg soil)] low to high in the surface and sub surface layers of site one respectively and generally very high [(71.08 to 73.12 cmol (+)/kg soil), surface, (32.98 cmol (+)/kg soil) last layer] at site two (Table 2). Medium to high CEC, (24.76, 40.38, 37.18 cmol (+)/kg soil) surface to subsurface, was registered at site three (Table 2).

The exchangeable sodium percentage (ESP) generally ranges from low to medium (0.8 to 2.3%, 1.5 to 2.1%) in site one and two, respectively. The exchangeable sodium percentage generally ranges from low to medium (1.5 to 2.1%). However, ESP is medium in the first and last layers (2.3 and 2.74%) but it is extremely high in the middle layer (40.1%) of site three (Table 2).

Organic matter and nitrogen

Organic matter was very low (0.52, 0.62 and 0.29) in site one and (0.72, 1.00, 0.86) in site two, organic matter content (%) obtained from surface layer to subsurface layers across soil depth is shown in Table 2. Similarly, it was low (0.52 to 0.55%) in the surface layers with the

Table 2. Chemical composition of soils irrigated at three sites across soil depth.

Depth (cm)	H_2O pH	EC_e (dS/m)	TN (%)	OC (%)	OM (%)	Available P (ppm)	CEC (cmol (+)/kg)	K (cmol (+)/kg)	Na (cmol (+)/kg)	ESP (%)	$CaCO_3$ (%)
Site One											
0-35	8.3	0.083	0.01	0.3	0.52	5.97	31.58	0.58	0.28	0.89	8.02
35-80	8	0.218	0.07	0.36	0.62	7.26	7.24	0.54	0.37	5.11	9.25
80-180	8.3	0.319	0.06	0.17	0.29	3.42	45.4	1.27	0.46	1.01	8.03
Site Two											
0-30	8.3	0.831	0.09	0.42	0.72	8.4	73.12	0.72	1.07	1.46	8.16
30-50	7.8	7.52	0.07	0.58	1.00	11.51	71.08	0.82	1.13	1.58	13.77
50-90	8.4	0.482	0.06	0.5	0.86	9.92	32.98	0.49	0.7	2.12	7.5
Site Three											
0-35	7.9	0.63	0.05	0.3	0.52	6.04	24.76	0.44	0.57	2.3	7.56
35-47	7.8	7.75	0.04	0.32	0.55	6.42	40.38	0.59	16.2	40.11	9.25
47-87	7.7	2.76	0.04	0.29	0.50	5.89	37.18	0.64	1.02	2.74	14.68

Source: Own soil analysis result.

same range in the sub soils (0.50%), organic matter content registered on site three is shown in Table 2. Likewise, the observed total nitrogen (%) in the three sampling sites was generally low (0.01, 0.07, 0.06) in site one, (0.07, 0.09, 0.06%), site two (0.05, 0.04, 0.04) and site three across surface to subsurface soil depth, respectively (Table 2).

Available phosphorus and carbonates

Available phosphorous is low (5.97 ppm) for the surface layer and for the next subsurface layer (7.26 ppm) but it decreases to 3.42 ppm for the last sub surface in site one. Whereas it ranges low to medium (8.40 to 11.51 ppm) increasing down ward for the surface layer and being in the medium range for the next subsurface layer (9.92 ppm) on site two. Likewise, available phosphorous is low in all the layers ranging 6.04 to 6.42 ppm for the surface layer and 5.89ppm for the next subsurface layer of site three (Table 2).

Generally the surface soils have strongly alkaline reactions on the surface (pH ranges from 7.9 to 8.3) and the subsurface soils do have lower but similar alkaline reactions in the lower layers (pH 7.7 to 8.30). Electrical conductivity (EC) measurements are used as indications of total quantities of soluble salts in the soil. The increase in EC with soil depth is generally registered but it is non-saline and ranges between 0.063 and 0.0831 dS/m on the surface soil, 0.218 and 2.76 ds/m in the sub soils of the lower layers. On the other hand, the organic carbon (OC) content of the soils ranges from 0.30 to 0.42% in the surface layer and its content decreases regularly (0.17 to 0.58%) with soil depth. In almost all the soils, the OC content of the soil layer is <1% for all layers. Such a low OC content of the soils could be due to the association of low humic substances (Brady and Weil, 2002). Similarly, total nitrogen (TN) content of the soils generally ranges from very low to low (0.01 to 0.09%). Subsurface soils have higher values than surface soils. The available phosphorous content of the soils is low on surface layer (5.97 ppm) and subsurface (7.26 to 3.42 ppm).

A widely used measure of the deleterious effects of high sodium level is the exchangeable sodium percenttage, which is defined as [exchangeable Na/CEC] x 100 (Brady and Weil, 2002). An ESP value of 15 is often regarded as the boundary between sodic and non-sodic soils (Brady and Weil, 2002), although, it has been realized that this is an arbitrary figure, since the properties of soils often exhibit no sharp change as the content of exchangeable Na increases. In some soils, exchangeable Na content of 2 to 3 cmol(+)/kg soil may be a more suitable criterion for distinguishing sodic samples. In general, soils with exchangeable Na >1 cmol(+)/kg should be regarded as potentially sodic (Frenkel, 1984; Brady and Weil, 2002). The exchangeable sodium percentage was generally classified as medium (0.8 to 2.1%) and commonly increases with depth, except in the mapping unit three which is extremely a high value (40.1%). This indicates that the soils are potentially sodic. The CEC varies between 24.76 and 73.12 cmol (+) kg^{-1} soil on the surface layers, while it ranges from 7.26 to 71.08 cmol (+) kg^{-1} on the sub surface soils. The CEC of the last layer is higher than the middle layer that ranges from 32.98 to 45.40 cmol (+) kg^{-1}. This indicates the availability of cation saturation in the study site.

Soil chemical characters among mapping units

The result of the analysis indicated that there is no significant difference for pH, electrical conductivity, total nitrogen, CEC, Ca, Mg, K, $CaCO_3$ and exchangeable sodium

Table 3. Physico-chemical properties of soils at three sites (mapping units) (Mean+SE).

Soil parameter	Mapping Unit			Level of Significance		
	Site one	Site Two	Site Three	F-value	(P-value)	Rating
pH	8.2±0.10	8.17±0.19	7.8±0.06	3.093	0.119	High
EC (dS/m)	0.21±0.07	2.94±2.29	3.71±2.11	1.051	0.406	Low
TN (%)	0.047±0.019	0.073±0.008	0.043±0.003	1.872	0.234	Low
OC (%)	0.28±0.06[a]	0.50±0.046[b**]	0.30±0.016[a]	8.33	0.019	Low
OM (%)	0.48±0.10[a]	0.86±0.08[b**]	0.52±0.014[a]	8.057	0.020	Low
Avail. P(ppm)	5.55±1.13[a]	9.94±0.89[b**]	6.11±0.16[a]	8.14	0.020	Low to medium
CEC(cmol(+)/kg)	28.07±11.15	59.06±13.05	34.11±4.76	2.55	0.158	High
K	0.79±0.236	0.68±0.097	0.56±0.06	0.623	0.568	High
Na	0.37±0.057	0.97±0.13	5.93±5.13	1.059	0.404	Medium to very high
ESP (%)	2.34±1.39	1.72±0.20	15.05±12.53	1.068	0.401	Low to medium
$CaCO_3$	8.43±0.41	9.81±1.98	10.49±2.14	0.379	0.700	*

Similar letters or no letters with rows indicate that there is no significant difference among parameters, α = 0.05.

Table 4. Chemical composition of water used for irrigation of the three sites.

Water parameter	Units	Degree of Restriction (Biswas, 1998; FAO soil Bulletin 55, 1985b; Wesstcott and Ayers,1985)			Values for Fursa River	Severity status
		None	Slight to moderate	Severe		
Electrical Conductivity(EC)	ds/m	<0.70	0.70-3.00	>3.00	1.31	Slight to moderate
Total dissolved solids (TDS)	ml/l	<450	450-2000	>2000	838.40	Slight to moderate
Sodium (Na^+)	meq/l		-		70.00	Severe
SAR	$meql^{-1/2}$	<3.00	3.00-9.00	>9.00	10.00	Severe
Adjusted SAR			-		20.40	
Calcium (Ca^{2+})	meq/l	0 to 800: normal range			88.80	Normal
Magnesium (Mg^{2+})	meq/L	0 -120: normal range			8.51	Normal
Potassium (K^+)		-	-		30.00	Normal
pH	pH scale	6.5 -8.4: normal range			7.36	Normal

percentage among the three mapping units. However, significantly higher (p≤0.05) OC, OM and available phosphorus were registered on mapping unit two (site two) as compared to mapping unit one and three (Table 3). Most soil properties (EC, TN, OM and OC) was found to be low and others such as pH, CEC, K and Na were available at high concentration when compared with standards set by FAO guideline (Table 3).

Irrigation water quality

Knowledge of the chemical composition and quality issues related to irrigation water sources in the study area are of particular significance for the proper management and wise utilization. The quality of irrigation water needs to be determined through laboratory analysis in order to maintain a safe salt balance in the soil (Brady and Weil, 2002). In an effort to this end, the water sources used for irrigation water resources of the area was surveyed and identified. Irrigation water quality was analyzed for SAR, pH and EC of the water.

Sodium absorption ratio (SAR)

Irrigation water containing large amounts of sodium is of special concern due to sodium effects on the soil and poses a sodium hazard usually expressed in terms of sodium adsorption ratio (SAR). SAR is calculated from the ratio of sodium to calcium and magnesium as they tend to counter effects of sodium. To determine the SAR value, water sample was taken at edge and middle of Fursa River for analysis of Na, Ca and Mg. And then SAR of the water solution was calculated from the concentrations of soluble Na, Ca and Mg. At the end of the analysis, the SAR value of Fursa River was found to be 10.0, while the adjusted SAR approaches 20.40 (Table 4). However, SAR value of water greater than nine (>9) was severely restricted to use for irrigation due to risk of sodium hazard (Biswas, 1998; FAO soil Bulletin 55, 1985; Wesstcott and Ayers, 1985). This implies early warning for potential hazard of sodic soil in the area.

pH and EC of the water

The pH of the water samples could be measured either in the field or in the laboratory using digital pH meter. From the same sample (with the same method) used for SAR analysis, the pH data was generated. The result of the analysis indicate that the pH of the Fursa River is slightly saline (7.36) or nearly neutral (Table 4). Electric conductivity (EC) of the water samples have been done like the pH analysis (Richards, 1954). The values of EC obtained from the analysis at room temperature needs to be corrected to 25°C using a temperature coefficient of 2.3%. By doing so, the laboratory result showed that the EC of the water is classified as medium (1.31 EC (dS/m) (Table 4) as outlined by different researchers (Biswas, 1998; FAO soil Bulletin 55, 1985; Wesstcott and Ayers, 1985). Moreover, the total dissolved solids were found to be slight to medium range (Table 4).

Soil salinity and sodicity

As a result of the strong relationship between the electrical conductivity of soil extract and the soil salt concentration, the salt content of a soil is commonly expressed by as EC. Measured at a reference temperature of 25°C, the EC is nowadays expressed in decisiemens per meter (dS/m). To evaluate soil salinity, we can measure the EC or the salt concentration in several soil water extracts. The most reliable evaluation is obtained by measuring the salt concentration in soil water at field capacity. The laboratory result shows that the ESP ranges from 0.8 to 2.3% in the surface layer (low to medium) and this indicates that the soils are classified as none saline to slightly saline on the surface but there is an increase in salinity in lower layer (Table 3). The salinity in the mapping unit three is however extremely sodic in lowest layer. Hence coupled with water and soil analysis results, there will be a potential danger of sodicity development in the intended irrigation scheme. Thus, selection of crop type and proper irrigation methods should be designed for sustainability of soil productivity in the study area.

Conclusion

The study showed that the distribution of silt, clay, sand, EC, pH, CEC, available phosphorus, exchangeable bases, carbonates, total nitrogen and organic matter was not uniform with profile/depth wise trend in the three mapping units. The soil salinity and sodicity level of the study area is classified as non-saline and non-sodic for mapping unit one, non-saline and non-sodic for the surface layer of mapping unit two and three, while it is saline for the subsurface layer of site three. There is indication of potential sodicity in the subsurface layer. Moreover, the SAR of the water is medium while the EC of the water is classified as medium. Values of sodicity and combining effect of Salinity and sodicity levels were above the FAO guidelines for water quality restriction limit. Thus, sodicity problem could be expected in the long run. There is indication of potential sodicity not only in the soil but also in the irrigation water. Hence, the study underscores the need for selection of salt tolerant crops and good water management by using appropriate irrigation methods to sustain productivity of soil in the intended irrigation scheme.

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