Appraisal and Mapping of Soil Salinity and Sodicity Problem in Abuarie-Addisalem Irrigatio Schemes, Raya Kobo Valley, Ethiopia.

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Abstract

In the arid and semi-arid irrigated areas of Ethiopia, soil salinity and sodicity is a widespread problem. In Abuarie-Addisalem irrigation scheme, many productive irrigated lands gone out of production due to soil salinity/sodicity. Regarding the sustainability of irrigation agriculture in the Raya Kobo Valley as the whole threatened by salinization but the thematic map has not been made before. Therefore, a study was conducted to characterize the salinity and sodicity problems of Abuarie-Addisalem irrigation scheme and to generate thematic maps using GIS for further management. Totally, 89 samples from the soil surface (0-30 cm) and 24 samples from 4 profile pits (0-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm) were collected systematically for representing 939.46 ha *irrigated farms. The pH, electrical conductivity (EC), soluble Na^{+}, Ca^{2+} and Mg^{2+} were analyzed following their standard procedures. Arc GIS 10.3 was used for mapping soil salinity and sodicity data. The result showed that nearly 42.4% (398.4ha) of the irrigated field was rated as non-saline non-sodic soil (EC< 4 and SAR <13). Whereas, 29.9% (280.7ha) was mapped as saline soil (EC> 4, and SAR< 13). On the other hand, 10.1% (95.09ha) and 17.6% (165.27ha) of the irrigated command has been mapped as saline-sodic (EC> 4 and SAR> 13) and sodic soil (EC< 4 and SAR> 13) respectively. Regarding the generated thematic maps, it can conclude that many parts of the scheme has abandoned due to the fast increasing salinity extent. Application of subsurface drainage for water table control, growing of salt absorbent species and agroforestry practices to minimize evaporation should be the only possible solutions for this uncultivable land made fit for cultivation.*

Keyword: Drainage, irrigation, mapping, salinity, sodicity

Introduction

In the world, nearly half of the irrigated lands seriously affected by salinity and/or secondary alkalinity (Flagella *et al*., 2002). Beltran *et al*., (2005) estimated that, 0.25 0.50 million ha of irrigated lands had gone out of production in the world every year due to salts buildup. Munns and Tester, (2008) stated that worldwide 1.5 million ha taken out of production each year due to high soil salinity. Elderly and Garcia, (2008) pointed out that the spread of salinization at a rate of up to 2 million ha a year is offsetting a good portion of the increased productivity achieved by expanding irrigation.

Salinization is recognized as the main threat to environmental resources in many countries; affecting almost 1 billion ha worldwide/globally representing about 7% of a country like Venezuela or 20 times the size of France (Metternicht and Zinck, 2003). It has been predicted that damaging global effects of increased salinization of arable lands could result in a 30% loss of productive land in the next 15 years and up to 50% by 2050 (Wang *et al*., 2003). The salinity induced problems are not associated with natural resources degradation, but they do affec
farmers were $11 billion a year in reduced income (FAO, 2009). The amount of such salts stored in the soil varies with the soil type, being low for sandy soils and high for soils contain a high percentage of clay minerals. It also varies inversely with average annual rainfall (Sultana *et al*., 2001).

Subsequent miss utilization of irrigation water without proper drainage accelerates waterlogging and salinization (Kotuby *et al*., 2000). In the arid and semi-arid lowlands and Valleys of Ethiopia are affected by major salinity and sodicity problems (Yonas, 2005). Nearly 11 million ha irrigated farms of the country have already salt abandoned. The magnitude of the coverage indicates that, Ethiopia is the highest from African countries (Fentaw, 2007) and ordered as 7^{th} in the world (Qureshi *et al*., 2018).

The Raya Kobo valley have a good potential in-terms of fertile agricultural land, abundant surface and groundwater resources. In the low land parts of the Valley in general and in Abuarie-Addisalem irrigation scheme in particular, large-scale irrigation projects have constructed. However the drainage design structures and on-farm drainage practices have missed and much attention have not given yet. During irrigation application, the farmers applied excess amount of water by flooding method without the provision of drainage concepts. In addition a huge runoff from the western and Northeastern Mountains were flow towards to Raya Kobo Valley which concentrated in the valley floors of Abuarie-Adisalem irrigation scheme. Those the mentioned issues are the primary causes for soil salinity and alkalinity. In this regard the area becoming waterlogged especially in the wet season and the groundwater table rises closer to the surface (<1.2 m). Before, the last 25 years the Abuarie-Addisalem irrigation scheme has covered by scattered trees. Now a days the plants were clear cut for the purpose of charcoal and the temperature has increasing. The presence of high evaporation and lack of sufficient rainfall for leaching were the secondary problems to promote substantial salt accumulation on the soil surface. The Na^+, ECw and TDS contents of the applied water shows salinity indication in smaller quantities and found within FAO, (1985) permissible level (Sisay *et al*., 2020). Kotuby *et al*., (2000) reported that all soils and irrigation water whether from canals or underground pumping, those including in a very good quality, contain some dissolved salts. Salts are common and the necessary component of the soil and many salts are essential for plant nutrients. However, nearly 500 ha productive irrigated areas also fully salt abandoned due the gradual buildup. The salinity expansion also going up which threats for Raya Kobo Valley as a whole (Sisay *et al*., 2020). This indicates that how much salinity and sodicity problem is the big agricultural issue for the Abuarie-Adisalem irrigation scheme.

The assessment and mapping of spatial salinity and sodicity variabilities with respect to soil salinity and/or sodicity induces (pH, EC, SAR and ESP) by the application of geographic information system (GIS) provides for generating information about the present and future alternative management options (Yonas, 2005). Therefore, this study aims to appraise the salinity and sodicity problems of Abuarie-Addisalem irrigation scheme and generate thematic maps using GIS to be used for further management option.

Materials and Methods

Description of the Study Area: Characterization of salt affected soils were conducted at Abuarie and Adissalem irrigation schemes, Eastern Amhara Regional State, during March and April 2018. The study site, is located at about 572 km away from Addis Ababa in the North east direction with an altitude of 1370 m.a.s.l. Geographically it is situated between 39.28°- 39.42^o E longitudes and 12.03 -12.08° N latitudes. The average minimum and maximum temperatures were 8.49 and 36.58°C, respectively with the mean annual rainfall of 644.05 mm.

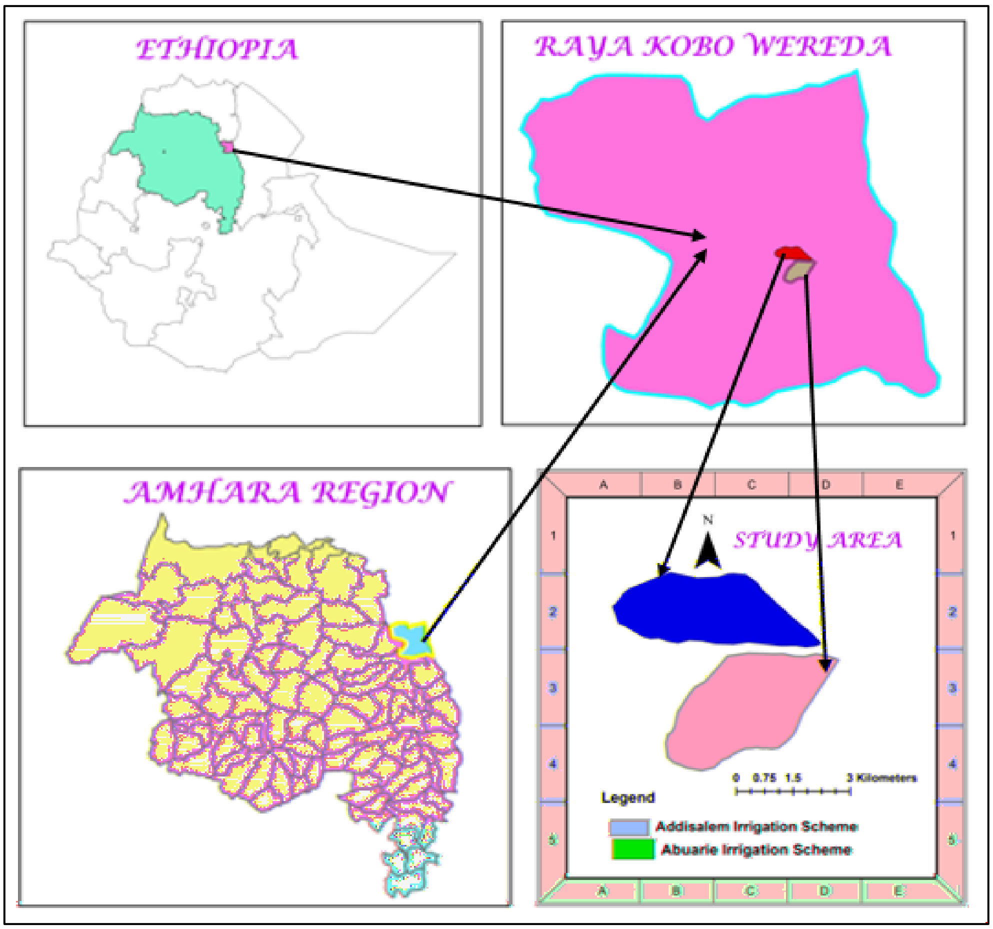


Figure 1: Location map of the study area

The Amhara region in Ethiopia; Raya Kobo Wereda in Amhara region; Abuarie and Adisalem irrigation scheme in Raya Kobo wereda.

Soil Sample Collection: Prior to sampling overall field visualization was carried out to examine the surface salt crust, vegetation growth and drainage circumstances of the irrigation command. Based on the heterogeneities of soil salinity and sodicity, eighty-nine representative surface soil samples (0-30 cm) were collected using auger. Compromising the extreme variability, the study site (939.46 ha) was categorized into 4 soil mapping units to understand the trend of salinity and sodicity down the depth. From each landing unit, one profile pit was opened up to 180 cm soil depth and 24 soil samples were collected from every 30 cm soil column. Simultaneously, the groundwater table was recorded at each sampling pits by extend the depth up to 2 m (https://www.youtube.com/watch?v=euvVw25yfmU). Due to the extreme similarities of the land features compared with 4D4, the sampling pits have not excavated at the northern side of Golina River. All the sampling points were navigated and geo-referenced using GPS instrument (Figure 2). The Collected soil samples were delivered to Sirinka and Debre Zeyit soil laboratories for analysis.

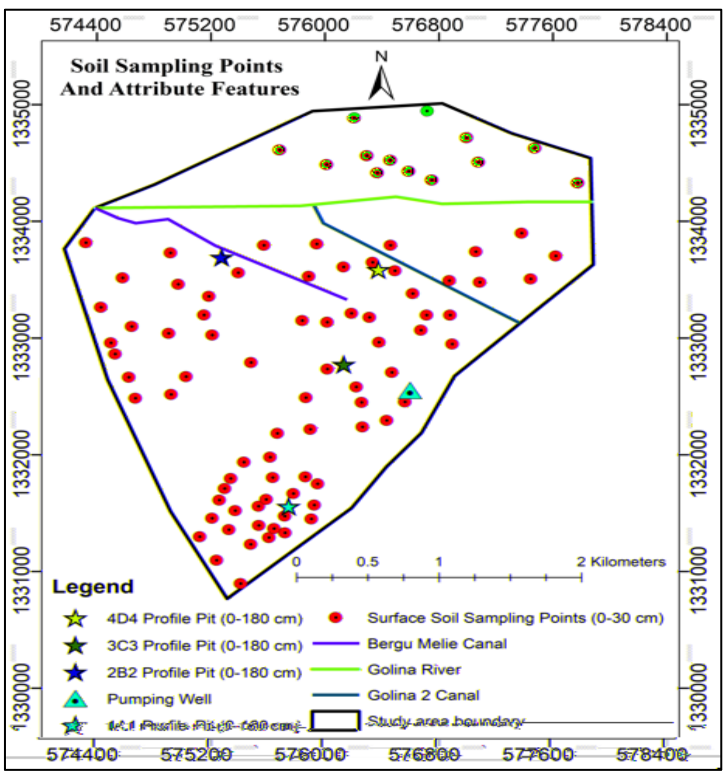


Figure 2. Spatially Referenced Soil Samples

Soil Analysis: The dried samples were grounded and sieved to made ready for laboratory analysis. Electrical conductivity (ECe), soil reaction (pHe), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) was the most critical parameters for classified salt-affected soil (*USSLS, 1954;* Gonzalez *et al.*, 2004; Horneck *et al.*, 2007). However, determination of ESP for indicated soil sodicity appraisal is tedious and subject to errors (FAO, 1988). The most preferable and recognized sodicity hazard indicator is sodium adsorption ratio (SAR) (USSLS, 1954 and FAO, 1988).

Electrical conductivity (EC), soil reaction (pHe) and soluble cations were obtained from saturated paste extract. Soil Electrical conductivity (ECe) and soil reaction (pHe) were determined using digital conductivity meter and pH-meter respectively (USSLS, 1954 and FAO, 1999). Soluble cations (Ca^{2+} and Mg^{2+}) were measured by Atomic Absorption Spectrophotometer (AAS) titration method and soluble Na^{+} was determined by flame photometer (Busenberg and Clemency, 1973*)*. Sodium adsorption ratio (SAR) was derived by the equation of *(USSLS, 1954;* Miller & Gardiner, 2007)*:*

(1)

Where meq/l, meq/l

Mapping of Soil Salinity and Sodicity Appraisal: The spatial distributions of soil salinity appraisal were described by electrical conductivity (ECe) map while, sodium adsorption ratio (SAR) map was carried out for indicated soil sodicity appraisal using Arc GIS 10.3 environment. The soil electrical conductivity (ECe) and sodium adsorption ratio (SAR) values at each georeferenced sampling points (Figure 1) were assigned as Z dimension. The raster map for those parameters (ECe and SAR) were developed using inverse Distance Weight (IDW) interpolation techniques. Regarding the minimum error result than other methods, IDW interpolation method was selected. Based on Lamond and Whitney, (1992) standard rating criteria the default EC and SAR raster layers were further reclassified into several classes using reclassify tool.

Result and Discussion

Soil Salinity and Sodicity Characteristics of the Mapping Units

Mapping Unit 1A1: Unlike the other mapping units, it is located near Kelkelit River and is sensitive for seasonal runoff and sediment. The groundwater table was discovered at the depth of 1.3 m beneath the surface. The soil below 1.3 m became fully saturated and releasing free water into the pit. Whereas the soil above 1.3 m is not a water bearing zone. In this mapping unit the range of pHe, ECe and SAR values of the six soil columns were 7.2-7.8, 0.4-2 *dS* m^{-1} *and 8.3-32.2 respectively* (Appendix Table 1, Figures 3, 4 and 5). The ECe content down the depth (0-180 cm) showed a little variability and rated within the range of non-saline soil (Appendix Table 3 and Figure 4) *(Lamond and Whitney, 1992)*.

Due to the decreasing of soluble sodium from 11 to 7 meq/l, the extent of soil pHe showed in a reducing tendency down the depth from 7.8 to 7.3 for 0-30 to 90-120 cm depth respectively. Similarly, the SAR values in the corresponding soil depth were reduced from 27.5 to 8.3. This indicates that, the soluble sodium, pH and SAR have a positive association. This uncommon appearance of the relatively high soluble sodium (11 meq/l) on the top soil layer (0-30 cm) might be due the seasonal impending of Kelkelit runoff. Because, in the lowland areas of Abuarie and Adisalem irrigation scheme almost all soils have salts/sodium (Sisay *et al*., 2020). Hence, the presence of this initial sodium has restrict the flow of water through the soil which is overtopped from Kelkelit River; and the upper layer can become swollen and water logged for aggravating sodium concentration is the main reason. The study agreed with Duan *et al*., (2010) reported that, the sodium affects soil structure, hydraulic conductivity and poses waterlogging for the gradual buildup of sodium concentration.

Whereas in the bottom two layers the soil becomes water logged and the concentration of soluble sodium is relatively high (13.7 and 16.1 meq/l) resulted for the simultaneously increasing of pH (7.6 and 7.7) and SAR (12 and 13.2). The finding agreed with many studies indicate that sodium absorption ratio value tends to be higher at lower depths due to the increased soluble sodium (Tsegaye, 2009; Abay and Sheleme, 2012). In general the first two (0-60 cm) and the bottom (150-180 cm) soil layers classified as sodic soil; while the rest three soil layers (60-150 cm) categorized as medium alkaline soil (USSLS, 1954 and Lamond and Whitney, 1992) (Appendix Table 3, Figures 3, 4 and 5).

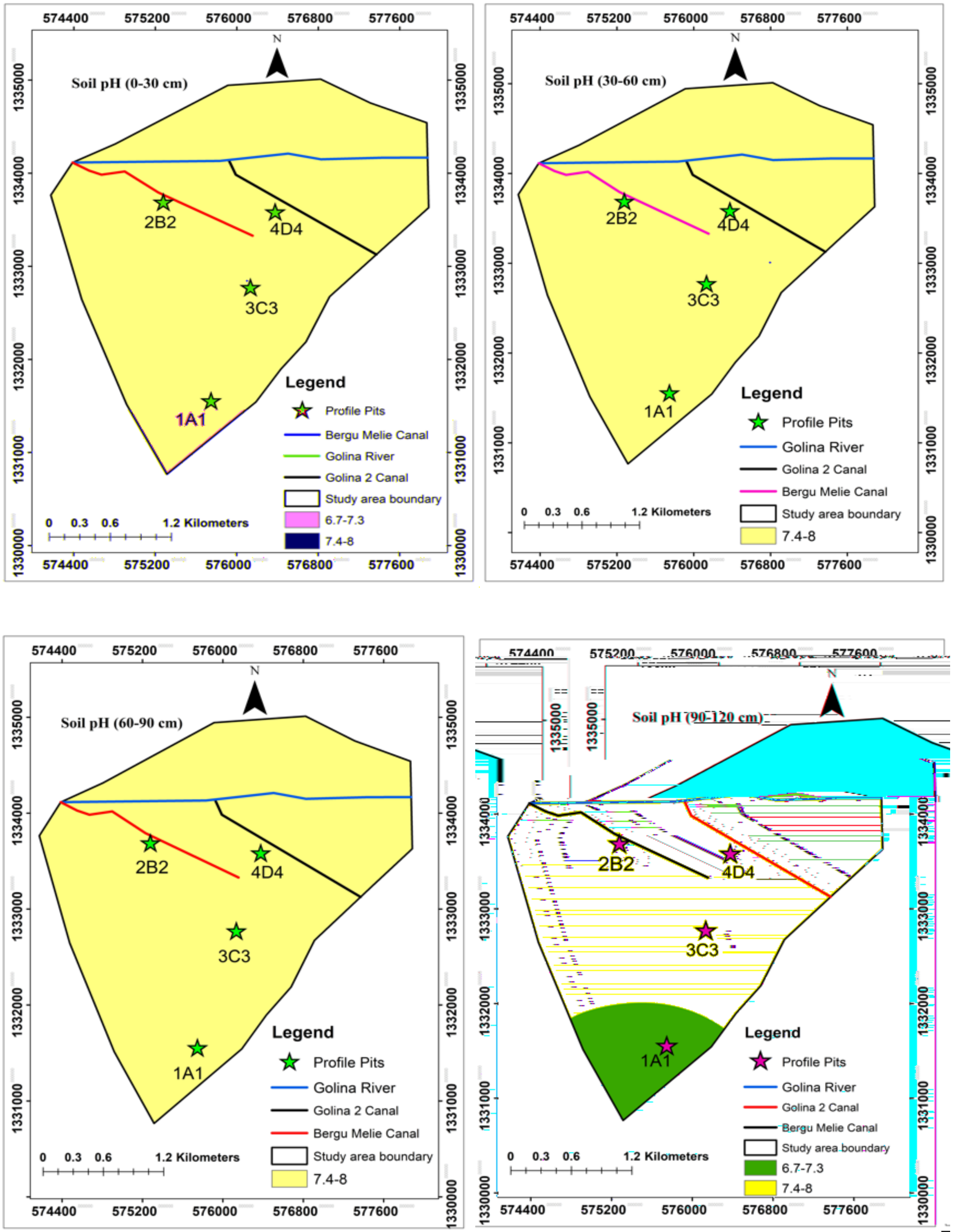
Mapping Unit 2B2: In this mapping unit the water table found at 1.5 m depth below the surface. Based on the visual observation of the drainage circumstances of the area and the profile pit data, this mapping unit exhibits relatively well drained surfaces than the other sampling pits. However, the soil below 1.5 m depth becoming moist and water logged. The extent of soil pHe ranged between 7.66-7.85, ECe between 0.4-3.4 dS m^{-1} and do not show a wider variability down the depth (Appendix Table 1). Based on Takalign *et al*., (1991) classification, that the soil pHe in all layers found between 7.4 and 8 categorized as *moderately alkaline* soil and the ECe in general found in non-saline class (USSLS,1954) *(*Appendix Table 3, Figures 3 and 4).

The SAR values in the six soil layers were found between 28.3 and 57.9. Due to the presence of excessive soluble sodium, the concentration of SAR in the bottom five layers were much higher than the first layer. Many studies indicate that sodium absorption ratio value tends to be higher at lower depths because of groundwater is the septic tanker of soluble salt (Keren and Ben-Hur, 2003*;* Tsegaye, 2009; Abay and Sheleme, 2012).

Mapping Unit 3C3: This mapping unit refers to a highly water logged areas as the water table found 0.7 m below the surface. The soil pHe and ECe in the six soil layers were varied within the range of 7.3 to 7.8 and *1.96 to 18.1 dS* m^{-1} *respectively* (*Appendix Table 1, Figures 3 and 4*). Except the first layer with the pH value of 7.3 (neutral in pH), all soil columns showed relatively high pHe within the range of 7.4 to 8. According to Takalign et al., (1991) classification criteria the pH of the five soil layers (30-180) rated as moderately alkaline soil (Appendix Table 3). It might be due to the increased of sodium concentration in the lower layers. The study conceded with Ann and Clain, (2005) reports that the pHe values increased down the depth due to the increased of sodium.

The higher EC value (18.1 dSm^{-1}) was found in the first 0-30 cm layer compared with all other soil columns. In fact, it related due to poor drainage practices and capillary action coupled with high evaporation facilitates salt accumulation on the surface than the bottom layers. The study agreed with many findings they reported as capillary action and high evaporation aggravates salt accumulation at the soil surface (Owens, 2001; Murtaza et al., 2006; Rengasamy, 2006; Ghafoor et al., 2008). Due to the presence of high soluble sodium in the bottom soil layers than the top layer, the SAR concentration parallelly increased. Abay and Sheleme, (2012) have similar experience reported that SAR values becoming higher at lower layer because the soluble sodium deposited in the lower soil layers (*Keren and Ben-Hur, 2003;* Tsegaye, 2009). The SAR value in the first layer was found within the range of 5-13 rated as medium alkaline soil, while all the bottom layers showed the presence of high alkalinity (Appendix Table 3). In general, except the first layer (saline) all soil columns (30-180 cm) classified as sodic soil (Lamond and Whitney, 1992).

Mapping Unit 4D4: This mapping unit indicates the slightly waterlogged portions of the scheme compared with mapping unit 1A1. The groundwater table is obtained at 1 m below the surface, it is slightly deeper than the mapping unit of 1A1 (0.7 m). In all soil layers the pHe values varied within the range of 7.45 and 7.7, thus according to Takalign et al., (1991) classification criteria rated within medium alkaline class. Based on USSLS, (1954) rating criteria the electrical conductivity value of the top soil layer (3.14 $dS\ m^{-1}$) classed as non-saline (normal soil), whereas the values in all other layers (60-180 cm) categorized as moderately saline soil (Lamond and Whitney, 1992). Due to the increasing trend of soluble sodium down the depth the SAR values in all layers tends to increased and much higher than 13 categorized as higher alkaline soil (Lamond and Whitney, 1992) *(*Appendix Tables 1and 3*).* Generally the top soil layer classified as sodic soil, while all other layers categorized as saline-sodic soil (USSLS, 1954 and Lamond and Whitney, 1992


Soil pH (0-30 cm)
2B2
4D4
3C3
1A1
Legend
Profile Pits
Bergu Melie Canal
Golina River
Golina 2 Canal
Study area boundary
6.7-7.3
7.4-8
0 0.3 0.6 1.2 Kilometers
Soil pH (30-60 cm)
2B2
4D4
3C3
1A1
Legend
Profile Pits
Golina River
Golina 2 Canal
Bergu Melie Canal
Study area boundary
7.4-8
0 0.3 0.6 1.2 Kilometers
Soil pH (60-90 cm)
2B2
4D4
3C3
1A1
Legend
Profile Pits
Golina River
Golina 2 Canal
Bergu Melie Canal
Study area boundary
7.4-8
0 0.3 0.6 1.2 Kilometers
Soil pH (90-120 cm)
2B2
4D4
3C3
1A1
Legend
Profile Pits
Golina River
Golina 2 Canal
Bergu Melie Canal
Study area boundary
6.7-7.3
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574400 575200 576000 576800 577600
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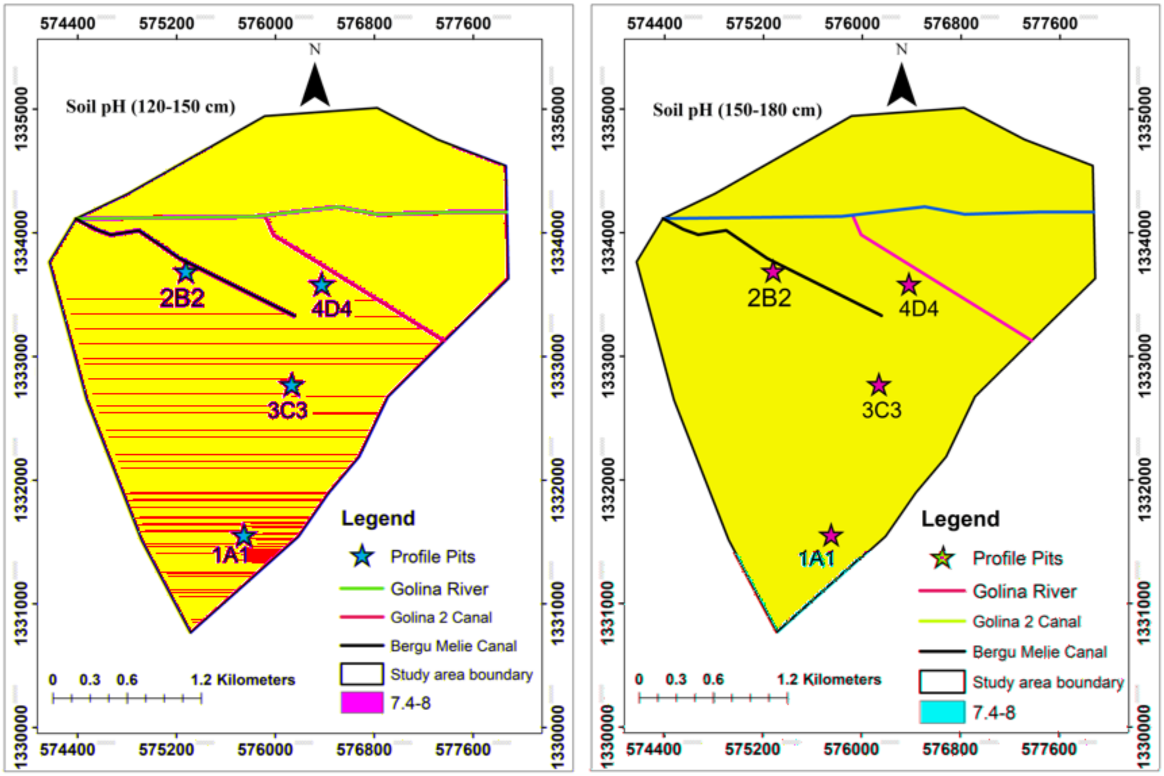
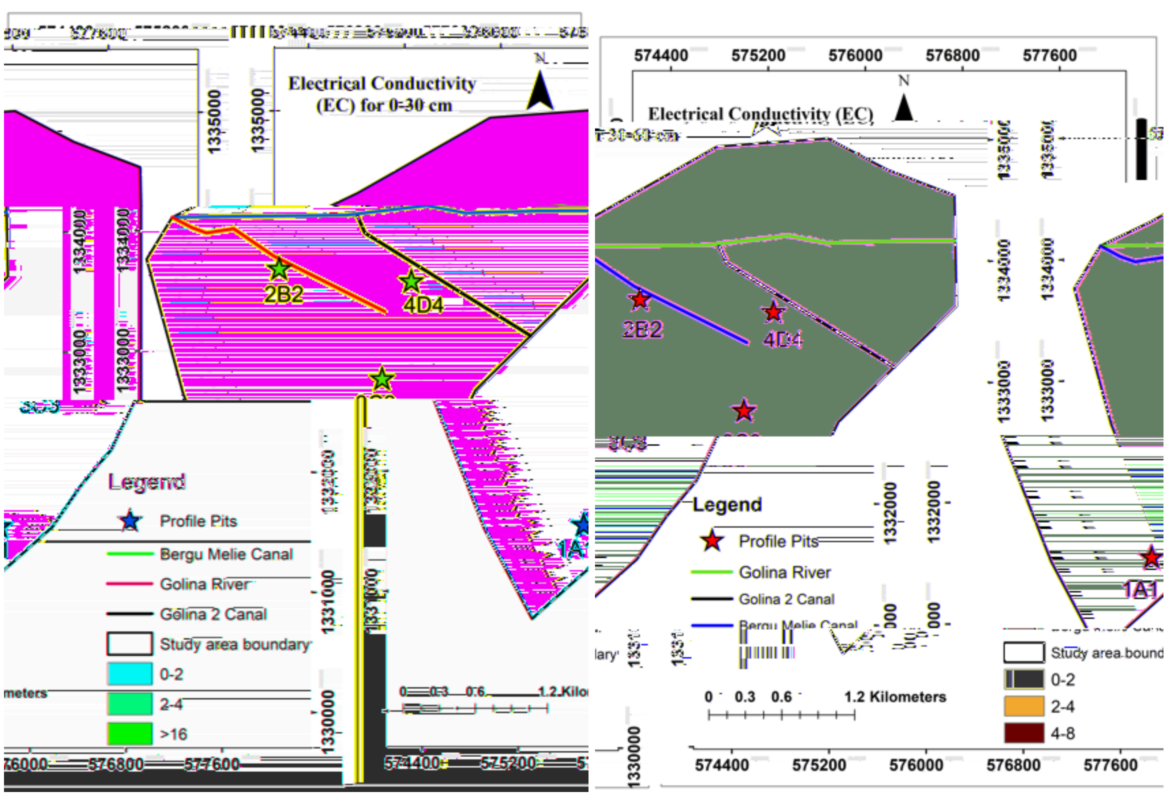


Figure 3: Soil pH for profile pits (0-180 cm)



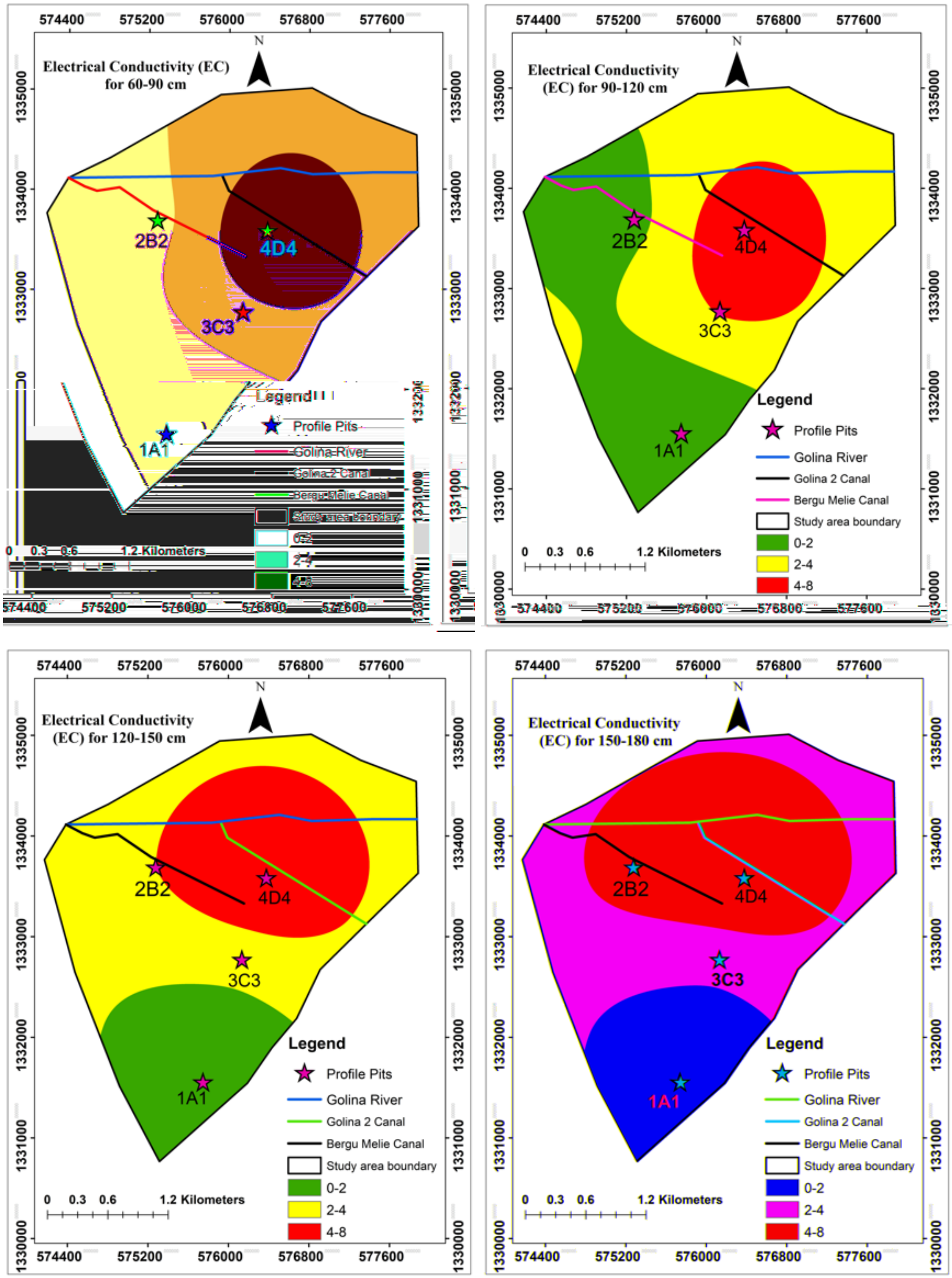


Figure 6: Soil electrical conductivity (EC) for profile pits (0-180 cm)

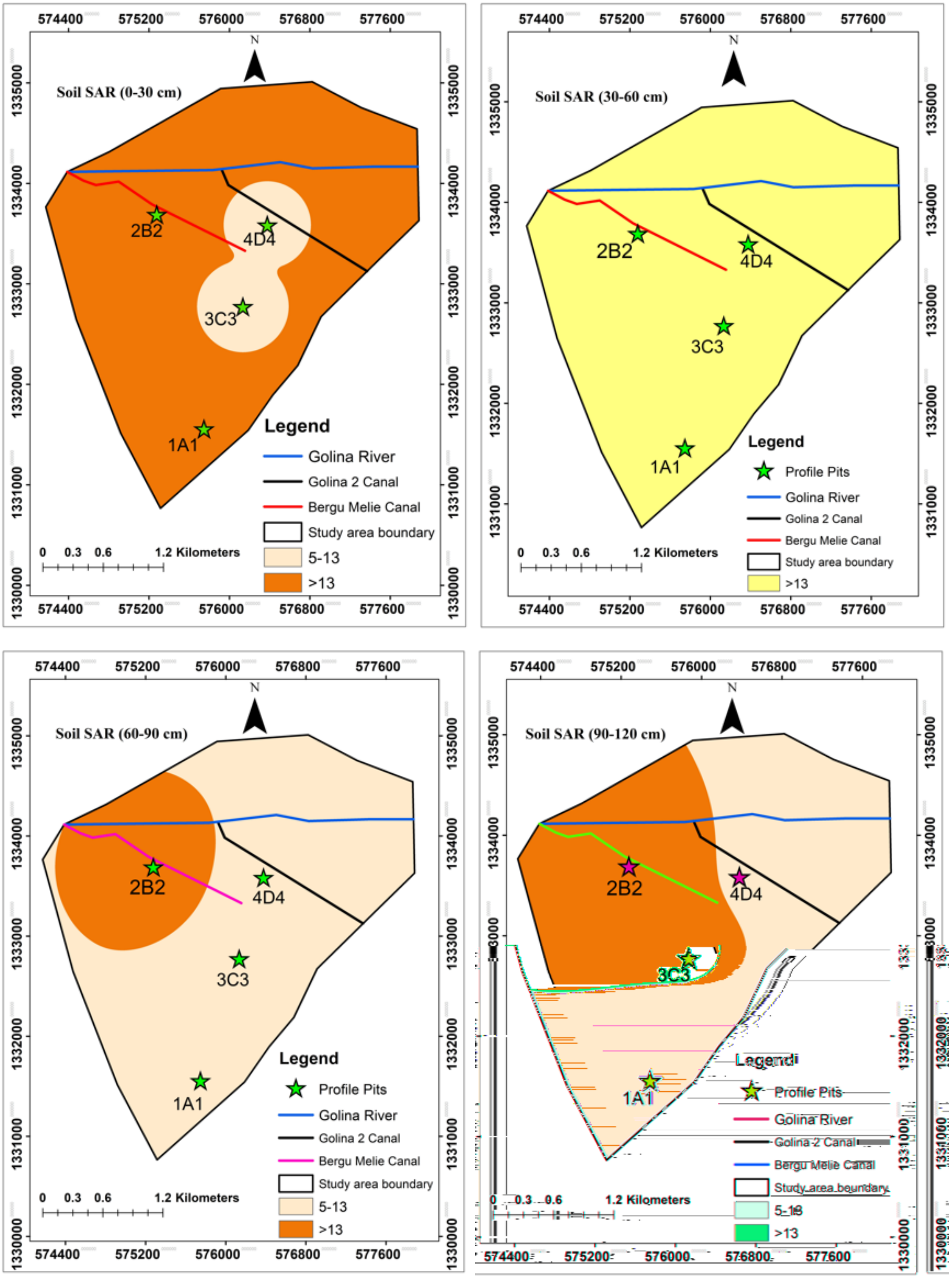

Soil SAR (0-30 cm)
Soil SAR (30-60 cm)
Soil SAR (60-90 cm)
Soil SAR (90-120 cm)
574400
575200
576000
576800
577600
1330000
1331000
1332000
1333000
1334000
1335000
N
2B2
4D4
3C3
1A1
Legend
Profile Pits
Golina River
Golina 2 Canal
Bergu Melie Canal
Study area boundary
5-13
>13
0 0.3 0.6 1.2 Kilometers

Figure 5: Soil SAR for profile pits (0-180 cm)

Soil Salinity and Sodicity Appraisal of Abuarie-Adissalem Salt-Affected Soil (0-30 Cm)

Soil Reaction (Phe): The soil pHe values of the surface soil layer (0-30 cm) varied within the range of 8.4 to 7. The relatively high pHe values appeared in the moderately and strongly alkaline soils due to the increase of bicarbonates, soluble and exchangeable sodium concentration (Appendix Table 2). Ann and Clain, (2005) have been similar reports as the pHe values increased due to the increased exchangeable sodium and bicarbonate (HCO_3^-) ions. Moreover, Tena, (2002) also revealed that high pHe values could be resulted due to the high concentration of bicarbonate (HCO3-). Based on Takalign et al., (1991) classification, that the soil pHe 6.7-7.3, 7.4-8 and >8 categorized as neutral soil, moderately alkaline soil and strongly alkaline soil respectively (Appendix Table 3). In general, 99.92%

Table 1. Area coverage per soil reaction for 0-30cm depth

Farm Unit	Percentage area per sodicity level			
	Total Area (ha)			
pH		6.7-7.3	7.4-8	>8
Abuarie-Adissalem	939.46	0.21	938.74	0.51
% Area	100	0.02	99.92	0.05
Salt affected soil class		Neutral	Moderately alkaline	Strongly alkaline

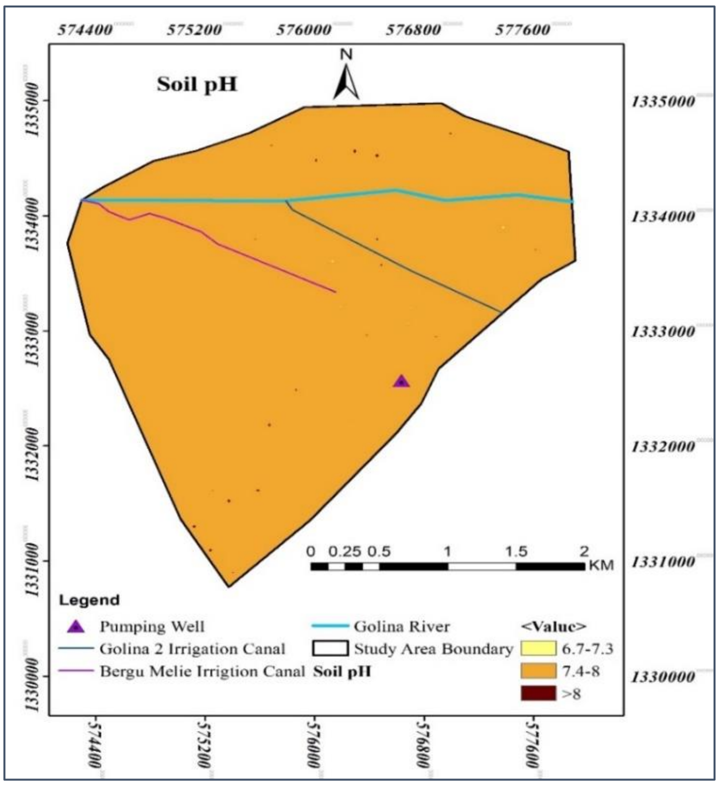


Figure 6: Soil reaction map of Abuarie-Adissalem irrigation scheme

Soil Salinity Appraisal: The electrical conductivity values of the saturated paste extract ranged between 0.2 and 20.2 dS m- (Appendix Table 2). The abundances of soluble salt concentration were found in the sediment and runoff deposited hot spot areas; which shows white surface crust. Because of the Kelkelit river that originated from the western mountains carry large volume of sediment and runoff which deposits on some parts of Abuarie-Adissalem flat plain might increases groundwater table. Whereas, the extent of salinity was less in well drained areas (Figure 7). The high salinity concentration also associated with capillary action and poor drainage practice coupled with high evaporation results a substantial build of soluble salts on the soil surface. The study coincided with other many findings they reported as capillary action and high evaporation promotes salt accumulation at the surface layer (Armstrong et al., 1996; Seelig, 2000; Owens, 2001; Murtaza et al., 2006; Rengasamy, 2006; Ghafoor et al., 2008).

The electrical conductivity values higher than 16 dS m^{-1} indicated that only salt-tolerant plants grow, most others show severe injury (Lamond and Whitney, 1992). According to USSLS, (1954) and Lamond and Whitney, (1992) classification criteria most of the areas as 377.37 ha (40.17%) and 423.02 ha (45.03%) were rated as non-saline and slightly saline soil respectively. But the extent of moderately saline, strongly saline and severe saline soils were relatively slight as 71.04 ha (7.56%), 46.62 ha (4.96%) and 21.41 ha (2.28%) respectively (Table 2).

Table 2. Area coverage per soil electrical conductivity (ECe) for 0-30 cm depth

Farm Unit	Percentage area per salinity level					
	Total Area (ha)	Non-Saline	Slightly Saline	Moderately Saline	Strongly Saline	Severe Salinity
ECe (dS/m)		0-2	2 to 4	4 to 8	8 to 16	>16
Abu. Adissalem*	939.46	377.37	423.02	71.04	46.62	21.41
% Area	100	40.17	45.03	7.56	4.96	2.28

* Abu. Adissalem: Abuarie-Adissalem

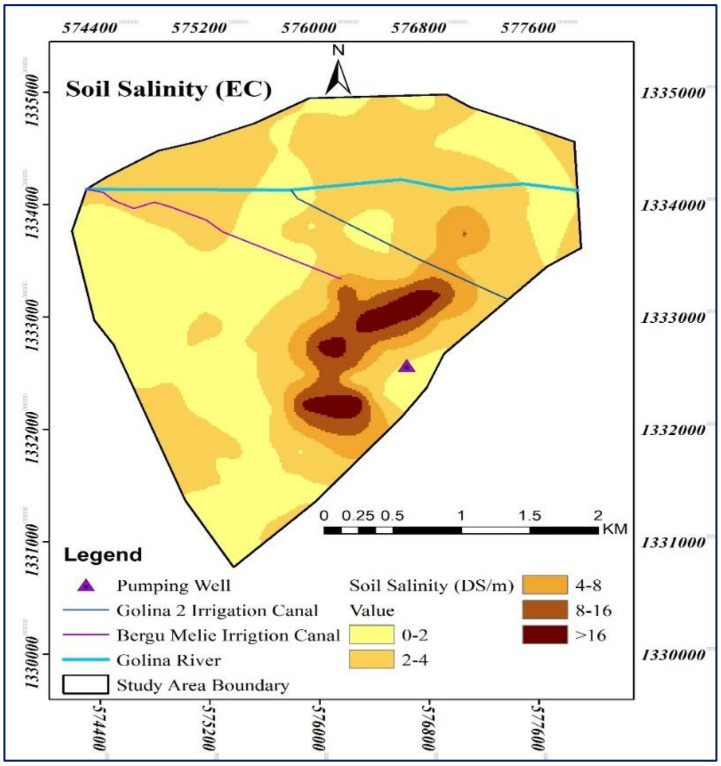


Figure 7: Soil reaction map of Abuarie-Adissalem irrigation scheme

Soil Sodicity Appraisal: The SAR values of Golina-Adisalem irrigation scheme were found within the wide range of 1.03 to 65.7 (Appendix Table 2). The extent of high SAR was observed in many parts of waterlogged and shallow water table hot spot areas (Figure 8). It might be due to the seasonal fluctuation of the groundwater table, the calcium and magnesium ion becoming precipitated and the sodium remains behind. Many studies indicate that the SAR value tends to be increased due to the increased of soluble sodium (Keren and Ben-Hur, 2003; Tsegaye, 2009; Abay and Sheleme, 2012).

Out of the total (939.46 ha) studied area nearly 760.59 ha (80.965%) of the scheme mapped as within the classes of low sodicity level. About 156.38 ha (16.65%) of the soil rated as medium sodicity level with the SAR values found between 5 to 13. The remaining 22.48 ha (23.93%) of the soil classified within high sodium level which affects soil aggregates (Lamond and Whitney, 1992) (Table 3).

Table 3: Area coverage per soil electrical conductivity (ECe) for 0-30 cm depth

Farm Unit	Percentage area per sodicity level			
	Total Area (ha)	Low	Medium	High
SAR		<5	5 to 13	>13
Abu. Adissalem*	939.46	760.59	156.38	22.48
% Area	100	80.96	16.65	23.93

* Abu. Adissalem: Abuarie-Adissalem

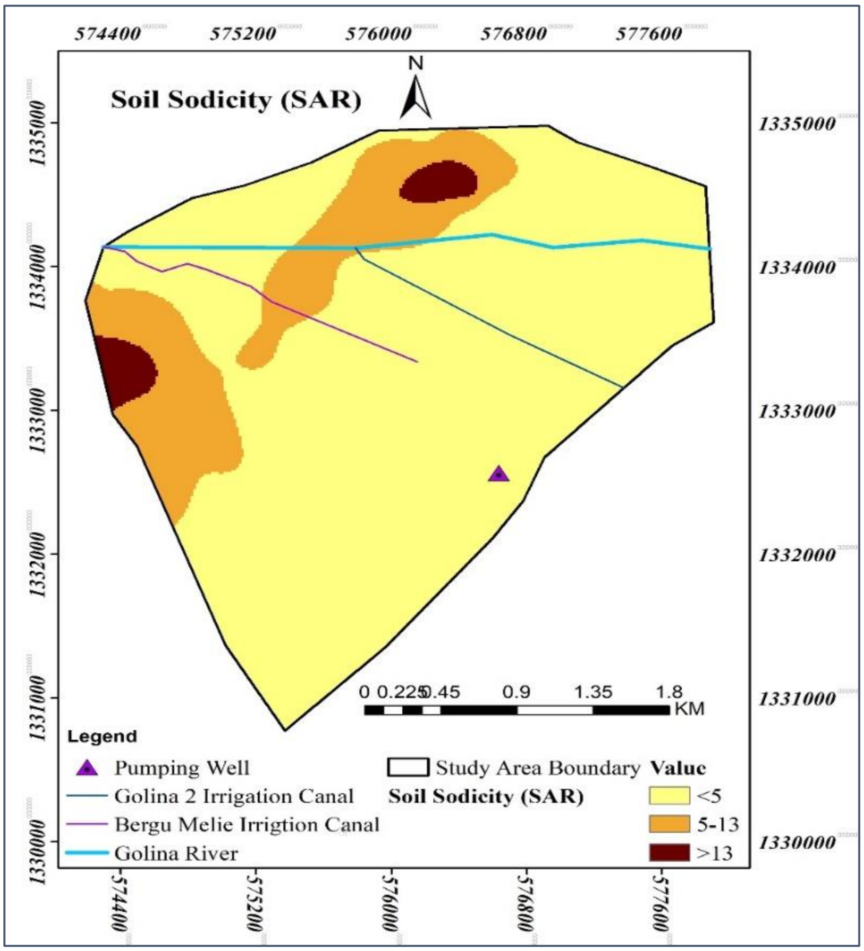


Figure 8: Soil SAR map of Abuarie-Adissalem irrigation scheme (0-30 cm)

Classification of Salt Affected Soils in Golina-Adissalem Irrigation Schemes

Based on USSLS, (1954*) and* Horneck et al., (2007) classification criteria with respect to ECe and SAR values, nearly 42.4% (398.4ha), 29.9% (280.7ha), 10.1% (95.09ha) and 17.6% (165.27ha) of Abuarie-Adissalem irrigation scheme classed as non-saline non-sodic soil, saline soil, saline-sodic soil and sodic soil respectively (Table 4).

Table 4: Area coverage per soil electrical conductivity (ECe) for 0-30 cm depth

No	Salt affected Soil Classes	EC (DS/m)	SAR	Area (ha)	%Area
1	Non-saline-non sodic soil	<4	<13	398.4	42.4
2	Saline soil	>4	<13	280.7	29.9
3	Saline-sodc soil	>4	>13	95.09	10.1
4	Sodic soil	<4	>13	165.27	17.6
	Total Area			**939.46**	**100%**

Conclusion and Recommendation

Abuarie-Adisalem, irrigation scheme was known by *highly abundant water resources and fertile land for irrigated agriculture*. However, due to the buildup of soil salinity and sodicity many productive lands already abounded. Mapping of spatial salinity and sodicity extent generates information for future intervention. Therefore, this study aims to characterize the salinity and sodicity problems of Abuarie-Addisalem irrigation scheme and generate thematic maps using GIS to be used for further management options. Totally 113 samples, 89 from surface soil (0-30 cm) and 24 samples from 4 profile pits up to 180 cm depth with 30 cm depth were collected systematically for representing *939.46 ha* land. Soil reaction (pHe), electrical conductivity (EC), soluble Na^+, Ca^{2+} and Mg^{2+} were determined by followed their procedures.

Based on the result 42.4% (398.4ha) of Abuarie-Adissalem irrigated farm was rated as non-saline non-sodic soil (EC< 4 and SAR <13) and 29.9% (280.7ha) was mapped as saline soil (EC> 4, and SAR< 13). While, 10.1% (95.09ha) and 17.6% (165.27ha) of the scheme classed as saline-sodic (EC> 4 and SAR> 13) and sodic soil (EC< 4 and SAR> 13) respectively. *From the* generated thematic maps *and field observation of the experimental site, the following recommendations are forwarded;*

- Application of subsurface drainage for water table control should be operationalized
- Leaching practices along with subsurface drainage
- Saline agriculture
- Growing of salt absorbent and tolerant species should be rehabilitated.
- Agroforestry practices will minimize evaporation and should be practiced. This could be practice as bio-drainage practice
- The sodic soil should be treated by chemical and organic amendments for structural improvement.
- The salinity and sodicity coverage increasing fast. Therefore, many other management options should be implemented.

Acknowledgement

We would like to thank Sirinka Agricultural Research Center for work facilitation and individuals participated in data collection. We extend our sincere gratitude to Amhara Agricultural Research Institute for the financial support and valuable comment to finish the whole work.

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Appendices

Appendix Table 1: Soil salinity and sodicity induces of soil mapping units

Mapping unit	Elevation (m)	Soil depth (cm)	pH	EC	Soluble cations		SAR	Textural class	Classification	Water table depth (m)
					Na^{+}	Ca^{2+} + Mg^{2+}				
1A1	1398	0-30	7.8	0.4	11	0.32	27.5	Loamy Sand	Sodic	
		30-60	7.7	0.5	10	0.83	15.6	Sandy Loam	sodic	1.3
		60-90	7.4	0.7	8	0.96	11.4	Loamy Sand	Medium sodic	
		90-120	7.3	1.5	7	1.4	8.3	Loamy Sand	Medium sodic	
		120-150	7.6	2	13.7	2.6	12	Sandy Loam	Medium sodic	
		150-180	7.7	0.8	16.1	0.5	32.2	Loamy Sand	Sodic	
2B2	1385	0-30	7.85	0.4	13	0.43	28.3	Clay	Sodic	
		30-60	7.8	0.9	27.8	0.46	57.9	Clay	Sodic	
		60-90	7.81	0.75	23.1	0.37	53.7	Clay	Sodic	1.5

Mapping unit	Elevation (m)	Soil depth (cm)	pH	EC	Soluble cations		SAR	Textural class	Classification	Water table depth (m)
					Na^{+}	Ca^{2+} + Mg^{2+}				
		90-120	7.66	2.1	39.9	1.67	43.8	Clay	Sodic	
		120-150	7.76	3.4	47.5	3.46	36	Silty Clay Loam	Sodic	
		150-180	7.76	3.2	37.3	1.94	38.1	Clay Liam	Sodic	
		0-30	7.3	18.1	14.3	3.7	10.5	Loam	Saline	
3C3	1378	30-60	7.7	3	32	3.9	32.8	Silty Loam	Sodic	
		60-90	7.6	3.23	22	4.7	14.4	Loam	Sodic	0.7
		90-120	7.74	3.37	43.3	4.3	29.5	Silty Loam	Sodic	
		120-150	7.7	2.95	39.5	3.8	28.7	Silty Loam	Sodic	
		150-180	7.8	1.96	33	1.9	33.8	Loam	Sodic	
		0-30	7.65	3.14	20.2	4.6	13.3	Loam	Sodic	
4D4	1376	30-60	7.45	5.7	31.2	9.8	14.1	Silty Loam	Saline-sodic	
		60-90	7.62	6.8	39.5	11	16.8	Silty Loam	Saline-sodic	1
		90-120	7.58	4.2	38.6	6.5	21.4	Loam	Saline-sodic	
		120-150	7.69	4.17	39.3	6.9	21.1	Loam	Saline-sodic	
		150-180	7.7	4.1	40.1	6.3	22.5	Loam	Saline-sodic	

Appendix Table 2: Salinity and sodicity status of Abuarie- Adissalem irrigation scheme for top soil layer (0-30 cm)

Lab.no	Coordinate		Field no.	%			Soil type			EC	Ca+Mg	Na	SAR	Ex. Na	CEC	ESP
	Northing	Easting		Clay	Silt	Sand		gm/cm^3	PH	dS/m	meq/l	meq/l		cmol(+)/Kg	cmol(+)/Kg	%
1	1333068	576676	A1	12.8	62	25.2	SiL	1.38	7.2	17.6	39.6	10.5	2.4	12	100.9	11.9
2	1333197	576715	A2	12.8	70	17.2	SiL	1.39	7.1	16.5	36.5	10.6	2.5	8.3	64.8	12.8
3	1333382	576618	A3	20.8	72	7.2	SiL	1.34	7.9	2.1	3	6.1	5	10.7	67.7	15.8
4	1333577	576493	A4	26.8	62	11.2	SiL	1.3	8.2	0.7	0.9	4.6	6.8	9.3	111.8	8.3
5	1333649	576336	A5	36.8	46	17.2	SiCL	1.37	7.5	0.5	0.8	4.2	6.8	9.4	83.6	11.2
6	1333806	575944	A6	48.8	44	7.2	SiC	1.36	7.8	0.5	0.7	4.4	7.8	9.3	88	10.6
7	1333529	575888	A7	56.8	36	7.2	C	1.39	7.8	0.3	0.7	4.2	7.1	10.7	86.9	12.3
8	1333150	575842	A8	20.8	56	23.2	SiL	1.38	8.1	1.6	2.7	4.3	3.7	8.3	90	9.2
9	1333136	576017	A9	20.8	60	19.2	SiL	1.36	8	0.9	1.6	4	4.4	7	72.9	9.6
10	1333212	576188	A10	8.8	58	33.2	SiL	1.39	7.2	14.4	32.9	4.4	1.1	9.5	80.5	11.8
11	1333177	576314	A11	22.8	60	17.2	SiL	1.41	7.7	6.2	12.5	12.1	4.8	16.8	99.8	16.8
12	1332964	576381	A12	18.8	60	21.2	SiL	1.46	8	18	26	27	7.5	43	162.7	26.4
13	1332706	576471	A13	8.8	52	39.2	SiL	1.45	7.5	5	10.3	12.4	5.5	17.8	74.1	24.1
14	1332453	576563	A14	8.8	56	35.2	SiL	0.38	7.9	0.5	0.7	4	6.9	10.9	70.5	15.5
15	1332294	576435	A15	10.8	26	63.2	SL	1.38	7.7	0.6	0.8	4.9	7.7	11.7	72.3	16.1
16	1332239	576265	A16	10.8	62	27.2	SiL	1.36	7.5	20.2	52	5.3	1	11.9	88.4	13.5
17	1332449	576259	A17	12.8	56	31.2	SiL	1.35	7.8	0.5	0.7	4.2	7.1	10.1	88.7	11.3
18	1332581	576221	A18	16.8	58	25.2	SiL	1.4	7.6	13.4	30.9	12.8	3.3	20	111.7	17.9

Lab.no	Coordinate		Field no.	%			Soil type		EC	Ca+Mg	Na	SAR	Ex. Na	CEC	ESP
	Northing	Easting		Clay	Silt	Sand		gm/cm^3	PH	dS/m	meq/l	meq/l		cmol(+)/Kg	cmol(+)/Kg	%
19	1332734	576018	A19	22.8	50	27.2	SiL/L	1.29	7.8	16.4	31.3	6.2	1.6	3.3	54.6	6
20	1332490	575868	A20	14.8	48	37.2	L		8.1	3.1	4.6	4.8	3.2	3	65.9	4.5
21	1332218	575899	A21	10.8	38	51.2	L	1.33	7.6	16.5	34.1	4.5	1.1	3.5	65	5.3
22	1332184	575668	A22	16.8	56	27.2	SiL	1.34	8.3	0.6	0.9	4.2	6.4	3.3	45.8	7.2
23	1333795	576462	A23	22.8	46	31.2	L	1.35	8.1	0.7	0.3	5	13.5	3.4	63.5	5.4
24	1333609	576132	A24	32.8	54	13.2	SiCL	1.36	7	3.2	4.3	3.4	2.3	4.2	62.4	6.8
25	1333740	577061	A25	28.8	62	9.2	SiCL	1.36	8	10.7	14.3	13.5	5	6.9	71.4	9.7
26	1333899	577382	A26	24.8	58	17.2	SiL	1.32	7.2	1.1	1.1	2.3	3.1	3.2	55.2	5.9
27	1333704	577621	A27	18.8	46	35.2	L	1.33	8.1	0.8	0.6	2.3	4.1	3.5	68.5	5.1
28	1333507	577446	A28	6.8	32	61.2	SL	1.38	8	2.1	2.7	3.8	3.3	3.7	47	8
29	1333478	577088	A29	40.8	52	7.2	SiC	1.4	8.1	3.1	2.2	8.4	8.1	5.7	53.5	10.6
30	1333492	576875	A30	14.8	68	17.2	SiL	1.39	7.9	6.2	9.1	5.5	2.6	3.8	49.7	7.6
31	1333197	576880	A31	12.8	62	25.2	SiL	1.38	7.7	14.8	27.8	4.4	1.2	3.7	59.6	6.2
32	1332949	576895	A32	14.8	58	27.2	SiL	1.38	8.1	3.5	2.5	4.1	3.6	3.9	47.6	8.3
33	1330896	575410	B1	10.8	64	25.2	SiL	1.4	8.1	0.5	1.6	3.5	3.9	9.9	75	13.2
34	1331097	575241	B2	32.8	58	9.2	SiCL	1.43	8.2	0.5	0.8	3.6	5.8	13.8	80.2	17.2
35	1331298	575123	B3	26.8	58	15.2	SiL	1.37	8.2	0.6	0.7	4.3	7.4	8.7	87.9	9.9
36	1331456	575209	B4	34.8	52	13.2	SiCL	1.35	7.3	0.7	1	3.8	5.5	8.8	106.3	8.2
37	1331359	575327	B5	22.8	60	17.2	SiL	1.39	7.7	0.4	0.7	3.9	6.5	10.5	101.6	10.3

Lab.no	Coordinate		Field no.	%			Soil type			EC	Ca+Mg	Na	SAR	Ex. Na	CEC	ESP
	Northing	Easting		Clay	Silt	Sand		gm/cm^3	PH	dS/m	meq/l	meq/l		cmol(+)/Kg	cmol(+)/Kg	%
38	1331233	575481	B6	8.8	26	65.2	SL	1.42	7.8	0.3	0.9	3.3	5	8.1	59	13.8
39	1331291	575609	B7	10.8	32	57.2	SL	1.43	7.5	0.7	1.2	3.8	4.9	8.5	61.7	13.8
40	1331368	575644	B8	8.8	44	47.2	L	1.42	7.9	0.4	0.7	3.7	6.1	6.8	48.4	14.1
41	1331559	575536	B9	26.8	58	15.2	SiL	1.38	7.8	0.9	1.6	3.9	4.3	6.8	80.7	8.4
42	1331521	575372	B10	16.8	52	31.2	SiL	1.4	8.3	0.9	2.1	4.6	4.5	10.3	96.2	10.7
43	1331612	575260	B11	20.8	46	33.2	L	1.39	8	1	1.6	5.1	5.7	10.2	102.9	10
44	1331710	575298	B12	16.8	54	29.2	SiL	1.38	8	0.5	0.9	3.8	5.7	10.7	85.2	12.5
45	1331450	575906	B13	10.8	40	49.2	L	1.42	7.6	0.8	7.4	4.1	2.1	10.1	59.6	16.9
46	1331569	575927	B14	12.8	54	33.2	SiL	1.4	7.5	1.3	2.5	4.2	3.7	10.1	72.3	13.9
47	1331751	575950	B15	16.8	56	27.2	SiL	1.42	7.7	0.6	0.9	4.4	6.7	12.5	89.7	14
48	1331811	575865	B16	8.8	46	45.2	L	1.43	7.8	0.4	0.9	3.9	5.8	10.9	70	15.6
49	1331668	575779	B17	12.8	36	51.2	L	1.38	7.8	1.9	4	4.4	3.1	10.1	85.6	11.8
50	1331474	575719	B18	10.8	22	67.2	SL	1.39	7.7	0.7	1.1	4.1	5.4	3.1	42.8	7.2
51	1331331	575722	B19	12.8	20	67.2	SL	1.36	7.8	0.3	0.6	4	7.4	3.3	48.8	6.8
52	1331394	575538	B20	4.8	4	91.2	S	1.43	8	0.2	0.3	4	9.6	3.7	22.3	16.7
53	1331618	575589	B21	6.8	38	55.2	SL	1.38	8.4	0.5	0.8	3.6	5.6	3.3	41.4	8.1
54	1331805	575635	B22	12.8	56	31.2	SiL	1.37	7.9	0.5	0.3	3.5	8.7	3.1	47.5	6.6
55	1331979	575617	B23	12.8	40	47.2	L	1.4	7.6	0.7	0.7	0.8	1.4	3.6	32.6	11.1
56	1332790	575483	B24	22.8	60	17.2	SiL	1.39	8	1.3	1.4	1	1.2	3.6	47.7	7.5
57	1331937	575433	B25	32.8	60	7.2	SiCL	1.37	7.9	0.6	0.6	4	7.5	3.1	50.4	6.1

Lab.no	Coordinate		Field no.	%			Soil type			EC	Ca+Mg	Na	SAR	Ex. Na	CEC	ESP
	Northing	Easting		Clay	Silt	Sand		gm/cm^3	PH	dS/m	meq/l	meq/l		cmol(+)/Kg	cmol(+)/Kg	%
58	1331797	575340	B26	26.8	58	15.2	SiL	1.39	7.2	1.7	1.8	4	4.2	3.9	57.7	6.8
59	1334330	577776	C1	14.8	52	33.2	SiL	1.38	7.9	1	0.9	8	11.9	3.3	51.4	6.5
60	1334627	577474	C2	12.8	56	31.2	SiL	1.39	7.9	0.5	0.3	7	17.1	3.7	45.4	8.1
61	1334507	577079	C3	16.8	62	21.2	SiL	1.37	7.9	0.7	0.6	7.6	14.4	3.8	49.8	7.6
62	1334717	576996	C4	46.8	28	25.2	C	1.38	8	1	0.6	10.9	19.7	3.9	48.9	8
63	1334945	576717	C5	12.8	38	49.2	L	1.35	7.9	0.6	0.5	6.3	13.3	2.8	42.6	6.7
64	1334354	576752	C6	16.8	38	45.2	L	1.34	8	1	0.8	9.6	15.1	3	43.1	6.9
65	1334429	576589	C7	10.8	22	67.2	SL	1.37	7.7	2.3	2.9	9.6	8	3.2	40.7	7.8
66	1334524	576460	C8	16.8	46	37.2	L	1.42	8.2	3.3	0.6	28.7	54.2	11.3	56.6	19.9
67	1334416	576369	C9	8.8	14	77.2	SL	1.4	7.6	0.8	0.1	6.1	27.2	2.9	27	10.6
68	1334562	576296	C10	30.8	38	31.2	CL	1.38	8.4	1.5	0.2	20.2	63.9	6.5	67.4	9.6
69	1334486	576013	C11	22.8	40	37.2	L	1.37	8.2	1.7	0.4	19.8	42.7	5.6	48.9	11.5
70	1334612	575683	C12	26.8	60	13.2	SiL	1.35	8	0.7	0.5	9.1	18.6	3	59.3	5.1
71	1334886	576206	C13	34.8	52	13.2	SiCL	1.37	7.9	0.5	0.3	7.4	19.8	5.1	66.9	7.7
72	1333817	574323	C14	42.4	43.2	14.4	SiC	1.32	7.6	0.2	0.3	9.3	23	1.6	55.3	2.8
73	1333730	574918	C15	50.4	35.2	14.4	C	1.3	7.9	0.8	0.7	10.4	18.2	1.7	71.8	2.4
74	1333795	575573	C16	56.4	33.2	10.4	C	1.31	8.1	0.5	0.5	13.3	26.7	1.9	55.8	3.4
75	1333559	575393	C17	52.4	31.2	16.4	C	1.29	7.9	0.4	0.3	8.7	22.4	1.7	52.6	3.1
76	1333357	575187	C18	48.4	37.2	14.4	C	1.31	7.8	0.5	0.3	9.9	26.6	1.6	56.8	2.8
77	1333026	575210	C19	42.4	47.2	10.4	SiC	1.34	7.9	0.9	0.7	9.9	17.4	1.7	50.5	3.3

Lab.no	Coordinate		Field no.	%			Soil type			EC	Ca+Mg	Na	SAR	Ex. Na	CEC	ESP
	Northing	Easting		Clay	Silt	Sand		gm/cm^3	PH	dS/m	meq/l	meq/l		cmol(+)/Kg	cmol(+)/Kg	%
78	1332669	575027	C20	38.4	47.2	14.4	SiCL	1.34	7.8	0.7	0.4	13.1	29.4	1.8	50.8	3.6
79	1332517	574922	C21	32.4	51.2	16.4	SiCL	1.32	7.8	0.8	0.7	11.2	18.9	1.8	63.2	2.9
80	1332484	574671	C22	44.4	43.2	12.4	SiC	1.32	7.9	0.6	0.5	15.7	31.4	1.8	52.1	3.5
81	1332664	574625	C23	32.4	55.2	12.4	SiCL	1.33	8	0.8	0.5	18.9	36.3	2.2	51.5	4.2
82	1332863	574529	C24	47.6	45.2	7.2	SiC	1.3	7.9	0.5	0.3	16.1	43	1.9	61.6	3.1
83	1332959	574499	C25	63.6	25.2	11.2	C	1.31	7.9	0.6	0.5	16.1	31	2.2	63.3	3.4
84	1333099	574646	C26	63.6	27.2	9.2	C	1.3	7.8	0.3	0.3	14	38.1	1.8	64	2.9
85	1333264	574429	C27	65.6	25.2	9.2	C	1.31	7.9	0.4	0.1	17.4	65.7	1.7	66	2.6
86	1333516	574581	C28	63.6	25.2	11.2	C	1.29	7.9	0.4	0.3	13.1	33.9	1.7	64.7	2.6
87	1333461	574972	C29	63.6	25.2	11.2	C	1.29	7.9	0.5	0.7	9.9	16.9	1.7	81.7	2
88	1333198	575153	C30	41.6	47.2	11.2	SiC	1.34	7.8	0.5	0.6	9.5	17.4	1.5	52.8	2.8
89	1333040	574905	C31	35.6	49.2	15.2	SiCL	1.35	8	0.6	0.6	15	27.5	1.8	54.1	3.4
A				**25.4**	**46.7**	**27.9**	**SiL**	**1.38**								

* SiL- Silty Loam, C- Clay, L- Loam, S- Sandy, SL- Sandy Loam, SiCL- Silty Clay Loam and SiC- Silty Clay.

Appendix Table 3: Rating of Soil Salinity and Sodicity Parameters

Parameter	Test method	Rating
Ece (dSm^{-1})	From saturated paste extract	< 2 (non-saline) no management option needed
		2 - 4 (slightly saline)
		4-8 (moderately saline)
		8-16 (highly saline)
		> 16 (extreme saline)
PHe		