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Assessment of Salt Affected Soil and Irrigation Water Quality in Amibara and Dubti irrigated Areas, Afar Regional states of Ethiopia

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ABSTRACT

In irrigated arid and semi-arid areas of Ethiopia, particularly in the Afar region, salinity is a serious problem, but clear information about its status and distribution is lacking. The study aimed to investigate salt-affected soils and irrigation water quality at Amibara and Dubti irrigated areas. About 890 soil samples were collected at a depth of 0-30 and 30-60 cm using systematic sampling technique, and water samples were collected from surface and sub-surface for irrigated areas. Standard methods were followed to measure soil and water properties. Arc GIS 9.3 was used to map the overall salinity and sodicity problem for both regions. Results showed that around 62.31 % of the Amibara irrigated area and 18.26 % Dubti irrigated area had been mapped as saline soil (EC > 4 dS/m and SAR < 13). On the other hand, only 10.23 % at Amibara irrigated area and 4.15 % Dubti irrigated area were classed as saline-sodic (ECe > 4 dS/m, and SAR >13). Furthermore, the irrigation water quality of different water sources indicated groundwater and field drain water has poor irrigation water qualities compared to diversion from the river, central canal, and field canal water sources. It is possible to infer that if the present irrigation practice, including irrigation water quality, is continuing, it is expected that most of the cultivated lands will become sterile within a short period. The water table control by rehabilitating the subsurface drainage system seems to be the only feasible way to improve the sustainability of both irrigated areas. Thus, it needs to be monitored regularly to secure up-to-date knowledge of its extent to improve management practices and take appropriate actions

KEYWORDS
Salt affected soil, irrigation water quality, GIS, irrigated areas, soil depth

INTRODUCTION

Soil salinity is a severe problem in irrigated arid and semi-arid areas of the world [1] due to irrigation water quality and inappropriate irrigation practices. Moreover, according to [2] and [3], on a regular, 20% of the world's irrigated lands are affected by salts, but this figure increases to more than 30% in countries like Egypt, Iran, and Argentina. [4] reported that the world is losing at least ten hectares of arable land every minute; from this, three of them are from salinization problem, particularly in irrigated arid and semi-arid regions of the world. Furthermore, [5] estimated that the total area of land affected by salinity in Ethiopia is 11,033,000 ha, and it is the first in Africa.

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In Ethiopia, salt-affected soils are prevalent in the Rift Valley and the lowlands [6] [7] [8] [9]. Ethiopia has immense potential for expanding irrigated agriculture [10] in which most of the irrigation developed today is found in the Awash River basin where the irrigation water management is under problem [11][12], accordingly large area is affected by salinity [5]. Moreover, currently, primary and secondary salinization at rift valley system, particularly Amibara and Dubti irrigated areas, widely distributed and the problem is through time become increasing [13] [7] [8] [14]. Consequently, considering irrigation water quality is an essential issue for modern irrigated agriculture for the controlling soil salinity and sodicity problem [15]. Insufficient quality water used for irrigation can create issues like toxicity, poor water infiltration, degradation of soil physical properties, and other miscellaneous issues that lead to a decrease in crop production [16]. Thus, evaluating the quality of irrigation water is the most critical undertaking [2]. Generally, irrigation water quality affects due to the variations in chemical concentrations and compositions of major anions and cations [17] [18] [19].

Conversely, knowledge of salt-affected soil and irrigation water quality status plays a significant role in improving crop production and soil productivity of the agricultural sector on a sustainable basis; little scientific information is available on the magnitude of soil and water productive changed. Also, its management impact pertinent to sustainable crop production in the country significantly affected parts of Amibara and Dubti irrigated lands. The purpose of this investigation was to examine the current status of salt-affected soil and irrigation water quality of Amibara and Dubti irrigated areas.

MATERIALS AND METHODS

Study areas

Amibara irrigated area is located in Amibara district of Afar National Regional State Ethiopia (Figure 1). It is located 278 km northeast of Addis Ababa (capital city of Ethiopia). The average elevation of the study area about 740 meters above sea level and is located at 8°58’08" to 9°56’45" Northing latitude and 40°05’41" to 40°46’55" Easting longitude in the study area, having a “semi-arid to arid” climatic characteristic. According to the data obtained from the meteorological station of Melka-Werer Agricultural Research Centre from 1970 to 2017, Amibara district is characterized by bimodal rainfall pattern with a mean annual 571.5 mm. The mean yearly ET, maximum and minimum temperature recorded is 2803 mm, 34.3 and 19.6°C, respectively. The soil of the study area is predominantly Eutric-Fluvents; order Fluvisols followed by Vertisols occupying about 30% of the total area [20] [21].

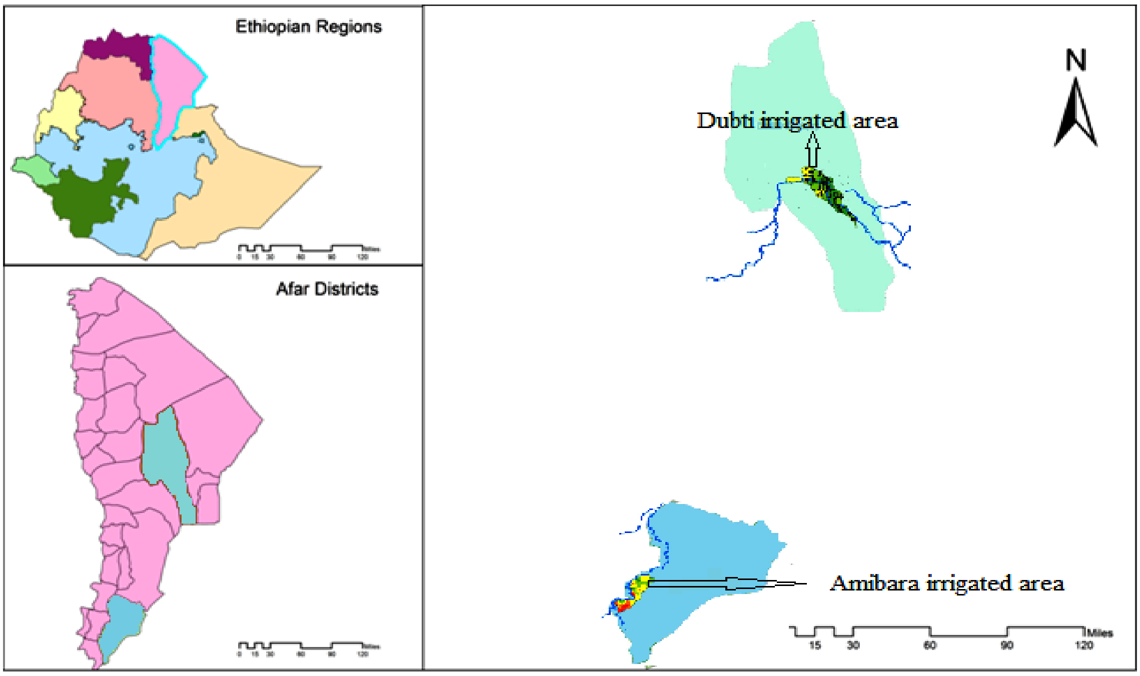

Figure 1. Map of the Amibara and Dubti irrigated areas of Afar regional states of Ethiopia

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Dubti irrigated area, which is in Afar National Regional State, the northern part of the Ethiopian Rift Valley at the lower portion of the Awash basin (Figure 1). The study area is located at around 600 km northeast of Addis Ababa. Geographically, it is situated between 10º58' 12" to12° 41'31" Northing Latitudes and 40°41' 20" to 41°29' 46" Easting Longitudes with an altitude that ranges from 339 - 381 meters above sea level [22]. Based on meteorological data obtained from Dubti station, the average annual 28 years (1986 – 2017) rainfall is 222 mm, characterized by bimodal rainfall patterns. The rainfall is erratic and is not sufficient for rainfed agriculture. Hence, crop production is practiced using irrigation. The annual mean minimum and maximum temperatures are 22.6 and 48.8 ^{0}C, respectively, with a mean annual ET of 2854 mm [8]. The soils of the district fall into five central soil units of Solonetz (39.35%), Calcisols (28.34%), Solonchak (14.55%), Vertisols (13.89%) and Fluvisols (3.88%) with most of them characterized by massive soil structure which is attributed to the dominance of exchangeable sodium [22] [8].

Method of soil and water samples collected

Soil sample collection was conducted during September and October 2017. Before sample collection, a reconnaissance survey was conducted to investigate the extent of soil variability/homogeneity based on variations in physiography, land use and visually observable soil features (drainage condition, the salt crust at the soil surface, soil texture and others). Method of sampling and sample quantity required to represent irrigated areas were determined. Based on the information obtained from the reconnaissance survey and topographic map (scale 1:50,000**)** of the study areas, 445 sampling spots/points were identified from two irrigated areas. Accordingly, a total of 890 soil samples were collected at a depth of 0-30 and 30-60 cm using a systematic sampling technique. During sample collection, any foreign material such as plant residues and gravels were discarded. Areas near trees and those with specific features such as undecomposed organic/inorganic soil materials, wet spots, and compost pits were excluded from sampling. All sampling points were geo-referenced and sampling dates were adequately recorded. Finally, about 1 kg of each composite soil sample was bagged, properly labeled, and transported to the laboratory for analysis. Prior to irrigation water sampling, a field survey was carried out. Based on the field observation, irrigation water sampling sources were selected. Accordingly, samples were taken from the selected sources (ground and surface water) and irrigation canals using plastic bottles. Each sample was numbered and labeled carefully and placed into boxes with location and references indicated. The sources of irrigation water sampling points were spatially geo-referenced using GPS and sampling dates were properly recorded.

Soil and water sample analysis

Soil samples were air-dried, ground to pass through 2 mm sieve and prepared for the determination of soil salinity and sodicity parameters. All laboratory analyses were done at laboratory Werer research centers. Soil particle size distribution was obtained by the Boycouos hydrometer method [23]. Soil pHe was measured potentiometrically using a digital pH-meter and ECe by digital conductivity meter according to the methods stated by [24]. Both exchangeable (Ca and Mg) and water-soluble (Ca^{2+} and Mg^{2+}) were determined by Atomic Absorption Spectrophotometer (AAS) and exchangeable (Na and K) and water-soluble (Na+ and K+) were determined by flame photometer. According to the percolation tube procedure, the cation exchange capacity (CEC) of the soils was determined by the neutral normal ammonium acetate method [25]. Exchangeable sodium percentage (ESP) was computed as the percentage of the exchangeable Na to the cation exchange capacity (CEC) of the soil.

$$\text{ESP}\ (\%) = \frac{\text{Exchangeable bases}\ (\text{Na}^{+})}{\text{CEC}} * 100 \ldots\ldots(1)$$

Where, concentrations were in cmol (+)/kg of soil.

The amount and kind of salt present in water essentially determine the quality of water for irrigation. One of the most used irrigation water quality classification systems is the [26] system. The salinity and sodicity of irrigation water are indicated by electrical conductivity (ECw) and sodium-adsorption ratio (SAR), respectively with respect to their effects on crops and soils with potential management requirements.

$$\text{SA}R = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \ldots\ldots \textbf{(2)}$$

Hereunder irrigation water quality, the residual sodium carbonate (RSC) will also be considered. Applying water containing carbonate plus bicarbonate concentration greater than calcium plus magnesium may increase sodium hazard since the bivalent cations may precipitate as carbonate, leaving the soil solution relatively concentrated in sodium [24].

$$RSC = [(HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})] \quad \textbf{(3)}$$

Where all concentrations were expressed in meq L^{-l} [24].

Soil and Water Classification Method

All 890 soil samples were analyzed for critical salinity and sodicity parameters. Based on analytical results, soils of study areas were evaluated and classified into the different salt-affected soil classes (Non-saline non-sodic, saline, sodic and saline-sodic soils) following the criteria established by the [24] as presented in Table 1.

Table 1. Guideline for Classification of salt-affected soils

Salt affected Soil type	ECe (dS/m)	ESP (%)	Reaction (pHe value)
Saline	> 4	< 15	<8.5
Saline sodic	> 4	> 15	<8.5
Sodic (Alkali)	< 4	> 15	8.5-10
Non-saline non-sodic	< 4	< 15	About neutral

All irrigation water samples collected from the different sources were analyzed for critical salinity sodicity and residual $NaCO_3$ hazard parameters. Based on analytical results, the irrigation water quality of study areas was evaluated and classified following the criteria established by [24] as presented in Table 2.

Table 2. Classification of irrigation waters based on salinity (EC) & sodicity (SAR & RSC) hazards.

Salinity (EC) hazard			**Sodicity (SAR) hazard**			**Residual ($NaCO_3$) RSC**		
Salinity class	Salinity hazard	EC µmhos/cm	Sodicity class	Sodicity hazard	SAR	RSC class	RSC hazard	RSC (meq/l)
C1	Low	100-250	**S1**	Low	<10	**1**	Safe (low)	<1.25
C2	Medium	250-750	**S2**	Medium	10-18	**2**	Marginal	1.25-2.50
C3	High	750-2250	**S3**	High	18-26	**3**	Unsafe	>2.50
C4	VH	>2250	**S4**	VH	>26	**-**	-	-

GIS data analyses

In preparation for the overlaying and analyses, the topographic map (1:50,000) of the study areas was scanned and vectorized. Samples were taken accordingly, and GPS recorded their absolute locations. Then, analyses of soil salinity and sodicity parameters were done. A geostatistical analyst extension tool in ArcGIS 10.1 software was used for interpolation of salinity and sodicity parameters to produce maps of salt-affected soils of the area. Raster Algebra analysis tools of the spatial analyst extension were used for combining and final computation of intermediate surfaces based on the combination decision rule and fundamental questions. The area of each map unit was also recorded based on soil laboratory analysis results and ratings. Finally, the soil salinity and sodicity status of the study areas was mapped.

RESULT AND DISCUSSION

Soil texture of surface soils

The particle size distribution results of the surface soils (0-30 cm) revealed that soil textural classes ranging from clay to silt clay loam with loam being dominant in both irrigated areas, with clay accounting for more than 39.78 % in Amibara irrigated areas and 33.65 % in Dubti irrigated area (Table 3). Based on the rating proposed by [27], the particle size distribution of the study area was characterized by low to moderate clay, moderate to very high silt and medium to a high level of sand in both irrigated areas.

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Table 3. Soil texture properties of surface soil (0-30 cm) of Amibara and Dubti irrigated areas

Salt affected soil Classes	Particle size (%)			Soil textural class
	Clay	Silt	Sand	
Amibara irrigated area (15,772.7 ha)				
Non-saline non-sodic soil	48.29	41.88	9.83	Silty Clay (SiC)
Saline soil	49.05	42.22	8.73	Silty Clay (SiC)
Sodic soil	50.92	38.46	10.62	Clay (C)
Saline sodic soil	39.78	50.26	9.96	Silty clay loam (SiCL)
Dubti irrigated area (36,700.24 ha)				
Non-saline non-sodic soil	38.05	45.34	16.61	Silty clay loam (SiCL)
Saline soil	39.94	50.28	15.78	Silty clay loam (SiCL)
Sodic soil	46.73	35.18	18.09	Clay (C)
Saline sodic soil	33.65	47.31	19.04	Silty clay loam (SiCL)

Salinity and Sodicity Characteristics of Soils in Amibara and Dubti districts

Soil reaction (pHe)

Soil pHe was found to be varied between slight to moderate alkaline classification in both districts. Soil reaction of Amibara irrigation area ranged from 7.15 to 8.90 and 7.05 to 8.64 for soil depth 0-30 and 30-60 cm, respectively (Table 4). According to the rating of [28], the surface soil of Amibara Irrigation project constitutes 0.02 % neutral, 13.1 % slightly alkaline, 84.95 %, moderately alkaline, 1.93 % strongly alkaline (Table 4). Many authors reported that the study area had a high pHe value [7] [14]. Similarly, in Dubti district, soil reactions ranged from 6.85 to 9.10 and 7.14 to 9.06 for the soil depth 0-30 and 30-60 cm, respectively (Table 4). Table 4 surface soil of Dubti Irrigated areas constitutes 7.64 % neutral, 17.02 % slightly alkaline, 64.75 % moderately alkaline, 10.23 % strongly alkaline, and 0.36 % very strongly alkaline. In general, the possible reason for the high pHe value in both districts might be accredited to the relative abundance of alkaline-forming cations and salts of carbonates. In addition to this, the areas have higher evapotranspiration than rainfall, the reason for the accumulation of basic cation at surface soil and its result for higher soil reaction.

Table 4: Percentage of area coverages soil pHe of Amibara and Dubti irrigated areas.

Soil pHe range	Soil pHe distribution (%) at different depth	
	0-30 (cm)	30-60 (cm)
Amibara irrigated area (15,772.7 ha)		
6.6-7.48	0.02	0.02
7.49-7.8	13.1	12.54
7.81-8.4	84.95	82.63
8.41-9	1.93	2.48
>9	0.00	2.33
Total	100	100
Maximum	8.90	8.64
Minimum	7.15	7.05
Dubti irrigated area (36,700.24 ha)		
6.6-7.48	7.64	7.89
7.49-7.8	17.02	16.98
7.81-8.4	64.75	65.05
8.41-9	10.23	9.89
>9	0.36	0.21
Total	100	100
Maximum	9.10	9.06
Minimum	6.85	7.14

Soils under normal and saline soil category in both irrigated areas exhibited lower mean pHe values. Value of pHe usually is governed by the relative concentration of Ca to Na in the soil solution-phase, especially for dryland soils [5]. Therefore, under saline soils where the soil solution phase is dominated by Ca, pHe was found to be close to neutral reaction due to counteracting the effect of neutral cations of calcium and magnesium and the reverse was seen in soils with sodic character dominated by alkaline-forming cation of Na. The results of this study were in line with those reported by different authors' [5] [29]. This could reveal high exchangeable and soluble sodium, which hydrolysis reactions with OH^-, CO_3^{-2} and HCO_3^- into the soil solution and retain as a sodium salt (Na2CO3 or NaHCO3) is strongly alkaline, thereby increase soil pHe values. This may influence the reduction availability and solubility of plant macronutrient and micronutrient [26].

Electrical conductivity (EC)

The analytical results obtained from Amibara irrigated area indicated that the electrical conductivity(EC) of the saturated paste extract at soil depths of 0-30 and 30-60 cm varied from 0.22 to 93.94 dS m^{-1} and 0.16 to 90.16 dS $m^{-1,}$ respectively (Table 5). Farther the result indicates that the percentage of area coverages by salinity soils at soil depths of 0-30 and 30-60 cm were recorded 5.18 % and 6.40 % for non-saline soil; 22.28 % and 25.53 % for slightly saline soil; 47.05 % and 46.72 % for moderately saline soil; 13.88 % and 13.82 % for strongly salty soil and 11.61 % and 7.53 % for very strongly saline soil, respectively (Table 5). For Dubti irrigated area, the saturated extract's electrical conductivity at soil depths of 0-30 and 30-60 cm varied from 0.17 to 55.62 dS m-1 and 0.21 to 59.50 dS m-1, respectively (Table 5). Similarly, the percentage of area coverages by salinity soils at soil depths of 0-30 and 30-60 cm were recorded 39.95 % and 33.21% for non-saline soil; 37.64 % and 46.60 % for slightly saline soil and 22.41 % and 20.19 % for moderately salty soil, respectively (Table 5).

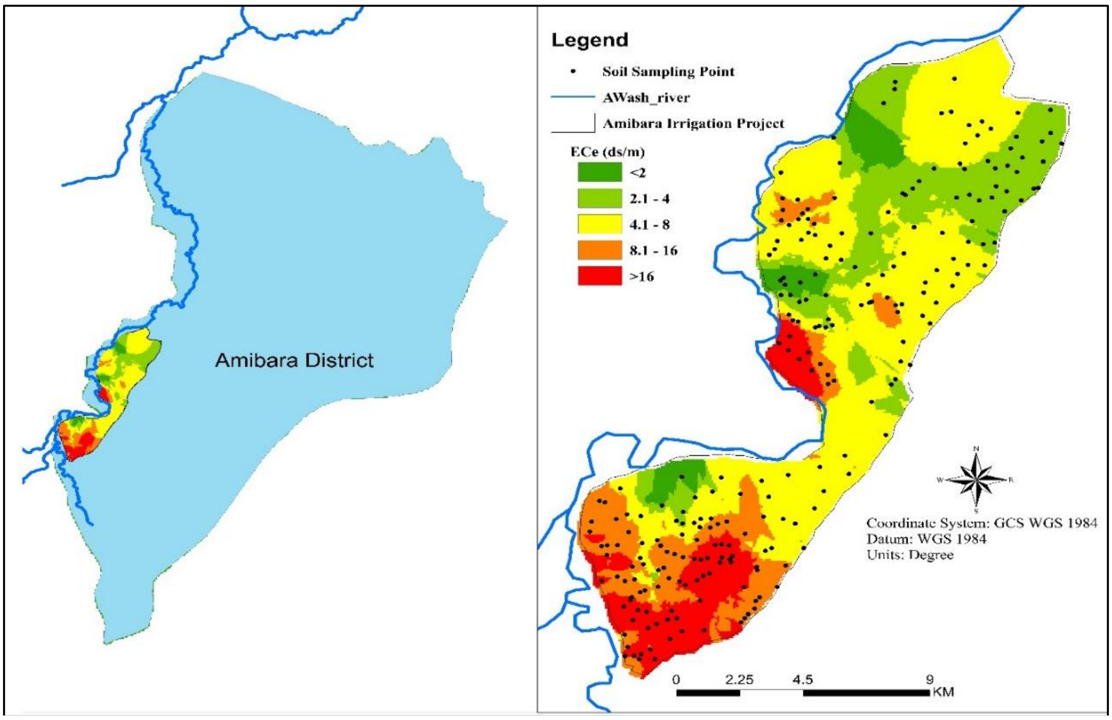

Figure 2: Amibara irrigation area soil electrical conductivity geospatial analysis.

The high evapotranspiration exceeding rainfall (evapotranspiration rate compared to annual precipitation) accompanied by lack of natural drainage to leach down salts from the plant rooting zone resulted in the development of salt-affected soils Amibara and Dubti irrigated command areas. This is also exacerbated by the poor irrigation practice and lack of an appropriate drainage system that resulted in the rising groundwater levels closer to the surface, making the farm areas prone to secondary salinization. In general, the result obtained from this study is in agreement with the findings reported by [30] [6] [7] [8] [14].

Table 5. Percentage of area coverages by salinity soils classes of Amibara and Dubti irrigated areas

Salinity soils classes	Percentage of area coverages by salinity soils classes (ECe)	
	0-30 (cm)	**30-60 (cm)**
Amibara irrigated area (15,772.7 ha)		
Non saline	5.18	6.40
Slightly saline	22.28	25.53
Moderately saline	47.05	46.72
Strongly saline	13.88	13.82
Very strongly saline	11.61	7.53
Total	**100.00**	**100.00**
Maximum	93.94	90.16
Minimum	0.22	0.16
Dubti irrigated area (36,700.24 ha)		
Non saline	39.95	33.21
Slightly saline	37.64	46.60
Moderately saline	22.41	20.19
Strongly saline	0.00	0.00
Very strongly saline	0.00	0.00
Total	**100.00**	**100.00**
Maximum	55.62	59.50
Minimum	0.17	0.21

Regarding the depth-wise distribution of salinity, it was seen to have no defined trend. The explanation is that the concentration of salts in the soil profile is governed by the ease of moisture content of the soil and the net movement of water. During the dry season, where net water movement is upward, salts tend to concentrate at the above surface layer and decrease with increasing depth and the reverse holds where net water movement is downward through the soil profile [6] [7] [14].

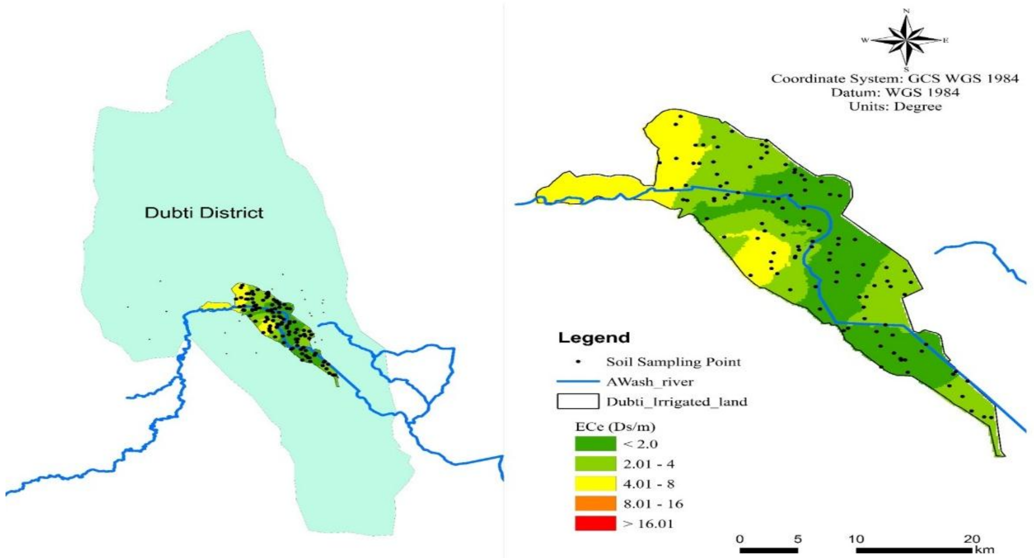

Figure 3. Dubti irrigation area soil electrical conductivity geo-spatial analysis.

Oscillation of salts through the soil profile is therefore governed by the balance between seasonal variations in precipitation and evapotranspiration rate [14]. From the present investigation, in majority areas salts was found to concentrate at the upper 30 cm soil layer expressed by higher values of ECe. An electrical conductivity value of above 6 dS/m is considered a threshold value for most tolerant crops in which salinity begins to affect crops growth thereby decreasing yield [5] significantly. As indicated in table 5, with salinity level above ten dS m^{-1} at the above surface soil layer could be regarded as degraded to the extent that no economic yield is expected unless efficient leaching is applied.

Exchangeable Sodium Percentage (ESP)

Exchangeable sodium percentage of the soils from the percentage of the exchangeable Na to the cation exchange capacity of Amibara irrigated area at soil depths of 0-30 varied from 0.33 to 98.12 and 30-60 cm 0.32 to 86.79 % (Table 6). Farther the result indicates that percentage of area coverages by sodium hazards soil at soil depths of 0-30 and 30-60 cm were recorded 84.73 and 82.10 % for non-sodic soil; 5.03 and 8.19 % for slightly sodic soil; 2.91 and 3.19 % for moderately sodic soil; 2.77 and 2.61 % for strongly sodic soil and 4.56 and 3.91 % for very strongly sodic soil, respectively (Table 6). Intended for Dubti irrigated area, exchangeable sodium percentage of soil at depths of 0-30 varied from 3.39 to 30.28 and 30-60 cm varied from 2.76 to 34.20 % (Table 6). Correspondingly, the percentage of area coverages by sodium hazard soils at depths of 0-30 and 30-60 cm were recorded 81.67 and 84.85% for non-sodic soil; 14.18 and 11.83 % for slightly sodic soil and 4.15 and 3.19 % for moderately sodic soil, respectively (Table 6).

Table 6. Percentage of area coverages by sodicity soils classes of Amibara and Dubti irrigated areas

Sodicity soils classes	Percentage of area coverages by sodicity soils classes (ESP)	
	0-30 (cm)	**30-60 (cm)**
Amibara irrigated area (15,772.7 ha)		
Non-sodicity	84.73	82.10
Slightly sodicity	5.03	8.19
Moderately sodicity	2.91	3.19
Strongly sodicity	2.77	2.61
Very strongly sodicity	4.56	3.91
Total	**100.00**	**100.00**
Maximum	98.12	86.79
Minimum	0.33	0.32
Dubti irrigated area (36,700.24 ha)		
Non-sodicity	81.67	84.85
Slightly sodicity	14.18	11.83
Moderately sodicity	4.15	3.19
Strongly sodicity	0.00	0.05
Very strongly sodicity	0.00	0.08
Total	**100.00**	**100.00**
Maximum	30.28	34.20
Minimum	3.39	2.76

Higher exchangeable sodium in especially sodic soils has a marked impact on the physical soil properties. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed, resulting in the breakdown of soil aggregates and lowering the permeability of the soil to air and water. If a ground has high Na^+ and the ECe is low, soil permeability, hydraulic conductivity, and the infiltration rate are decreased due to swelling and dispersion of clays and slaking of aggregates [31] [32]. Excess levels of exchangeable sodium and associated high pH of sodic soils affect the transformations and availability of several essential plant nutrients and also specific ion toxicity, especially sodium, molybdenum and boron [33].

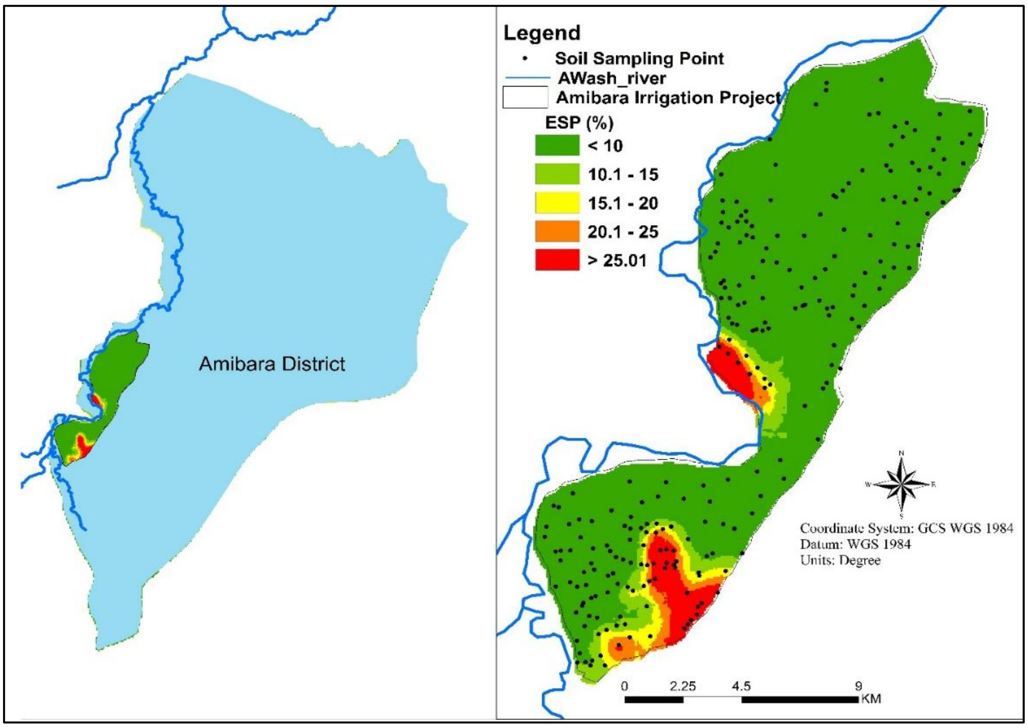

Figure 4: Amibara Irrigation area exchangeable sodium percentage geospatial analysis.

On the other hand, among the two soil depths, the exchangeable sodium percentage decreased from surface (0-30 cm) to the subsurface (30- 60 cm) soil layers, especially from strongly to very strongly sodicity in Dubti district (Table 6). Whereas in Amibara district, it was increased from surface soil to subsurface soil, mainly moderately sodicity. The decrease in soil alkalinity at lower soil depths may be due to the decline in soil pH and exchangeable sodium with soil depth. In general, higher exchangeable sodium percentage was found to occur in normal and saline soil than sodic or saline-sodic soil, due to lower solute transportation in the later due to small pore size between soil particles that why sodic or saline-sodic soil [34].

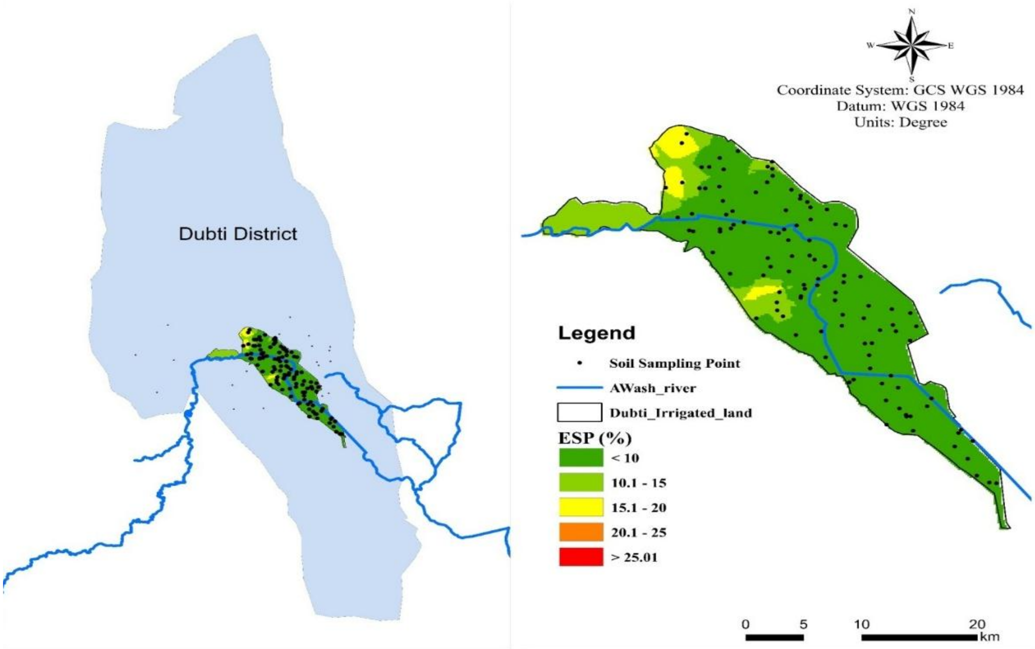

Figure 5: Dubti Irrigated area exchangeable sodium percentage geospatial analysis.

Salt affected soil of Amibara and Dubti irrigated areas

The analytical results obtained from Amibara district indicated that the electrical conductivity of the saturated paste extract at soil depths of 0-30 and 30-60 cm varied from 0.22 to 3.67 dS m^{-1} and 0.16 to 3.95 dS m^{-1} for non-saline non-sodic soil; 4.16 to 76.30 dS m^{-1} and 4.50 to 38.08 dS m^{-1} for saline soils; 4.33 to 93.94 dS m^{-1} and 4.77 to 90.16 dS m^{-1} for saline-sodic soils and 1.33 to 3.43 dS m^{-1} and 1.29 to 3.84 dS m^{-1} for sodic soils, respectively (Figure 6 and Table 5). For Dubti district, that the electrical conductivity of the saturated extract at soil depths of 0-30 and 30-60 cm varied from 0.17 to 3.88 dS m^{-1} and 0.21 to 3.85 dS m^{-1} for non-saline non-sodic soil; and 4.08 to 55.62 dS m^{-1} and 4.16 to 59.50 dS m^{-1} for saline soils; 4.23 to 21.50 dS m^{-1} and 4.36 to 34.16 dS m^{-1} for saline-sodic soils and 1.32 to 3.81 dS m^{-1} and 0.98 to 3.89 dS m^{-1} for sodic soils, respectively (Figure 7 and Table 5).

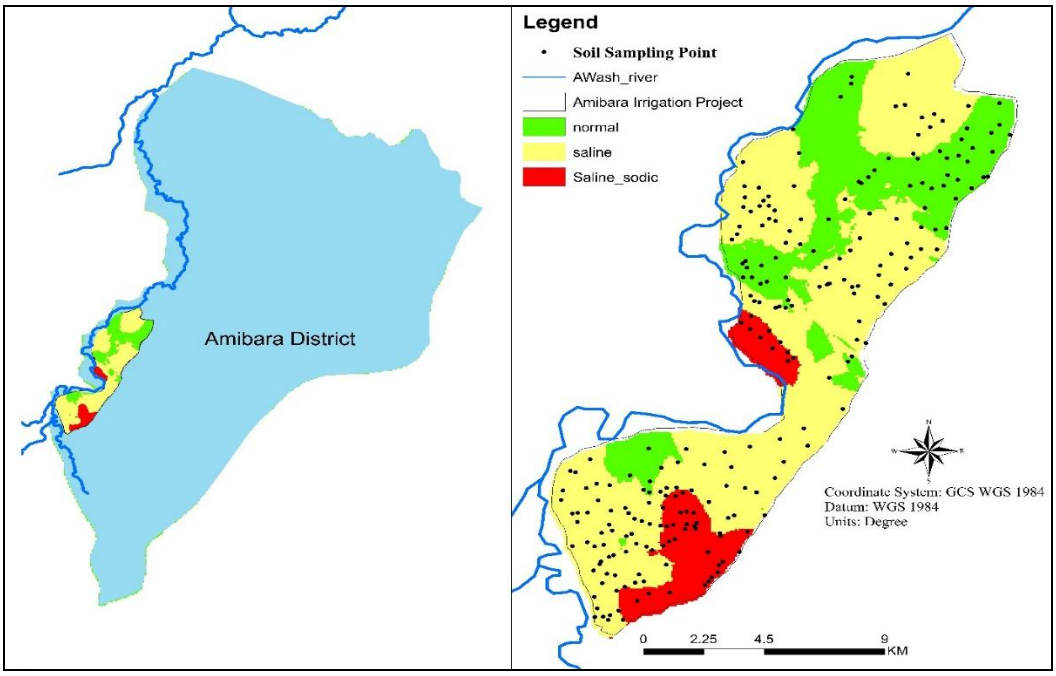

Figure 6. Amibara Irrigated area salt-affected soil class geospatial analysis.

Exchangeable sodium percentage of the soils from a portion of the exchangeable Na to the cation exchange capacity of Amibara districts at soil depths of 0-30 and 30-60 cm varied from 0.33 to 14.90 and 0.32 to 14.40 % for non-saline non-sodic soil; 1.13 to 11.45 and 0.93 to 13.52 % for saline soils; 29.38 to 98.12 and 15.13 to 86.79 % for saline-sodic soils and 17.65 to 63.28 and 16.54 to 59.01 % for sodic soils, respectively (Figure 6 and Table 6). For Dubti district, the exchangeable sodium percentage at soil depth of 0-30 and 30-60 cm varied from 3.39 to 8.29 and 2.76 to 9.11 for non-saline non-sodic soil; and 5.78 to 13.89 and 4.86 to 13.65 for saline soils 15.45 to 30.28 and 15.13 to 34.20 % for saline-sodic soils and 15.13 to 23.14 and 16.54 to 29.01 % for sodic soils, respectively (Figure 7 and Table 6).

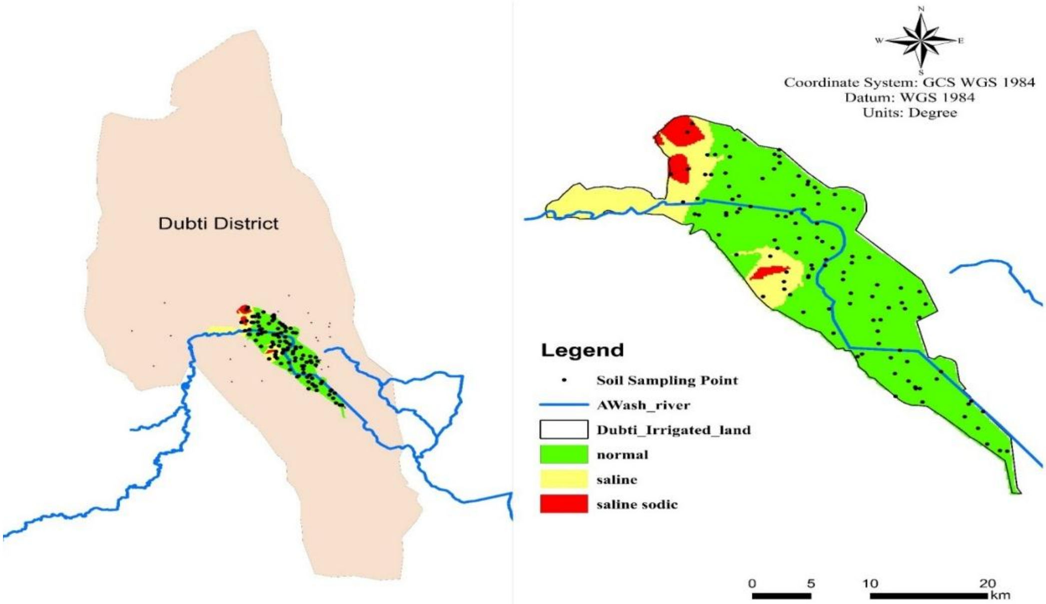

Figure 7. Dubti Irrigated area salt-affected soil class geospatial analysis.

According to [24] classification, significant parts of Amibara and Dubti irrigated areas were mapped as usual, saline, sodic and saline-sodic soils. Around 27.46 % in Amibara irrigated area and 77.59 % Dubti irrigated area are non-saline nonsodic soil with ECe less than 4 dS m^{-1} and ESP less than 15 %. About 62.31 % in Amibara irrigated area and 18.26 % Dubti irrigated area are saline soils with ECe greater than 4 dS m^{-1} and ESP less than 15. Approximately 10.23 % in Amibara irrigated area and 4.15 % Dubti irrigated area are mapped as saline-sodic soils with EC and ESP values greater than 4 dS m^{-1} and 15, respectively (Table 7). Among the two irrigated areas, a significant area of farms under the Amibara irrigated area was affected by salinity and sodicity problem; whereas in Dubti irrigated area, the area affected by salinity and soil was less severe.

Table 7. Class and extent of salt-affected soil of Amibara and Dubti irrigated areas

SAS Class	Percentage of area coverages by salt affected soil	
	0-30	**30-60**
Amibara irrigated area (15,772.7 ha)		
Non-saline non sodic soil	27.46	31.93
Saline soil	62.31	58.36
Sodic soil	0.00	0.00
Saline sodic soil	10.23	9.71
Total	100.00	100.00
Dubti irrigated area (36,700.24 ha)		
Non-saline non sodic soil	77.59	78.95
Saline	18.26	17.73
Sodic	0.00	1.05
Saline sodic	4.15	2.27
Total	100.00	100.00

Water Quality for Irrigation Propose

The mean values of most chemical properties of higher in groundwater followed by field drain water means poor water qualities for irrigation compared to another water source of Amibara and Dubti irrigated areas (Table 8 and 9). The increase of pHw and Na % in groundwater could be due to high concentrations of HCO_3^- relative to Ca and Mg ions in both irrigated areas. These results were in concurrence with that of [35], who stated that the presence of HCO_3^- ions causes alkalizing effect and increases pHw by dissociating Ca and Mg in irrigation water. The electrical conductivity values of different irrigation water sources of Amibara irrigated area ranged from 0.41 to 2.17 dS m^{-1} water samples taken from diversion from river and groundwater, respectively (Table 8). Whereas in Dubti irrigated area, the highest and lowest ECw was recorded at groundwater and diversion from dam, respectively (Table 9). According to the classification of [24], irrigation water salinity of different water sources, especially diversion from river or dam, main canals and field canals were classified C2 as moderate saline waters and groundwater and field drain water was classified C3 which means highly saline waters. Still, water samples taken from groundwater and field drain have higher ECw values that suffer for growing plant. Long-term uses of moderately saline water with existing poor irrigation water management may have significantly affect soil productivity and crop production.

Table 8. Irrigation water quality of Amibara irrigated area

Water sample	pHw	ECw	Dissolved Cations (meq /l)				SAR	Dissolved Anions (meq/l)				RSC
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
GW	8.21	2.17	3.10	0.96	10.7	0.29	7.49	2.45	9.22	0.56	4.01	7.61
DFR	8.07	0.41	1.01	0.41	4.05	0.15	4.81	Nill	4.97	0.31	1.34	3.55
MC	8.11	0.44	1.52	0.53	3.98	0.11	3.93	Nill	5.06	0.41	1.30	3.01
FC	7.89	0.56	1.47	0.39	4.08	0.21	4.23	Nill	5.34	0.38	1.73	3.48
FD	8.34	1.15	4.21	0.69	8.97	0.31	5.73	1.16	6.09	0.41	4.32	2.35

GW ground water; DFR* diversion from river; MC* main canal; FC* field canal; FDW* field drain*

Sodium Adsorption Ratio (SAR) of different water sources of Amibara irrigated area ranged from 3.93 to 7.49 at was obtained at the main canal and groundwater, respectively (Table 8). Whereas in Dubti irrigated area, the highest and lowest SAR was recorded at groundwater and diversion from dam, respectively (Table 9). Based on [24] classifications, all water sources of Amibara and Dubti irrigated areas are classified to lower sodium hazards for irrigation water. Long-term groundwater and field drain water uses with existing poor irrigation water management may have significantly affected soil productivity and crop production. These results agreed with those reported by [36] [37]. The residual sodium carbonate contents followed similar trends with the sodium adsorption ratio within all irrigation water sources.

Table 9. Irrigation water quality of Dubti irrigated area.

Water sample	pHw	ECw	Dissolved Cations (meq /l)				SAR	Dissolved Anions (meq/l)				RSC
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
GW	8.35	1.3	2.59	1.07	9.98	0.41	7.83	0.21	8.56	0.28	5.01	5.11
DFD	8.21	0.57	2.56	1.21	7.96	0.18	5.80	Nill	5.98	0.34	3.05	2.21
MC	8.26	0.59	2.18	0.99	7.98	0.19	5.96	Nill	5.72	0.31	2.98	2.55
FC	7.98	0.58	2.49	0.95	7.78	0.21	5.93	Nill	5.76	0.29	3.10	2.32
FD	8.31	0.76	2.56	1.98	10.7	0.31	7.08	Nill	7.98	0.24	4.21	3.44

GW groundwater; DFD* diversion from the river; MC* main canal; FC* field canal; FDW* field drain*

On the contrary, parameters of pHw, ECw, Mg, Ca, K, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SAR, and RSC was recorded higher in the groundwater compared to the other water sources, which could be due to the application of irrigation water are all soluble salt join groundwater for high salt and alkali in both irrigated areas (Table 8 and 9). This finding is supported by different reports [38] [39]. The carbonate alkalinity is negligible at the diversion from river, central canal and field canal water in Amibara and Dubti irrigated areas. Hence, the high pHw (total alkalinity) recorded in both study areas are mostly due to the presence of Cl^{-}, HCO_3^{-} and CO_3^{2-}.

CONCLUSION AND RECOMMENDATION

Grounded on the findings result in the former section, soil salinity and sodicity assessed showed that significant parts of Amibara and Dubti irrigated areas were regularly and continuously affected by salinity. A significant percentage of the irrigated areas have been abandoned or soon will be abandoned mainly because of secondary salinization resulted from shallow saline groundwater table and irrigation water quality. Given the conclusion stated and the field observation, the following recommendations are forwarded. The subsurface drainage system should be rehabilitated the existed one and operationalized with immediate effect of saline soil and areas where sodicity is affecting the soil health should be made reclamation by gypsum for leaching of sodium problem. More and more lands are abandoned in salt affected soil; further research should be made in different management options including growing more salt tolerant crops. Hence further research on other alternative management options should be done. There is no clarity on what to do with already affected and abandoned soil. This has to be addressed immediately.

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