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Salinity Status of Soils of Irrigated Lands and Irrigation Water Quality at Raya Alamata District, Northern Ethiopia

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Abstract **– Information about salinity/sodicity status of soils and irrigation water quality plays a vital role for proper management of irrigated fields. Studies on salinity/sodicity status and irrigation water quality were conducted during 2016 at Raya Alamata District at two sites (Tumuga and Gerjale) with the objectives to characterize the salinity/ sodicity status of soils of irrigated lands and irrigation water quality. Based on the field reconnaissance survey, sampling units for surface and profile soil samples as well as irrigation water were identified. Accordingly, irrigated surface and profiles soils, and irrigation water samples were collected using systematic sampling. Samples were analyzed for their salinity/sodicity indicators and irrigation water quality parameters. The magnitude of the exchangeable cations in all sites were in the order of Ca> Mg> Na > K. All sites were within the range of moderate to very high and very high with respect to PBS and CEC respectively. Soluble cations (Ca^{2+} and Na^+) and anions (SO_4^{2-} and Cl^-) were dominant. Residual sodium carbonate of the irrigation water indicated that, 85.71% and 87.50% were suitable and 14.29% and 12.50% were not suitable for irrigation purpose at Tumuga and Gerjale sites, respectively. Considering agricultural purposes, the electrical conductivity values for the surface soils indicated that only a small portion of the total irrigated area was classified as saline soil, whereas it was below the threshold level throughout the soil profiles to qualify for the salt affected soil classes in both sites of the study area. Continuous assessment and monitoring to avoid the possible occurrence of soil and irrigation water salinity/sodicity should be followed in both sites of the irrigated areas.**

Keywords **– Salt Affected Soil Classes, Irrigation Water Quality, Soil Properties.**

I. INTRODUCTION

The quality of soil, as a major sub-system of agricultural and, is changing over time as a result of changes in its environment or management practices (El-kader *et al.*, 2006). Agriculture faces various environmental stresses like extreme temperature, soil salinity, drought and flood that affect the production of crops in dry land areas. Among these, soil salinity is one of the most devastating environmental stresses happened due to mismanagement of irrigation and aridity (Shahbaz and Ashraf, 2013). Irrigation agriculture ensuring food security for billions of people in the past. However, their current and future state leaves much to be desired due to low crop yield and land degradation (Mason, 2002). Poor irrigation agriculture in arid and semi-arid regions results in land degradation through soil salinity/sodicity development in the world. Hence, the study of arid lands and salt affected soils is important for modern agricultural management, particularly for developing countries like Ethiopia, where agriculture is the main economic sector (Seleshi *et al.*, 2007).

The cultivated agricultural land of Ethiopia is about 12 million hectare (MoA, 2011). Moreover, Even if the potential and actual irrigated area is not precisely investigated (Belay and Bewket, 2013) estimates of irrigable land in Ethiopia vary between 1.5 and 4.3 million ha, averaged about 3.5 million ha (Seleshi *et al.*, 2007; Makombe *et al.*, 2011). Groundwater quality is important since crop production mainly depends on groundwater for irrigation in several arid regions in the world. However, the long-term application of ground water of moderate to low quality in poorly drained land may accumulate high quantity of salts in the agricultural land (Abdulaziz *et al*., 2003).

Salt affected soils and the associated poor soil drainage conditions are the results from poor management of soils and irrigation systems (Tessema, 2011). Therefore, irrigation water quality should be evaluated before implementation of irrigation projects (Al-Ghobari, 2011). Physical observation and available information of soils on the recently initiated small scale irrigation schemes and groundwater sources in Tigray region show accumulation of soluble salts (Kidane *et al.*, 2006). Farms under irrigation require a periodic evaluation of soil salinity/sodicity and irrigation water quality so as to adjust future production for a given area. This is particularly important in southern zone of Tigray, Raya Alamata district, where poor land and water management is encountered.

Information about soil salinity/sodicity and irrigation water quality status plays a vital role for proper management of agricultural fields. However, the salinity status of soils and irrigation water quality of the study area has never been characterized and documented for designing intervention scenarios. As a result, the farming communities do not have sufficient information regarding the status of soil salinity/sodicity and irrigation water quality of the study area. In response to this lack of information, this study was conducted to characterize the salinity/sodicity status of soils of irrigated lands and irrigation water quality of the study area.

II. MATERIALS AND METHODS

2.1. *Description of the Study Area*

The study was conducted in southern zone of Tigray Raya Alamata district, northern Ethiopia at two irrigated sites, namely Tumuga and Gerjale. The district is located at 600 km north of Addis Ababa (IPMS-ILRI, 2005) and geographically located between 12°25’ and 12°55’ North latitudes and 39°33’ and 39° 53’ East longitudes with an elevation of 1520 meter above sea level (REST, 1998). The major soil types found in the district are Cambisols, Fluvisols, Leptosols and Vertisols. The landform of the district is largely level plain where Vertisols and Fluvisols are the dominant and found extensively in farmlands (Amanuel *et al.*, 2015). The district has a bimodal rainfall pattern, though diminishing from time to time and has considerable surface water potential that comes from the highlands and ground water potential. The annual rainfall (mm), minimum and maximum temperatures (O_C) collected from National Meteorology Service Agency (1997-2016) showed 663.12, 14.70 and 28.17, respectively (REST, 1996).

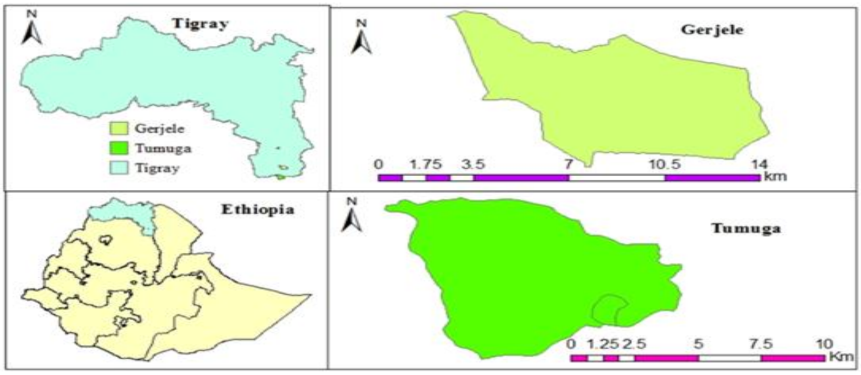

Fig. 1. Location map of the study.

2.2. *Soil Sample Collection and Method of Sampling*

General visual field reconnaissance survey was carried out in the study area to have a general view of the variations/homogeneity of the study area by traversing walk in the field. Based on the observation, the field was divided in to a number of sampling units based on similarities of surface soil color, drainage condition, land use system, vegetation cover, slope and cropping history of the study area and then sampling points were selected from each of the demarcated sampling units. Accordingly, surface soil samples (0-30 cm) using Augur (Wilding, 1985) and fresh profile soil samples with a standard dimensions (1.5 m width and 2 m length) according to FAO (2006) guidelines from different depths (0-30, 30-60, 60-100, 100-130 and 130+ cm) were collected. The depth of the soil profiles were restricted by parent material and depth of the ground water table and then soil samples were collected. All sampling points of the surface and soil profiles were geo-referenced using global positioning system (GPS) and sampling dates were properly recorded.

2.3. *Soil Sample Preparation and Analysis*

The collected soil samples were air-dried, ground to pass through 2 mm sieve and prepared for the determination of soil salinity/sodicity status and selected soil chemical properties. Soil reaction (pHe) and electrical conductivity (ECe) were determined from saturated paste extract following the methods described by FAO (1999). Soil pHe was measured potentiometrically using a digital pH-meter and ECe by digital conductivity meter according to the methods stated by USSLS (1954), respectively. The exchangeable bases (Ca, Mg, Na and K) were determined from the extraction of neutral normal ammonium acetate. The water soluble bases (Ca2+, Mg2+, Na+ and K+) and water soluble anions (CO32-, HCO3-, Cl- and SO42-) were determined from the saturated paste extracts prepared for pHe and ECe as outlined by FAO(1999). Both exchangeable (Ca and Mg) and water soluble (Ca2+ and Mg2+) were determined by Atomic Absorption Spectrophotometer (AAS) and exchangeable (Na and K) and water soluble (Na+ and K+) were determined by flame photometer.

The cation exchange capacity (CEC) of the soils was determined by the neutral normal ammonium acetate method according to the percolation tube procedure (Van Reeuwijk, 1992). Exchangeable sodium percentage (ESP) was computed as the percentage of the exchangeable Na to the cation exchange capacity (CEC) of the soil and percent base saturation (PBS) was computed as the percentage of the exchangeable bases to the CEC of the soil in which concentrations were expressed in cmol (+) kg-1 of soil. Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) of the soil solution were calculated from the concentrations of soluble cations (Na+, Ca 2+ and Mg 2+) and soluble anions (CO32- and HCO3-) in which both expressed by meq L-1 (USSLS, 1954). Water soluble anions (CO32-, HCO3-) were determined by titrating with sulfuric acid using phenolphthalein and methyl orange indicators, respectively (USSLS, 1954). Chloride (Cl-) was determined by titration with the extract against silver nitrate (AgNO3) solution using potassium chromate (K2Cr2O7) as an indicator while sulfate (SO42-) was determined turbidimetrically.

2.4. *Irrigation Water Sample Collection and Methods of Sampling*

Prior to irrigation water sampling, field survey was carried out. Based on the field observation, irrigation water sampling sources were selected. Accordingly, samples were taken from the selected sources and irrigation canals.

Irrigation water samples from irrigation canals were collected by mixing several sub-samples taken at 5 minutes interval at the inlet of the irrigated lands in order to obtain representative samples. Samples were taken from the groundwater only after it has been pumped for sometimes and after checking the water being free of mud and foreign materials. Plastic bottles (one liter) were used to collect the water samples from all the water sources and irrigation canals. Before collecting the samples, the bottles were washed properly and rinsed thoroughly with distilled water so as to remove any contamination. Each sample was numbered and labeled carefully and placed in to boxes with location and sources indicated. The sources of irrigation water sampling points were spatially geo-referenced using GPS and sampling dates were properly recorded.

2.5. *Analysis of Selected Irrigation Water Quality Parameters*

Electrical conductivity and pH of the water samples were measured using conductivity meter and a digital pH meter, respectively (USSLS, 1954). Ca2+ and Mg2+ of the irrigation water samples were directly measured using AAS, while Na+ and K+ were analyzed using flame photometer. Similarly, the anions (CO32-,HCO3-, Cl- and SO42-) of the irrigation water samples were determined following the procedures described for their respective methods of determination in the soil after saturation paste extract has been made. Boron (B) was determined following Curcumin analytical method as outlined by Dible et al. (1954). Irrigation water salinity, as total dissolved salts (TDS) was determined by summing the concentrations of the individual ions (Bryan et al., 2007). The RSC and SAR were determined from the concentrations of HCO3-, CO32-, Na+, Ca2+ and Mg2+ using equations the following formulas:

$$\mathrm{RSC} = [(\mathrm{HCO_3^-} + \mathrm{CO_3^{2-}}) - (\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}})] \quad (1)$$

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\frac{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}}{2}}} \quad (2)$$

where, all concentrations were expressed in meq L^{-1} (USSLS, 1954).

III. RESULTS AND DISCUSSIONS

3.1. *Selected Soil Properties*

3.1.1. *Soil pHe and ECe*

The analytical results of soil reaction (pHe) from saturated paste extract of the surface soil ranged from 8.01 to 8.47 with an average value of 8.29 (Table 1) and from 7.96 to 8.41 with an average value of 8.21 (Table 2) at Tumuga and Gerjale sites, respectively. The pHe value of soil profiles slightly increased with increasing profile depth except, at the depth of 100-130 cm for both sites (Table 3). This could be due to increased values of basic cations at the subsurface layers resulted to the downward movement of these constituents from the surface to the subsurface layers within in the soil profile (Okbay, 2015). According to the rating of Jones (2003), pHe of the surface and profile soil was rated from moderately alkaline to strongly alkaline range and this range of pHe may have effect on nutrient availability. In general, the probable reason for the higher soil pHe values of the study area could be due to relative abundance of alkaline forming cations.

Table 1. Exchangeable Properties of Surface Soils Studied at Tumuga Site.

Sample Code	pHe	ECe (dSm^{-1})	Exchangeable Bases (cmol (+) kg^{-1})				CEC (cmol (+) kg^{1})	PBS (%)	ESP (%)
			Ca	Mg	Na	K			
1	8.20	0.04	14.66	3.40	0.37	0.42	58.82	32.05	0.63
2	8.35	0.12	20.75	8.03	0.74	1.11	59.40	51.57	1.25
3	8.34	0.15	28.25	10.48	0.81	0.59	61.50	65.25	1.32
4	8.39	0.09	23.83	8.37	0.61	0.63	57.36	58.30	1.06
5	8.36	0.08	26.02	8.88	0.72	0.78	57.48	63.33	1.25
6	8.30	0.17	28.03	10.39	1.18	0.66	54.18	74.31	2.18
7	8.45	0.11	26.10	10.82	0.98	0.81	59.26	65.32	1.65
8	8.25	0.18	30.02	12.37	1.32	0.72	53.96	82.34	2.45
9	8.47	0.14	26.93	17.66	1.63	1.13	52.04	90.99	3.13
10	8.30	0.16	14.75	4.61	0.52	0.59	49.82	41.09	1.04
11	8.27	0.08	35.87	10.41	0.54	1.02	51.08	93.66	1.06
12	8.24	0.06	34.51	9.10	0.56	1.06	49.82	90.79	1.12
13	8.28	1.12	40.03	9.18	0.67	1.19	55.18	92.55	1.21
14	8.01	4.15	24.05	9.29	2.62	0.49	60.40	60.35	4.34
15	8.16	0.07	24.30	6.29	0.59	0.58	50.46	62.94	1.17
16	8.30	0.11	30.39	8.84	1.34	0.60	57.08	72.13	2.35
17	8.17	0.06	17.25	7.33	1.98	0.19	60.12	44.49	3.29
18	8.12	0.03	16.58	4.38	1.63	0.59	61.76	37.53	2.64
19	8.24	0.07	16.35	7.18	0.54	0.50	45.16	54.41	1.20
20	8.47	0.13	26.44	11.67	0.56	1.13	44.06	90.33	1.27
21	8.41	0.09	26.87	12.50	0.67	0.76	55.68	73.28	1.20
Mean	8.29	0.34	25.33	9.10	0.98	0.74	54.98	66.52	1.75

pHe = pH of Saturated Paste Extract; ECe = Electrical Conductivity of Saturated Paste Extract; CEC = Cation exchange capacity; PBS = Percent base saturation; ESP = Exchangeable sodium percentage.

The surface soil of the study area exhibited high variation with respect to ECe values for both sites. Accordingly, ECe values varied from 0.03 dS m-1 to 4.15 dS m-1 at Tumuga (Table 1) and from 0.05 dS m-1 to 7.45 dS m-1 in Gerjale site (Table 2). This could be due to the reason that, salt concentration in soils may vary greatly with sampling spot, sampling unit and horizontal or vertical distance (Achalu et al., 2012). In line with the pHe, the ECe value of the soil profile also increased slightly with depth for both sites (Table 3). This implied that the down ward movement of the salt (leaching) was dominant over that of the upward (capillary) movement of salts. Heluf (1985), also observed relatively higher concentrations of ECe at lower soil profile depths in irrigated soils of middle Awash river basin of Ethiopia and attributed the situation to the dominance of downward leaching/ removal of soluble salts over surface accumulation of salts. Allotey et al. (2008), also reve-

-aled that, increasing trends in ECe with increasing depths were observed in soil profiles.

3.1.2. *Exchangeable Bases*

Exchangeable calcium (Ca) followed by exchangeable magnesium (Mg) were the dominant basic cations in the exchange complex of the surface (Tables 1 and 2) and soil profiles (Table 3) for both sites of the study area. The magnitude of the soil exchangeable cations for both sites were in the order of Ca > Mg > Na > K. The domination of exchangeable Ca and M contents imply that the soil parent material primarily is rich in basic cations and the divalent cations are retained in higher concentrations for longer periods by the soil colloidal particles because of their higher selectivity coefficient over the monovalent cations (Mesfin, 1998 and Eyelachew, 2001). Both of the exchangeable bases in all sites of the soil profiles did not show consistent trend with increasing soil depth.

Table 2. Exchangeable Properties of Surface Soils Studied at Gerjale Site.

Sample Code	**pHe**	**ECe (dSm^{-1})**	**Exchangeable Bases (cmol(+)kg^{-1})**				**CEC (cmol (+) kg^{1})**	**PBS (%)**	**ESP (%)**
			Ca	**Mg**	**Na**	**K**			
22	8.26	0.07	31.33	6.80	0.21	0.71	55.18	70.77	0.38
23	8.24	0.06	31.30	6.86	0.12	0.61	57.10	68.11	0.21
24	8.41	0.06	30.53	7.37	0.14	0.72	54.56	71.04	0.26
25	8.29	7.45	31.91	13.39	3.59	0.70	54.96	90.23	6.53
26	8.39	0.06	31.83	7.63	0.14	0.65	46.02	87.46	0.30
27	8.29	0.10	24.48	4.21	0.32	0.83	52.48	56.86	0.61
28	8.20	0.07	32.99	5.57	0.32	0.91	49.86	79.80	0.64
29	8.17	0.06	35.23	7.06	0.25	0.94	51.92	83.74	0.48
30	8.16	0.05	30.20	6.55	0.19	1.02	54.74	69.35	0.35
31	8.33	0.09	27.32	4.74	0.32	0.94	57.88	57.57	0.55
32	8.14	0.05	26.93	5.72	0.32	0.37	58.36	57.13	0.55
33	8.07	0.06	19.91	6.25	0.19	0.95	58.18	46.92	0.33
34	8.14	0.08	19.51	5.46	1.63	0.68	58.26	46.82	2.80
35	8.09	0.05	22.57	6.40	1.54	1.07	58.80	53.71	2.62
36	8.38	0.08	16.99	5.53	1.29	0.95	57.90	42.76	2.23
37	8.32	0.07	17.18	5.57	1.18	0.93	52.42	47.42	2.25
38	8.03	0.30	24.34	6.38	1.71	1.17	53.66	62.62	3.19
39	7.96	0.06	24.70	8.01	1.21	1.13	60.96	57.50	1.98
40	8.07	0.06	20.04	8.25	1.25	1.12	44.06	69.59	2.84
41	8.29	0.07	33.36	10.52	2.20	0.54	52.02	89.62	4.23
42	8.21	0.06	31.56	7.67	0.23	0.87	58.18	69.32	0.40

Sample Code	pHe	ECe (dSm^{-1})	Exchangeable Bases (cmol(+)kg^{-1})				CEC (cmol (+) kg^{1})	PBS (%)	ESP (%)
			Ca	Mg	Na	K			
Mean	8.21	0.43	26.87	6.95	0.87	0.85	54.64	65.64	1.61

pHe = pH of Saturated Paste Extract; ECe = Electrical Conductivity of Saturated Paste Extract; CEC = Cation exchange capacity; PBS = Percent base saturation; ESP = Exchangeable sodium percentage.

The cation exchange capacity (CEC) of the surface soil at Tumuga site ranged from 44.06 to 61.76 cmol(+) kg-1 (Table 1) while, it varied from 44.06 to 60.96 cmol(+) kg-1 in Gerjale site (Table 2). Following the variation in exchangeable bases and CEC, the percent base saturation (PBS) of the soil in the study area showed considerable variability. According to the rating set by Hazelton and Murphy (2007), both surface and profile soils of the two sites were within the range of very high with respect to CEC and moderate to very high with respect to PBS. The CEC of the soil profiles consistently decreased with soil depth in Gerjale soil profiles. The PBS of the soil profiles of the study area did not reveal any consistent trend with soil depth (Table 3).

Table 3. Exchangeable Properties of Soil Profiles in the Study Area.

Site Name	Soil Depth (cm)	PHe	ECe (dSm^{-1})	Exchangeable Bases (cmol (+) Kg^{-1})				CEC (cmol (+) Kg^{-1})	PBS (%)	ESP (%)
				Ca	Mg	Na	K			
Tumuga	0-30	8.13	0.05	25.86	10.99	2.24	0.96	56.04	71.47	4.00
	30-60	8.21	0.07	28.95	10.46	1.91	0.64	55.80	75.20	3.42
	60-100	8.26	0.07	24.28	8.52	1.76	0.67	54.02	65.22	3.26
	100-130	8.25	0.06	26.84	18.00	2.00	1.11	55.62	86.21	3.60
	130^{+}	8.38	0.08	32.59	7.95	1.21	0.82	56.04	75.96	2.16
	Mean	8.25	0.07	27.70	11.18	1.82	0.84	55.50	74.81	3.29
Gerjale	0-30	8.17	0.03	23.93	6.84	1.63	1.16	57.66	58.20	2.83
	30-60	8.20	0.04	21.16	7.20	1.49	1.12	55.64	55.66	2.68
	60-100	8.22	0.06	28.22	9.37	1.27	0.94	53.12	74.92	2.39
	100-130	8.19	0.05	27.82	10.26	1.13	0.78	51.88	77.08	2.18
	130^{+}	8.28	0.07	18.09	10.52	0.68	0.76	48.64	61.78	1.40
	Mean	8.21	0.05	23.84	8.84	1.24	0.95	53.39	65.53	2.29

pHe = pH of Saturated Paste Extract; ECe = Electrical Conductivity of Saturated Paste Extract; CEC = Cation exchange capacity; PBS = Percent base saturation; ESP = Exchangeable sodium.

3.1.3. *Soil Soluble IONS Composition, Sodium Adsorption Ratio and Residual Sodium Carbonate*

The soil soluble ions considered in the study were: cations (Ca2+, Mg 2+, Na+ and K+) and anions (CO32-, HCO3-, Cl- and SO42-). Accordingly, Ca2+ followed by Na+ > Mg 2+ > K+ in this order were dominant soluble cations and Cl- = SO42- followed by HCO3- were dominant among the anions in Tumuga surface soils (Table 4). Similarly, Na+ followed by Ca2+, Mg2+ and K+ in this order were the dominant soluble cations and

SO42- = Cl- or followed by Cl- and HCO3- were dominant among the anions at Gerjale site. The sodium adsorption ratio (SAR) of the soil solution ranged from 0.39 to 4.05 for surface soils of Tumuga site. Similarly, it was ranged from 0.57 to 6.72 at Gerjale site.

Table 4. Soluble IONS Composition, SAR and RSC of Surface Soils Studied at Tumuga Site.

Sample Code	**Soluble Cations (meq L^{-1})**				**SAR**	**Soluble Anions (meq L^{-1})**				**RSC (meq L^{-1})**
	Ca^{2+}	**Mg^{2+}**	**Na^{+}**	**K^{+}**		**CO$_3^{2-}$**	**HCO$_3^{-}$**	**SO$_4^{2-}$**	**Cl^{-}**	
1	0.64	13.36	1.05	0.15	0.40	Trace	0.16	0.14	0.11	Trace
2	0.74	0.13	1.88	0.33	2.85	Trace	0.10	0.14	0.08	Trace
3	0.88	0.31	2.45	0.27	3.18	Trace	0.06	0.14	0.11	Trace
4	11.31	0.19	0.94	0.14	0.39	Trace	0.06	0.14	0.06	Trace
5	0.52	0.02	1.61	0.18	3.10	Trace	0.13	0.14	0.08	Trace
6	0.77	0.59	3.17	0.23	3.84	Trace	0.11	0.15	0.16	Trace
7	0.50	0.08	2.18	0.29	4.05	Trace	0.17	0.14	0.10	Trace
8	1.02	0.88	2.94	0.26	3.02	Trace	0.10	0.14	0.16	Trace
9	0.72	0.57	2.90	0.35	3.61	Trace	0.10	0.14	0.11	Trace
10	0.87	0.48	2.76	0.47	3.36	Trace	0.10	0.14	0.14	Trace
11	0.59	0.13	1.27	0.25	2.12	Trace	0.11	0.14	0.20	Trace
12	0.47	0.34	1.09	0.18	1.71	Trace	0.18	0.14	0.15	Trace
13	0.93	1.34	2.04	0.33	1.91	Trace	0.13	0.15	0.14	Trace
14	19.71	5.81	12.53	0.35	3.51	Trace	0.08	0.15	0.56	Trace
15	20.07	0.36	1.39	0.17	0.43	Trace	0.11	0.14	0.12	Trace
16	0.48	0.52	2.49	0.17	3.52	Trace	0.10	0.15	0.13	Trace
17	0.46	0.59	1.12	0.17	1.55	Trace	0.09	0.14	0.08	Trace
18	0.08	0.09	0.55	0.10	1.89	Trace	0.09	0.14	0.09	Trace
19	0.30	0.57	1.14	0.17	1.73	Trace	0.11	0.14	0.16	Trace
20	0.85	2.26	2.04	0.35	1.64	Trace	0.12	0.14	0.15	Trace
21	0.66	1.03	1.39	0.22	1.51	Trace	0.15	0.14	0.15	Trace
Mean	2.98	1.41	2.33	0.24	2.35	Trace	0.11	0.14	0.14	Trace

SAR = Sodium adsorption ratio; RSC = Residual sodium carbonate.

The dominance of the sum of the soluble cations of Ca2+ and Mg2+ over the sum of the anions of CO32- and HCO3- was reflected in the generally trace values of RSC in the study area. Soluble sodium (Na+) followed by soluble calcium (Ca2+) were the dominant basic cations while, SO42- = Cl- followed by HCO3- appeared to be dominant among the anions of Tumuga soil profile and Mg2+ followed by Na+ were the dominant basic cations while, SO42- = Cl- followed by HCO3- appeared to be dominant among the anions of Gerjale soil profile.

Table 5. Soluble IONS Composition, SAR and RSC of Surface Soils Studied at Gerjale Site.

Sample Code	Soluble Cations (meq L^{-1})				SAR	Soluble Anions (meq L^{-1})				RSC (meq L^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
22	0.47	0.08	0.89	0.25	1.70	Trace	0.12	0.17	0.08	Trace
23	0.84	0.35	0.67	0.18	0.87	Trace	0.11	0.18	0.08	Trace
24	0.82	0.06	0.85	0.22	1.28	Trace	0.11	0.18	0.07	Trace
25	22.60	4.61	24.8	0.73	6.72	Trace	0.20	0.22	0.34	Trace
26	0.68	0.36	0.73	0.18	1.01	Trace	0.09	0.17	0.07	Trace
27	0.57	0.19	1.00	0.39	1.62	Trace	0.10	0.17	0.08	Trace
28	0.63	0.37	1.00	0.26	1.41	Trace	0.13	0.17	0.14	Trace
29	1.00	0.06	0.58	0.21	0.80	Trace	0.14	0.17	0.23	Trace
30	0.47	0.31	0.67	0.23	1.07	Trace	0.11	0.17	0.10	Trace
31	1.46	0.65	0.87	0.27	0.85	Trace	0.15	0.17	0.08	Trace
32	0.26	0.17	0.82	0.22	1.77	Trace	0.12	0.17	0.08	Trace
33	0.67	0.67	0.69	0.25	0.84	Trace	0.10	0.18	0.06	Trace
34	1.30	1.09	0.62	0.14	0.57	Trace	0.13	0.17	0.10	Trace
35	0.63	0.35	0.44	0.17	0.63	Trace	0.08	0.17	0.09	Trace
36	0.24	0.80	1.43	0.19	1.98	Trace	0.13	0.17	0.12	Trace
37	1.14	0.94	1.72	0.21	1.69	Trace	0.13	0.17	0.12	Trace
38	1.04	3.19	6.83	0.22	4.70	Trace	0.10	0.17	0.32	Trace
39	0.52	0.44	0.73	0.25	1.05	Trace	0.15	0.17	0.08	Trace
40	0.57	0.19	0.73	0.27	1.18	Trace	0.11	0.17	0.11	Trace
41	0.93	0.08	0.82	0.27	1.15	Trace	0.12	0.17	0.15	Trace
42	0.93	0.38	0.58	0.17	0.72	Trace	0.08	0.17	0.15	Trace
Mean	1.80	0.73	2.26	0.25	1.60	Trace	0.12	0.17	0.13	Trace

The concentration of K+ was the lowest among the cations and CO32- was trace among the anions in both sites of the soil profiles. The concentrations of soluble cations and anions did not show consistent trend with increasing depth throughout the soil profile in both sites. The SAR of the soil profiles did not reveal any consistent trend in both sites (Table 6).

Table 6. Soluble IONS Composition, SAR and RSC of the Soil Profiles.

Site Name	Soil Depth (cm)	Soluble Cations (meq L^{-1})				SAR	Soluble Anions (meq L^{-1})				RSC (meq L^{-1})
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{-2}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
Tumuga	0-30	0.58	0.44	0.69	0.23	0.97	Trace	0.09	0.17	0.08	Trace
	30-60	0.32	0.23	0.51	0.06	0.97	Trace	0.13	0.17	0.10	Trace

Site Name	Soil Depth (cm)	Soluble Cations (meq L^{-1})				SAR	Soluble Anions (meq L^{-1})				RSC (meq L^{-1})
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{-2}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
	60-100	0.47	0.29	1.86	0.22	3.02	Trace	0.14	0.17	0.11	Trace
	100-130	0.19	0.06	1.54	0.11	4.36	Trace	0.13	0.17	0.12	Trace
	130⁺	0.26	0.08	1.59	0.11	3.86	Trace	0.12	0.17	0.17	Trace
	Mean	0.36	0.22	1.24	0.15	2.63	Trace	0.12	0.17	0.12	Trace
	0-30	0.78	0.38	0.46	0.22	0.60	Trace	0.10	0.17	0.11	Trace
Gerjale	30-60	0.24	0.55	0.60	0.18	0.95	Trace	0.14	0.17	0.12	Trace
	60-100	0.36	0.71	0.58	0.14	0.79	Trace	0.13	0.17	0.17	Trace
	100-130	0.19	0.71	0.60	0.13	0.89	Trace	0.11	0.17	0.11	Trace
	130⁺	0.28	1.11	0.89	0.14	1.07	Trace	0.11	0.17	0.17	Trace
	Mean	0.37	0.69	0.63	0.16	0.86	Trace	0.12	0.17	0.14	Trace

SAR = Sodium adsorption ratio; RSC = Residual sodium carbonate.

3.2. *Soil Salinity/Sodicity Status of the Study Area*

Analytical results of soil reaction (pHe), electrical conductivity of the saturation paste extract (ECe), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) of the soil solution were used to explain soil salinity/sodicity characteristics of the study area. Threshold value of 4 dS m-1 for ECe 13 for SAR, 15 % for ESP and 8.5 for pHe were used as criteria for grouping the soils in to different classes of salt affected soils (USSLS, 1954). Accordingly, considering agricultural purposes, the ECe values for the surface soil of the study area indicated that only a small portion of the total irrigated area was classified as saline (Tables 1 and 2) as per the criteria set by USSLS (1954). Similarly, the ECe values measured throughout the soil profiles in both sites were below the threshold level to qualify for the salt affected soil classes (Table 3).

3.3. *Chemical Composition of Irrigation Water*

3.3.1. *pH and ECw of Irrigation Water*

The pH of the irrigation water varied from 7.59 to 8.82 and 7.60 to 8.48 at Tumuga and Gerjale sites, respectively. According to Bryan et al. (2007), irrigation water quality of the study area classified as slight to moderate and severe potential irrigation problem with regard to pH. Electrical conductivity of irrigation water (ECw) also ranged from 0.13 to 0.34 dSm-1 at Tumuga and from 0.07 to 0.37 dSm-1 at Gerjale (Table 7). According to USSLS (1954) and FAO (1985) classification, irrigation water quality of the study area classified from class one (C1) which is low salinity hazard to class two (C2) or medium salinity hazard. The maximum ECw value of irrigation water at both sites were found at the maximum corresponding values of Na+ and Cl- which is in agreement with Mali et al. (2012).

3.3.2. *Major Ions of the Irrigation Water*

Among the cations, Mg+2 was dominant followed by Ca+2, Na+ and k+ at Tumuga site respectively. However, Ca+2 was the dominant cation in irrigation water at Gerjale site followed by Mg+2, Na+ and K+.

Among the anions, HCO3- was dominant followed by Cl-, CO3-2 and SO4-2 at both Tumuga and Gerjale site, respectively (Table 7). According to FAO (1988), the irrigation water quality based on degree of restriction to use for their Cl-, classified as none to slight to moderate problem. The concentration of Boron was found to be in a smaller amount at both sites, respectively. Thus, according to USSLS (1954), the concentration of boron was below the standard set for the toxicity level of sensitive crops.

Table 7. Chemical Compositions of Irrigation Water Sources in the Study Area.

Sample Code	**pH**	**ECw (dS m^{-1})**	**Dissolved Cations (meq L^{-1})**				**SAR**	**Dissolved Anions (meq L^{-1})**				**B (mg L^{-1})**	**RSC (meq L^{-1})**	**TDS (mg L^{-1})**
			Ca^{2+}	**Mg^{2+}**	**Na^{+}**	**K^{+}**		**CO_3^{2-}**	**HCO_3^{-}**	**SO_4^{2-}**	**Cl^{-}**			
Tumuga Irrigation Water Quality														
T1/TS	7.59	0.16	4.76	5.05	0.43	0.03	0.19	Trace	7.00	0.06	3.50	0.04	Trace	723.68
T2/TIC	7.78	0.14	4.36	5.76	1.88	0.04	0.84	Trace	8.00	0.04	3.30	0.23	Trace	811.04
T3/TS	8.63	0.34	3.56	3.55	9.34	0.41	4.95	Trace	10.20	0.25	6.60	0.42	3.09	1215.41
T4/TIC	8.10	0.13	3.09	4.68	2.07	0.04	1.05	1.20	6.80	0.02	2.30	0.18	0.23	702.69
T5/TIC	8.82	0.16	1.39	6.34	3.53	0.06	1.80	2.00	6.60	0.05	2.80	0.16	0.87	753.50
T6/TIC	8.10	0.13	3.68	4.59	1.44	0.07	0.71	0.40	6.60	0.08	2.50	0.27	Trace	674.17
T7/TIC	8.18	0.20	3.70	6.54	3.53	0.07	1.56	2.20	7.90	0.07	3.90	0.09	Trace	928.66
Mean	8.17	0.18	3.51	5.22	3.17	0.10	1.59	0.83	7.59	0.08	3.56	0.20		829.88
Gerjale Irrigation Water Quality														
G1/GIC	7.60	0.09	4.46	2.42	0.47	0.03	0.25	Trace	5.10	0.03	1.70	0.15	Trace	505.42
G2/GGw	8.48	0.37	3.19	5.33	6.77	0.50	3.28	Trace	11.50	0.28	5.20	0.27	2.98	1204.87
G3/GGw	7.78	0.09	2.38	2.58	0.62	0.03	0.39	0.60	5.20	0.01	1.80	0.19	0.84	495.11
G4/GGw	7.95	0.07	2.90	1.80	0.91	0.03	0.59	0.40	4.60	0.00	1.60	0.13	0.30	452.66
G5/GGw	8.00	0.08	3.72	2.10	0.91	0.03	0.53	0.60	4.50	0.02	1.50	0.05	Trace	470.27
G6/GGw	7.98	0.07	3.73	1.89	0.81	0.03	0.48	0.80	3.70	0.01	1.10	0.11	Trace	408.21
G7/GGw	7.70	0.09	4.66	2.54	0.72	0.03	0.38	0.60	5.20	0.03	1.80	0.02	Trace	544.22
G8/GIC	7.60	0.09	4.48	2.57	0.62	0.08	0.33	0.60	5.30	0.04	1.60	0.28	Trace	540.32
Mean	7.89	0.12	3.69	2.65	1.48	0.10	0.78	0.45	5.64	0.05	2.04	0.15		577.64

T = Tumuga; TS = Tumuga stream water; TIC = Tumuga irrigated canal; GIC = ; G = Gerjale; Gerjale irrigated canal; GGw = Gerjale ground water; ECw = Electrical conductivity of irrigation water; SAR = Sodium adsorption ratio; RSC = Residual sodium carbonate; TDS = Total dissolved salts.

3.3.3. *Sodium Adsorption Ratio, Residual Sodium Carbonate and TDS*

The sodium adsorption ration (SAR) of the irrigation water ranged from 0.19 to 4.95 at Tumuga and from 0.25 to 3.28 at Gerjale (Table 7). The observed irrigation water at both sites were suitable for irrigation purposes with regard to SAR (USSLS, 1954|). The concentration of Ca+2 and Mg+2 were higher in the irrigation water at both sites relative to Na+ and hence, enough to counter the effect of Na+ hazard. Dhembare (2012) reported that the dominance of Ca2+ and Mg2+ in irrigation water tends to counter the effects of Na+ hazard. Residual sodium carbonate (RSC) values of irrigation water ranged from trace to 3.09 meq L-1 and 2.98 meq L– 1 at Tumuga and Gerjale sites, respectively (Table 7). The trace values of RSC were due to non-presence of CO32- in some irrigation water samples. However, water was suitable for irrigation from RSC point of view (Dhembare, 2012).

The dominance of the sum of Ca2+ and Mg2+ over the sum of CO32- and HCO3- was reflected in the trace values of RSC in this specific irrigation water quality of the study area. Among the irrigation water samples with regard to RSC, 85.71% and 87.50% were suitable and 14.29% and 12.5% were not suitable for irrigation purpose at Tumuga and Gerjale sites, respectively (USSLS, 1954). The TDS in the irrigation water ranges from 674.17 to 1215.41 mg L-1 at Tumuga and from 408.21 to 1204.87 mg L– 1 at Gerjale (Table 7). Based on degree of restriction set by FAO (1988) on use of water for irrigation, the concentration of TDS in the study area were classified under slight to moderate in their potential problem. Therefore, major salinity problem is expected from irrigation water if proper management is not conducted.

IV. CONCLUSIONS

This study was initiated to characterize the salinity/sodicity status of soils of irrigated lands and irrigation water quality at Raya Alamata District, Northern Ethiopia. Surface and profile soil samples were collected from irrigated lands while, irrigation water were collected from streams and ground water sources. The magnitude of the exchangeable cations of both the surface and profile soil were in the order of Ca> Mg> Na > K. pHe of the surface soil was rated from moderately alkaline to strongly alkaline and moderately alkaline at the surface and subsurface soil profiles. The pHe and ECe values of profile soils slightly increased with depth. Among the samples, 4.76% of surface soils were rated as saline and the rest (95.24 %) were classified as non-saline with respect to ECe.

The values of ECe observed throughout the depths of the profiles of both sites were below the limit to qualify for the salt affected soil classes. All sites of irrigation water were good for irrigation purposes with regard to SAR. The concentrations of Boron and TDS were below the standard set for the toxicity level of sensitive crops and slight to moderate in their potential irrigation problems, respectively. This study presents important findings concerning soil chemical characteristics, soil salinity/sodicity status and irrigation water suitability classes. From the analytical result of soil and irrigation water and field observation, the following recommendations can be forwarded. Even though, the study area is not under problem with respect to salinity/sodicity, there are some indicators from the soil and irrigation water results and symptom of plants. Therefore, continuous assessment and monitoring should be implemented to avoid the occurrence of soil salinity/sodicity status. Indeed, periodic evaluation and proper application of irrigation water should be carried out to avoid the occurrence of soil salinity/sodicity in the study area.

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