Original Research Article

Spatial Variability and Temporal Fluctuation of Soil Salinity and Sodicity in irrigated areas of Amibara districts, Middle Awash, Ethiopia

Commented [D1]: Temporal Fluctuation of Measured Chemical Properties in Irrigated Areas of of Amibara districts, Middle Awash, Ethiopia

ABSTRACT

This study was conducted to investigate Spatial Variability and Temporal Fluctuation of Soil Salinity and Sodicity in Fluvisols and Vertisols Areas of Amibara, Middle Awash, Ethiopia. A Total of 182 soil samples with two sampling depths (0-30 cm and 30-60 cm) were collected from irrigated and non-irrigated fields at the months of August, October and December. Based on the mean values of laboratory analysis result, the textural class in Fluvisols ranged from silt clay, clay loam to clay whereas it was clay in Vertisols areas. The mean pHe values ranged from moderately alkaline to strongly alkaline in both soil types. The ECe values varied from 0.48 to 21.8 dS/m and 0.70 to 5.4 dS/m, respectively for soil samples collected from Fluvisols and Vertisols areas of the AIS. The mean SAR values ranged from 1.7 to 18.2, in Fluvisols, while it ranged from 2.8 to 14.6 at 0-30 cm depth in Vertisols areas. Generally by combining all salinity and sodicity parameters, about 71.43, 19.05 and 9.52% in Fluvisols and 77.78, 11.11 and 11.11% of the soil samples in Vertisols area grouped under normal, saline and saline sodic class, respectively. The temporal trends of soil ECe varies with irrigation water application interval and type of field covers. Generally increasing trends has been occurred in fields covered by cotton crops and tree plants, while irregular trends has been observed in fields covered by sugarcane crops. Higher increment of each soil chemical properties were observed in irrigated farm compared to non-irrigated farm, at surface than subsurface soil depth and in Fluvisols than in Vertisols. Generally, in addition to quality reduction of Awash River water, poor management of irrigation, absence of adequate surface and subsurface drainage structures are aggravating soil salinity in the study area

Key words: Soil salinity and Sodicity, Fluvisols, Vertisols, Electrical conductivity and Sodium adsorption ratio

1. INTRODUCTION

Irrigated agriculture is a major human activity, which often leads to secondary salinization of land and water resources in arid and semi-arid conditions. In the hot and dry regions of the world the soils are frequently saline with low agricultural potential. Salinization can be described as an increase in the salt concentration to the extent that optimal soil use is no longer possible [1]. Salinization is the process by which water-soluble salts accumulate in the soil. Soil salinization impairs food production, environmental health and socio-economic wellbeing [2, 3]. Salinization commonly occurs as an outcome of agricultural practices, either associated with irrigation or due to long-term changes in water flow in the landscape that can follow land clearance or changed water management. Salinization associated with agriculture occurs when salts build up in the root zone, either because the soil is intrinsically saline, or because the drainage of water from the sub-soil is not sufficient to prevent saline waters rising into the root zone. It is therefore, tend to be common in arid and semi-arid regions where leaching of salt is poor due to low rainfall; where there are strongly saline sub-soils formed from marine deposits or where irrigation changes water tables and salt flow [4].

Salt buildup can result in three types of soils: saline, saline-sodic and sodic. Saline soils are the easiest to correct; sodic soils are more difficult. Each type of soil has unique properties that require special managements [5]. Salt-affected soils occur in all continents and under almost all climatic conditions. Their distribution, however, is relatively more extensive in the arid and semi-arid regions compared to the humid regions [6]. In Ethiopia, the Amibara Irrigation Scheme (AIS), found in the Awash River Basin, encounters problems of salinization and rising water tables to varying degrees. Irrigated agriculture at Amibara Irrigation Project, located in the Middle Awash region, was started towards late sixties [7]. The soils at the farm area were generally non-saline and groundwater table in the area was below 10 [8]. However, subsequent mismanagement of irrigation water, in the absence of a complementary drainage system, gave rise to water logging, salinization of fully productive areas and considerable losses in crop yields. This severe problem resulted in abandonment of substantial areas of Melkasedi cotton producing fields.

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Fluvisols have large pores and coarse soil texture, the solute transport to soil surface that forms salt crust is higher than in Vertisols which have very fine pores and fine soil texture [9]. Since they are composed of small particles, clay soils can hold more water and are slower to drain than coarse textured soils and smaller particles can pack closely together, block the spaces between particles and prevent water from passing through soil especially on sodic soil [3]. In a sandy soil, the upward flow is slower than in a clay loam soil [10]. According to the report by [11] the Amibara area soil texture in Vertisols is clay while in Fluvisols ranges from clay and silt clay to silt clay loam.

Sufficient information has been developed so far regarding the assessment of soil salinity and sodicity level. But information both on the spatial variability and temporal fluctuation of soil salinity and sodicity in Fluvisols and Vertisols areas of Amibara irrigation project has not been reported sufficiently. Therefore, this study was conducted with the objective to investigate the spatial variability and temporal fluctuation of soil salinity and sodicity in Fluvisols and Vertisols areas of amibara, middle awash, Ethiopia.

Commented [D3]: No spatial variability approach is used

2. MATERIALS AND METHODS

The study was conducted at Amibara irrigation scheme, in Amibara Woreda, Gabiressu Zone of Afar National Regional State (Figure 1). The study area lies on a long broad alluvial plain along the right bank of the Awash River, which includes Melka Sedi, Melka Werer and Ambash-Sheleko irrigated farms with a gross command area of more than 15,000 ha. The area has an elevation ranging from 724 to 745 m with average of about 734.5 meters above sea level. It is located at 9° 14' 1.2" to 9°27'12.1" N latitude and 40° 6' 19.2" to 40°14'26.1" E longitude in the Middle Awash Valley, close to the main high way linking Addis Ababa to Djibouti at a distance of 280 km from Addis Ababa to the Northeast direction (WARC).

2.1 Topography, geology and soil type

The topography of the study area reflects the recent geomorphic history of the Middle Awash valley, through which deposits from the Awash River formed on extensive alluvial plain. Slope gradients are generally very low, and predominantly lying in the range between 1 and 2%. The parent materials of the alluvial deposits in the rift valley of the study area are volcanic rocks. These include granites, feldspars and aluminosilicates of sodium and potassium, hyper alkaline silica lavas, alkaline olivine-and dolerite-andesite basaltic magmas, carbonate, volcanic ash, tuff, pumice, and rhyolite parent materials [12, 13]. The soil of area is developed through the transportation and deposition of materials coming from volcanic highlands by the Awash River and its tributaries. The soils of the study area is predominantly Eutric Fluvents, order Fluvisols followed by Vertisols occupying about 30% of the total area [12, 14]. The soil texture of the area varies from silty clay to clay in Vertisols where as it ranges from sandy loam to silty loam in Fluvisols [13, 14]. Fluvisols are constituents of muscovite/illite clay minerals and Vertisols are dominated by montmorillonite clay minerals [15].

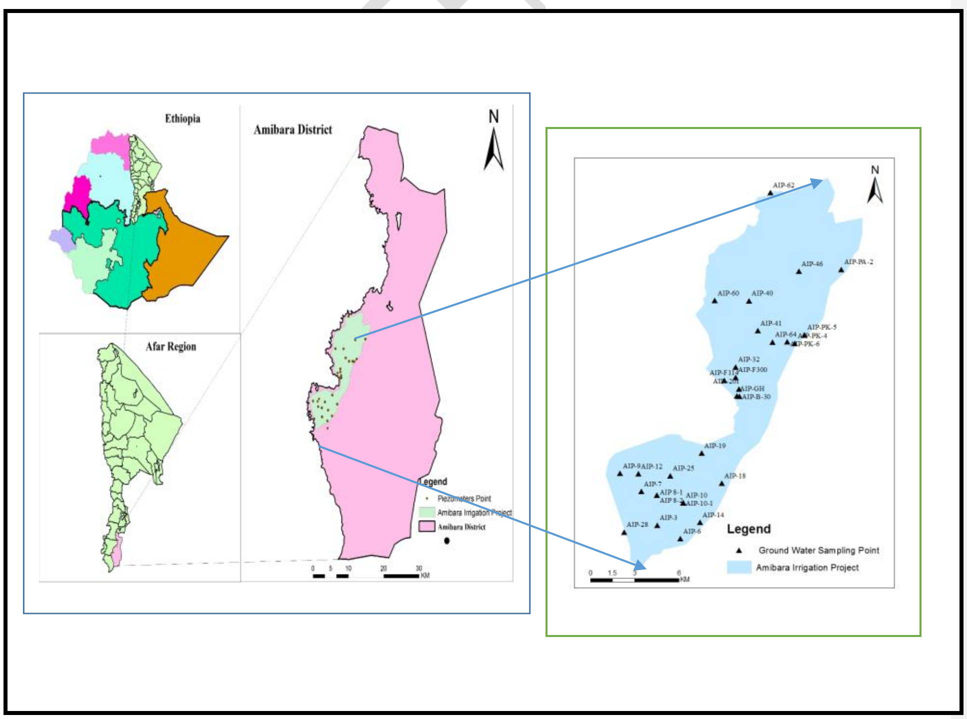

Figure 1 Location map of the study area

Figure 1. Location map of the study area

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2.2 Climate

According to the classification of Agro-ecological zones by the Ministry of Agriculture and Rural Development (MoARD) the area is classified as semi-arid [16]. According to Werer Agricultural Research Center mean climatic data for the period of 1970-2017, the average annual rainfall is around 736.2 mm, accumulated with the long and short rains. More than 85% of the rain occurs from June to September, with July and August being the wettest months. The mean annual free water evaporation as recorded by the class A pan is around 2708.7 mm. The mean minimum and maximum temperatures are 16.8 and 32.6 ^{0}c, respectively (Appendix Table 1). As shown on the Figure 2, the mean evapotranspiration and rain fall in the study periods showed an increasing trend, while rainfall decreases from August to December in the soil and water sampling seasons which may affect the level of ground water in the study area.

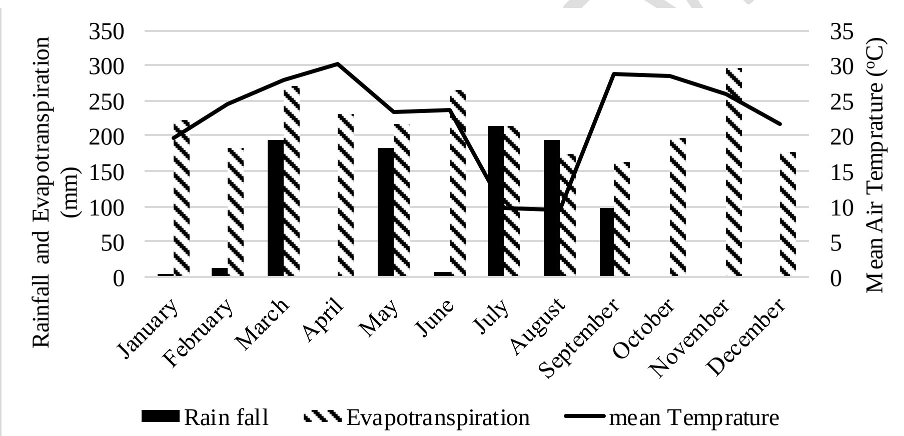

Figure 2 Mean annual rainfall, evapotranspiration and air temperature in the study area (January – December, 2017)

2.3 Land use and land cover

Since the establishment of irrigated agriculture, fragments of forest, mainly *Acacia neolithica*, are found along both sides of the Awash River bank [14]. Nowadays, an exotic tree species called *Prosopis julifora* is invading the grazing and irrigated areas predominantly on salt affected abandoned lands. It also covers vast areas of the non-irrigated land such as road sides, field boarders and also the irrigation canals sides. The major crop grown was cotton by the private farms and minor crops including maize, sesame, banana and vegetables which are cultivated by some agro-pastorals and Werer Research Center. Starting from 2006/2007 E.C all of the Melkasedi state farms and some parts of Melka Werer farmlands have been changed to sugarcane plantation and totally it covers around 6019 ha of land. Generally the area was covered by three main types of land uses: sugarcane, cotton, forage and trees and shrubs fields. The sugarcane field received irrigation throughout the year while cotton fields irrigated for some months. Trees and shrub fields never get irrigation water except rain water since they are either abandoned lands or simply covered by tree plants.

2.5 Irrigation water source and management

The main source of irrigation water is the Awash River by making use of diversion weir at MelkaSedi and by installing other motor pumps at different locations to divert water from Awash River down to the irrigation area. The project area is protected from flooding, both from the Awash River and from the adjacent hillside catchments, by a series of earth dykes. Irrigation water in the scheme is applied using furrow irrigation technique by directly connecting from different field canals. The furrow length ranges from 200 to 250 m with furrow spacing of 0.9 m in cotton fields, while it has an average furrow length of 240 m and furrow spacing of 1.45 m in sugarcane fields. Due to these extended length of furrow combined with poor land leveling, the irrigation water wastage had been observed throughout the irrigated areas, especially in sugarcane fields (personal communication).

2.6 Soil sampling

Soil samples were collected to assess the occurrence and status of soil salinity and sodicity for surface soil. Soil samples were collected at the months of August, October and December, 2017 three times with two months interval. Eight sub-samples per composite sample diagonally in 10 meters interval were collected. Accordingly, a total of 60 soil samples were collected at a depth of 0-30 and 30-60 cm using systematic sampling technique in once sampling time and a total of 180 samples in three sampling months. One composite sample also was taken from non-irrigated land. During sample collection any foreign material such as plant residues and gravels were properly removed from entering to the sample. Finally, about 1 kg of each composite soil sample was bagged, properly labeled, and transported to the laboratory for preparation and analysis. All sampling points were geo-referenced and the latitude and longitude of each sampling points were taken with GPS.

Commented [D5]: need sampling location map

2.7 Sample preparation soil sample analysis

All the soil samples were air-dried, ground to pass through 2 mm sieve and prepared for laboratory analysis. Similarly, all the water samples were filtered with a watsman (101) filter paper and made ready for detailed laboratory analysis. All laboratory analysis works for physical and chemical properties of each soil and water samples were conducted at soil and water analysis laboratories of Werer and Melekasa Agricultural Research Centers. Soil particle size distribution was determined by the Bouyocous hydrometer method as described by [17]. Saturated paste extracts were prepared following the methods described in [18]. Soil pH was measured potentiometrically using a digital pH-meter and electrical conductivity (ECe) by digital conductivity meter according to the method outlined by [18, 19] respectively from the sample prepared by saturation paste extract. Calcium carbonate was determined by acid neutralization method as described in [20].

Basic water soluble cation were determined from saturated paste extracts using atomic absorption spectrophotometry for Ca^{2+} and Mg^{2+} while and flame photometer for Na^{+} and K^{+}, and expressed as $meql^{-1}$ of extract [21]. HCO_3^- and CO_3^{2-} ions were determined by titration with standard hydrochloric acid using phenolphthalein and methyl orange as indicators, respectively. Sodium Adsorption Ratio (SAR) value was determined from the proportion of water soluble sodium to calcium plus magnesium in the soil and is expressed in an equation below.

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$$SAR_{ss} = \frac{(Na^{+})}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \text{..............} \quad (1)$$

The exchangeable bases (Ca, Mg, Na and K) were determined from extraction of neutral ammonium acetate extraction method. Ca and Mg ions were measured by atomic absorption spectrophotometry, while Na and K were determined by flame photometer. All exchangeable bases were expressed as cmol $_{(+)}$ kg^{-1} of soil. The cation exchange capacity (CEC) of the soils was determined by the neutral ammonium acetate method according to the percolation tube procedure [21]. The residual sodium carbonate (RSC) was calculated by subtracting the sum of Ca^{2+} and Mg^{2+} from the sum of CO_3^{-2} and HCO_3^- as:

$$RSC = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+} + Mg^{2+}) \quad (2)$$

2.9 Data analysis

All collected data were subjected to descriptive statistics and their range and mean were determined in excel sheet. Finally, all soil salinity parameters were used to classify them in to different salinity and sodicity classes based on the guidelines outlined by [19]. To see of the temporal fluctuation, three months data for soil electrical conductivity, SAR and some cations and anions, time series graphs were developed on Microsoft excel.

3. RESULTS AND DISCUSSION

3.1 Soil texture

The particle size distribution of soil samples collected from Amibara irrigation scheme (Appendix Tables 2 and 3) indicated that, the textural class in Fluvisols ranged from silt clay, clay loam to clay whereas it was clay in Vertisols areas. The soil texture did not show any variation with sampling depths. The clay particle size distribution ranged from 13.2 to 69.2% in Fluvisols while it ranged from 55.2 to 70.4% in Vertisols areas of the AIS. The result is in line with [11] who stated that the salt affected soil classes of the study area had textural classes ranging from the clayey to silt clay loam.

3.2 Calcium carbonate content

The percentage of calcium carbonate ($CaCO_3$) ranged from 2.5 to 36 and 3 to 37.5 at 0-30 cm and 30-60 cm soil sampling depths, respectively in Fluvisols areas while it ranges from 2 to 23.5 and 2.5 to 25.5 at 0-30 cm and 30-60 cm soil sampling depths, respectively in Vertisols areas (Appendix Tables 2 and 3). According to [22], about 38.10, 42.86 and 19.05% of the sampling points fall under medium, high and very high range at 0- 30 cm soil depth while 33.33, 47.62 and 19.05% of sampling points fall under medium, high and very high range at 30-60 cm soil depth in Fluvisols areas of AIS. Similarly, about 33.33, 55.56 and 11.11% of soil samples fall under medium, high and very high range at 0-30 cm soil depth, while 22.22, 55.56 and 22.22% of soil samples fall under medium, high and very high range of calcium carbonate content in Vertisols area. The calcium carbonate content for the soil sample taken from non-irrigated field also indicate higher content of this mineral in these areas, which falls under high range.

3.3 Soil reaction

Soil pHe, a good indicator of intensity of acidity or alkalinity of the soil, was determined from saturated paste extract. The mean pH values of composite soil samples collected from 30 sampling points with two depths, in both soil types is presented in Appendix Tables 4 and 5. The mean pHe values ranged from moderately alkaline (7.6-8.3) to strongly alkaline (8.4-8.5) in Fluvisols. It was also ranged from moderately alkaline (7.9 to 8.3) to strongly alkaline (8.4) in Vertisols areas of the AIS [23]. The pH values under both soil types did not show any variation along the sampling depths. Generally 14.3% and 85.7% of the sampling point showed moderate and strongly alkaline reaction, respectively in Fluvisols, while 88.9 and 11.1% of soil samples collected from Vertisols were grouped under moderately and strongly alkaline reaction, respectively. The report of [24] also stated that the pHe value of the Amibara irrigation area has a value greater than 7 and the author suggested that the probable reason for high pH value could be attributed to high concentration of bicarbonates. Similarly in this study high values of bicarbonates has been recorded in most soil samples. In addition [25] also reported that generally the pH of the area in alkaline reaction.

3.4 Soil electrical conductivity

Soils of the study area showed high range of variation with respect to mean ECe values (Appendix Tables 4 and 5). The ECe values varied from 0.48 to 21.8 dS/m and 0.70 to 5.4 dS/m, respectively for soil samples collected from Fluvisols and Vertisols areas of the AIS. Regarding the soil sampling depth, the mean ECe values ranged from 0.54 to 3.8 dS/m at 0-30 and 0.67 to 3.62 dS/m at 30-60 cm for non-saline class, while it ranged from 4.9 to 15.72 dS/m at 0-30 and from 5.9 to 21.8 dS/m at 30-60 cm soil depth for saline soil class in Fluvisols area. In Vertisols, ECe ranged from 0.7 to 3.9 dS/m at 0-30 and from 0.75 to 3.4 dS/m at 30-60 cm soil depth for non-saline while it ranged from 4.30 to 5.4 at 0-30 cm for saline soil class in Vertisols areas. According to the classification system of the [19], out of 30 surface soil samples, about 16% and 84% of the soil samples are grouped under saline and non-saline soil classes, respectively.

3.5 Water soluble anions

The mean values of water soluble anions is presented in Appendix Tables 4 and 5. The mean value of bicarbonate ranged from 0.7 to 13.7 meq/l and from 0.8 to 17.7 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 4.5 to 15.3 meq/l and from 4.8 to 16. 2 meq/l at 0 -30 and 30-60 cm, respectively in Vertisols areas. Chloride ranged from 3.4 to 106.8 meq/l and from 5.6 to 158.7 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 7.8 to 57.9 meq/l and 9.1 to 26.3 meq/l at 0-30 and 30-60 cm, respectively in Vertisols areas. Sulfate ranged from 0.2 to 9.7 meq/l and from 0.2 to 10.2 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 0.3 to 2.9 meq/l and 0.4 to 3.4 meq/l at 0-30 and 30-60 cm, respectively in Vertisols areas. Carbonate was in trace range at all sampling points and depths in both soil types. Crop yields are affected when Cl ion in saturated extracts was 710 me/l or 354.6 mg/l [26], but the Cl concentration was lower than the lower restriction limit at all sampling points in this study. The usual range for carbonate content in irrigation water is from 0 to 30 mg/l and that of bicarbonate is 61 mg/l. based on that carbonate and bicarbonate content in most samples were lower than the restriction limits. The usual range of SO_4^{2-} in irrigation water is 8.3 me/l. Thus, its content is lower than the restriction limit.

Commented [D7]: need table for chemical analysis of irrigation water with quality (classification USDA)

3.6 Water soluble cations

The mean values of three months laboratory analysis result of water soluble cations (Ca, Mg, Na and K) for the soil samples collected from thirty different points in both soil types, with two sampling depths (0 - 30 cm and 30-60 cm) is presented in Appendix Tables 4 and 5. The mean values of calcium (Ca) ranged from 3.1 to 45.1 meq/l and from 2.4 to 58.8 meq/l at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 2 to 14.9 meq/l and from 1.8 to 10.1 meq/l at 0-30 and 30-60 cm, respectively in Vertisols areas. Magnesium (Mg) ranged from 1.2 to 18.1 meq/l and from 1.1 to 24.9 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 0.6 to 7.9 meq/l and from 0.7 to 5.8 meq/l at 0-30 and 30-60 cm, respectively in Vertisols areas. Sodium (Na) ranged from 0.6 to 56.8 meq/l and from 0.6 to 88.8 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 5.7 (AIP-46) to 43.1 meq/l and from 6.5 to 23.9 meq/l at 0-30 and 30-60 cm, respectively in Vertisols areas. Potassium (K) ranged from 0.7 to 7.3 meq/l and from 0.4 to 5.7 meq/l at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 0.4 to 1.1 meq/l and from 0.6 to 1.9 meq/l at 0-30 and 30-60 cm respectively, in Vertisols areas.

3.7 Sodium adsorption ratio

The calculated mean value of SAR for the soil samples taken from different field cover in both Fluvisols and Vertisols area at two sampling depths (0-30 and 30-60cm) is presented in the Appendix Tables 4 and 5. As shown on the table, the mean SAR values ranged from 1.7 to 18.2 and from 2.5 to 22.3, for the soil samples taken at 0-30 and 30-60 cm sampling depths, respectively in Fluvisols areas, while it ranges from 2.8 to 14.6 and from 3 to 9 for the soil samples taken at 0-30 and 30-60 cm sampling depths, respectively in Vertisols areas.

According to [27] classification, taking the SAR values of the saturated paste extract at a soil depth of 0-30 cm, soil samples taken near AIP-GH and AIP-41, in Fluvisols and near AIP-46 in Vertisols area were grouped under non-sodic with SAR values less than 3, while soil samples taken near AIP-F114, AIP-8-2, AIP-8-1, AIP-PA-2, AIP-B30, AIP-60, AIP-6, AIP-3, AIP-18, AIP-19, AIP-7, AIP-28, AIP-9, AIP-60 and AIP-40 in Fluvisols areas and soil samples taken from Vertisols areas near AIP-F300 and AIP-12 are classified as very slightly sodic class with mean SAR values ranging from 3 to 7. The soil samples taken near AIP-14 and AIP-32 in Fluvisols and near AIP-64, AIP-PK-6, AIP-PK-5, AIP-PK-4, AIP-F201 and AIP-25 in Vertisols areas are grouped under slightly sodic soil class with mean SAR values ranging between 7 and 13, while the remaining soil samples taken near AIP-10-1 and AIP-10 in Fluvisols areas were grouped under strongly sodic soil class with mean SAR values showed above 13. Generally out of 21 soil samples taken from Fluvisols areas at 0-30 cm soil depth, about 9.52, 71.43, 9.52 and 9.52% of the soil samples are grouped under non-sodic, very slightly sodic, slightly sodic and sodic soil class, respectively. Similarly, out of nine soil samples taken from Vertisols area at the same sampling depth, about 22.22, 66.67 and 11.11% of the soil samples are grouped under non-sodic, very slightly sodic and slightly sodic class, respectively.

3.8 Residual sodium carbonates

The calculated three months mean values of residual sodium carbonate (RSC) is presented in Appendix Tables 4 and 5. The result shows, the mean value of RSC varies among different sampling points. The RSC ranges from -51.2 to 7.1 and -76.5 to 8.4 meq/l at 0-30 and 30-60 cm soil depths, respectively in Fluvisols areas, while it ranges from -11.7 to 9 and from - 8 to 10.1 meq/l at 0-30 cm and 30-60 cm soil sampling depths, respectively in Vertisols areas. According to [28, 29], about 47.62 and 57.14 in Fluvisols and 44.44 and 44.44% in Vertisols areas of the soil samples revealed RSC values less than zero at depths of 0-30 and 30-60 cm, respectively which will not have impact on SAR values of soil. But about 4.76, 14.29 and 33.33% and 0.00, 14.29 and 28.57% of the soil samples taken at 0-30 cm and 30-60 cm depth, respectively the RSC values have a moderate, high and very high effect on SAR in Fluvisols areas of AIS. Similarly about 0.00, 11.12 and 44.44% of the soil samples taken at 0-30 cm and 0.00, 11.12 and 44.44% at 30-60 cm depth, the RSC values will have a moderate, high and very high effect on soil SAR values with its values ranging from 0-1.25, 1.25 to 2.5 and greater than 2.5 meq/l, respectively in Vertisols areas.

3.9 Exchange property of the fluvisols and vertisols

The other important characteristics of soil is its exchange property. The mean values of soil exchangeable cations (Ca, Mg, Na and K) for the soil samples collected from both soil types, with two sampling depths (0 -30 cm and 30-60 cm) is presented in Appendix Tables 4 and 5. The mean values of calcium (Ca) ranged from 41.7 to 60.7 and from 37.3 to 61.7 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 41.7 to 52 and from 42.3 to 54.7 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Vertisols areas. Magnesium (Mg) ranged from 6.7 to 18 and from 5.7 to 13 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 7.7 to 17.3 and from 8.7 to 14 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Vertisols areas. Sodium (Na) ranged from 3.9 to 25.7 and from 2.9 to 32.5 cmol $_{(+)}$ kg-1 at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 5.6 to 12.6 and from 6.1 to 11.8 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Vertisols areas. Potassium (K) ranged from 2.4 to 5.5 and from 1.8 to 4.1 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm, respectively in Fluvisols, while it ranged from 2.9 to 4.1 and from 2.1 to 3.8 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm respectively, in Vertisols areas. The soils of study area revealed presence of higher exchangeable cations, which may be associated with absence of adequate rainfall to leach the exchangeable basic cations from the root depth of the soil. The result is in line with the findings of [11].

3.10 Cation exchange capacity

The mean values of cation exchange capacity (CEC) for soil samples taken from Fluvisols and Vertisols area is presented in Appendix Tables 4 and 5, respectively. The mean values of CEC ranged from 41.6

to 64.3 and from 39.7 to 85.2 cmol $_{(+)}$ kg^{-1} at 0-30 cm and 30-60 cm soil depths, respectively in Fluvisols areas. It ranged from 48.4 to 60.4 and it varied from 43.1 to 64.2 cmol $_{(+)}$ kg^{-1} at 0-30 and 30-60 cm soil sampling depths, respectively in Vertisols area. Relatively higher mean CEC values of 53.51 and 52.41 cmol (+) kg-1 were recorded in Vertisols as compared to 50.51 and 51.24 cmol $_{(+)}$ kg-1 in Fluvisols at 0-30 and 30-60 cm depths, respectively. This may be associated with presence of higher clay contents in Vertisols as compared to in Fluvisols. The result is in line with findings of [30] who stated that Cation exchange sites are found primarily on clay minerals and organic matter (OM) surfaces. According to [31] the mean value of CEC was at very high range for both soil types.

3.11 Classes of salt affected soils

The guidelines outlined by [19] for salt affected soils classification uses pH, ECe and SAR as classifying parameters. The author used ECe below and greater than 4 dS/m for non- saline non-sodic (normal soil) and saline soil, respectively. Sodium adsorption ratio (SAR) greater than 13 and ECe less than 4 dS/m for sodic soil and ECe greater than 4 dS/m and SAR greater than 13 for saline sodic soil class.

According to [19] classification, about 71.43, 19.05 and 9.52% of the sampling points in Fluvisols and around 77.78, 11.11 and 11.11% of the sampling points in Vertisols area were grouped to normal soil, saline and saline-sodic soil classes, respectively. The extent of salinity is higher in Fluvisols area as compared to Vertisols area. This may be due to the coarse texture nature and low clay content in Fluvisols which favors movement of solutes upward from saline ground water which induces surface accumulation of salt materials whereas high exchange capacity of Vertisols hinder accumulation of soluble salts. Similar results was reported by [9], who stated that Fluvisols have large pores and coarse soil texture, the solute transport to soil surface that forms salt crust is higher than in Vertisols which have very fine pores and fine soil texture

3.12 Temporal trend of soil electrical conductivity

The ECe values for Fluvisols area varied with depth and among months under different land and irrigation management practice (Figures 3 (A, B and C)). The ECe values showed an increasing trend at both sampling depths except AIP-60, which showed a decreasing trend throughout the sampling seasons in Fluvisols areas, where the field were covered by cotton crop (Figure 3 (A)). The reason may be due to high evaporation rate during the sampling months and absence of irrigation water application to leach the salt crust accumulated due to capillary rise from ground water and irrigation water, from the surface of the earth to the lower depths of the soil where agreed with [32]. The authors suggested that, high temperature and a little rainfall are always conducive for accumulation of salts in the surface and sub-surface of the soil because the salts cannot be leached down completely. Moreover, net water movement in the soil remains upwards. The water brings dissolved salts with it, evaporates and leaves these salts on the surface or nearer underneath. Thus, this process slowly and gradually builds up the saline soils. The process is always active, especially in dry seasons in arid and semi-arid climates.

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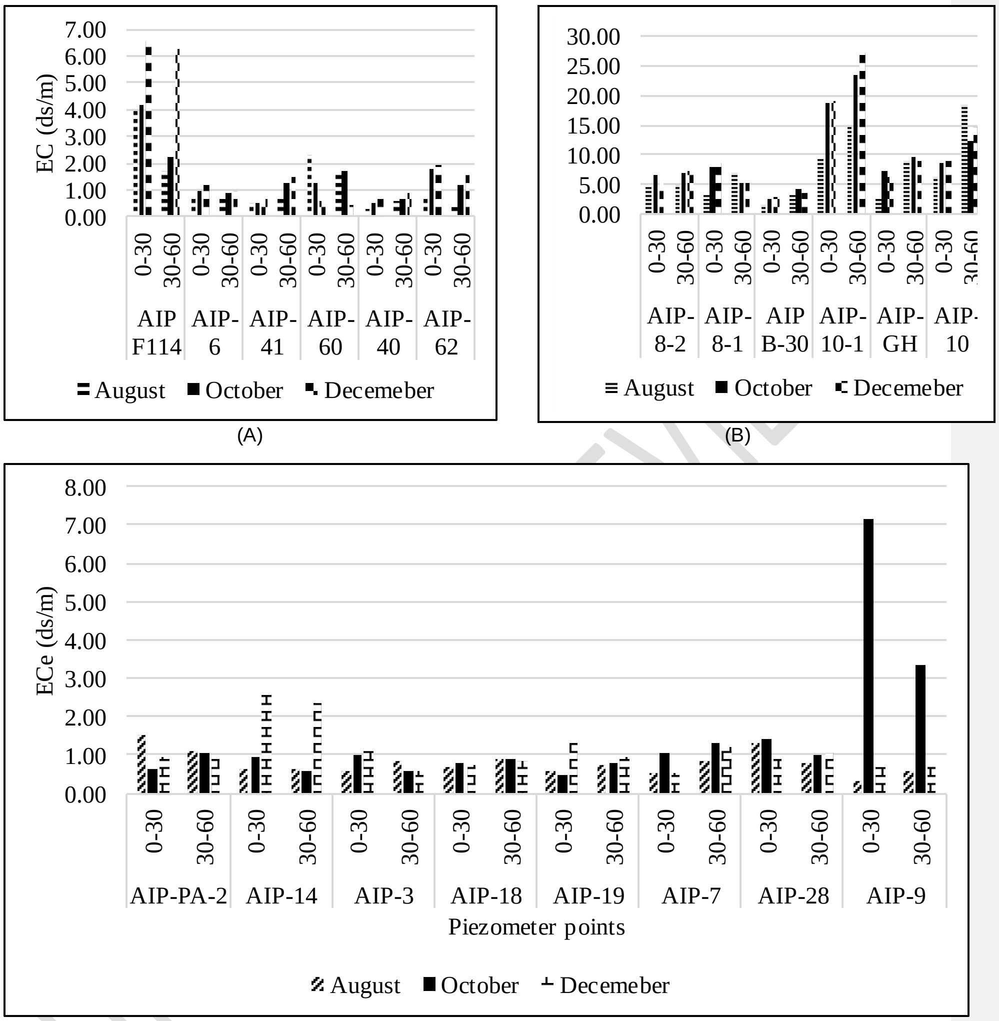

(A) (B)

(C)

Figure 3 Temporal trend of soil electrical conductivity in Fluvisols (A) cotton fields, (B) trees and shrubs fields and (C) sugarcane fields

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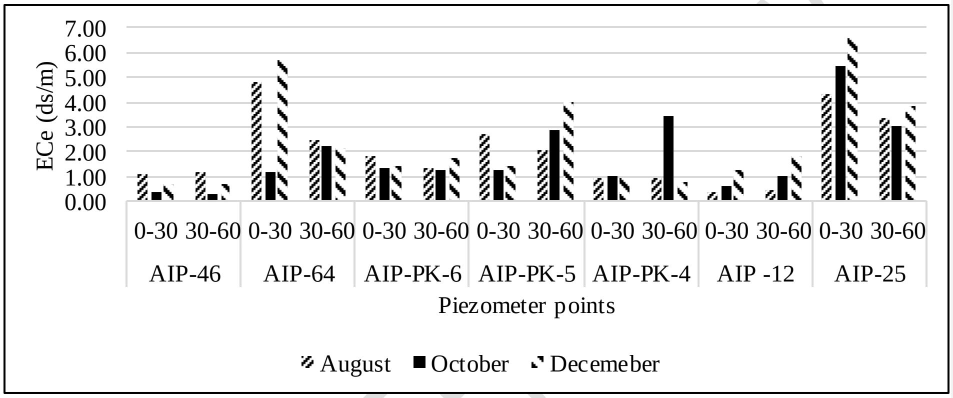
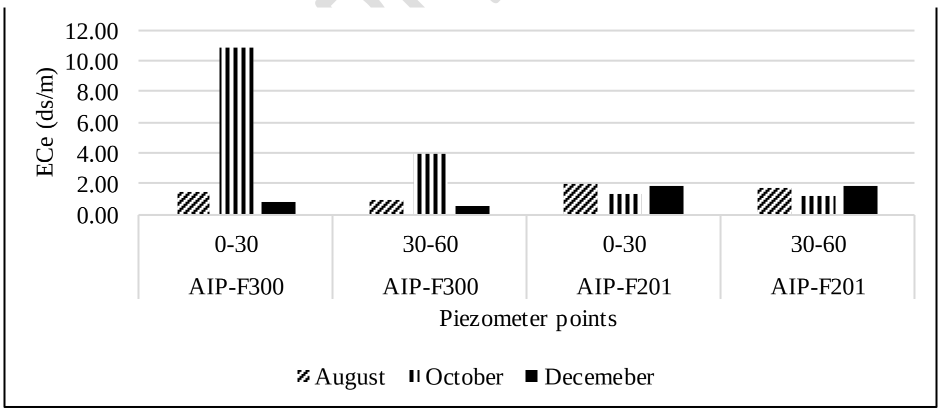
As shown in Figure 3 (B) samples collected from sugarcane fields showed an increasing trend in AIP-14, AIP-19 and AIP-7 in both sampling depths, while a decreasing trend has been recorded at AIP-PA-2 in both sampling depths. In contrary to the above, an increasing (0-30 cm) and decreasing (30-60 cm) trends occurred at AIP-3 and AIP-18, while a decreasing (0-30 cm) and increasing (30-60 cm) trends has been demonstrated at AIP-28 and irregular trend has been shown near AIP-9 at both sampling depths. The primary reason for existence of non-uniform change in the sampling season could be due to the variation in the irrigation water application frequency and duration at the sampling fields since the crop planting dates, at different location was not conducted at the same time.

Similar to that occurred in cotton fields, the ECe values of the soil covered by shrubs and tree plants showed an increasing trend along the sampling months (Figure 3 (C)). The reason might be the absence of application of irrigation water to those fields to leach salt crusts that were developed near the surface of the earth, since the field is not used as irrigation purpose.

According to the three months data for the soil samples taken from Vertisols areas of AIS, the ECe values vary with depth and months in different field covers (Figure 4 (A and B)). The ECe values for the soil samples taken from sugarcane field showed an increasing trend (AIP-12 and AIP-25) both at 0-30 cm and 30-60 cm and decreasing trend (AIP-46) at both depths. But near AIP-64 AIP-PK-5 and AIPPK-6, the ECe revealed an increasing and decreasing trend at 0-30 cm and 30-60 cm depths, respectively. In other points irregular trends has been occurred along the sampling seasons (Figure 4 (A)).



(A)



(B)

Figure 4 Temporal trend of soil electrical conductivity at sugarcane fields (A) and cotton and forage fields (B) in Vertisols areas

Commented [D12]: add the peozmetric depth of the water table as Z axis on the figure to support your discussion

Figure 4 (B) shows the temporal trend of soil electrical conductivity for the soil samples collected from forage (AIP-F300) and cotton fields (AIP-F201) in Vertisols area. The result indicated, an irregular trend of the ECe were observed at the soil samples taken from the filed covered by cotton and forage field, due to the variation in irrigation water application in both fields.

Generally, the soil ECe at the root zone varied with depth and irrigation water management and it agreed with the report of [33]. They obtained that the soil salt content varied with amount of irrigation water near the soil surface to many times that of the applied water at the bottom of the rooting depth. Salt concentration increases with depth due to plants extracting water but leaving salts behind in a greatly reduced volume of soil water. Each subsequent irrigation pushes (leaches) the salts deeper into the root zone where they continue to accumulate until leached. The lower rooting depth salinity will depend upon the leaching that has occurred. Following an irrigation, the most readily available water is in the upper root zone which is a low salinity area. As the crop uses water, the upper root zone becomes depleted and the zone of most readily available water changes towards the deeper parts as the time interval between irrigations is extended. These lower depths are usually more salty [33]. Depending on the above argument the soil salt content is directly related with the irrigation practice and the mean salt content in irrigated area. The mean ECe values in Fluvisols were 3.11 and 3.81 ds/m at 0-30 and 30-60 cm, respectively while it were 2.35 and 1.9 ds/m in Vertisols at 0-30 and 30-60 cm, respectively. But the soil samples taken from non-irrigated farm revealed an ECe values of 0.72 and 1.6 ds/m at 0-30 and 30-60 cm sampling depths which were less than that of in irrigated farms.

3.13 Temporal trend of sodium adsorption ratio

The temporal trend of three months SAR values for the soil samples taken at surface layer (0-30 cm) from Fluvisols areas of Amibara irrigation scheme is presented in Figure 5. The soil samples taken from fields covered by cotton crop near AIP-F114, AIP-6, AIP-41, AIP-40, AIP-62, revealed an increasing trend along the sampling season from August to December, while it showed a decreasing trend in soil sample taken near AIP-60. It showed an increasing trend in soil samples taken near piezometers AIP-14, AIP-18, AIP-19 and AIP-7) while it revealed a decreasing trends in sampling points near AIP-PA-2, AIP-3, AIP-28 and AIP-9 at surface soil (0-30 cm) which located in sugarcane fields. In contrary to the above, the SAR values for the soil samples collected from the field covered by shrub and tree plants showed an increasing trend near all piezometers AIP-8-1, AIP-8-2, AIP-GH, AIP-B30, AIP-10-1 and AIP-10 at the surface layer of soil.

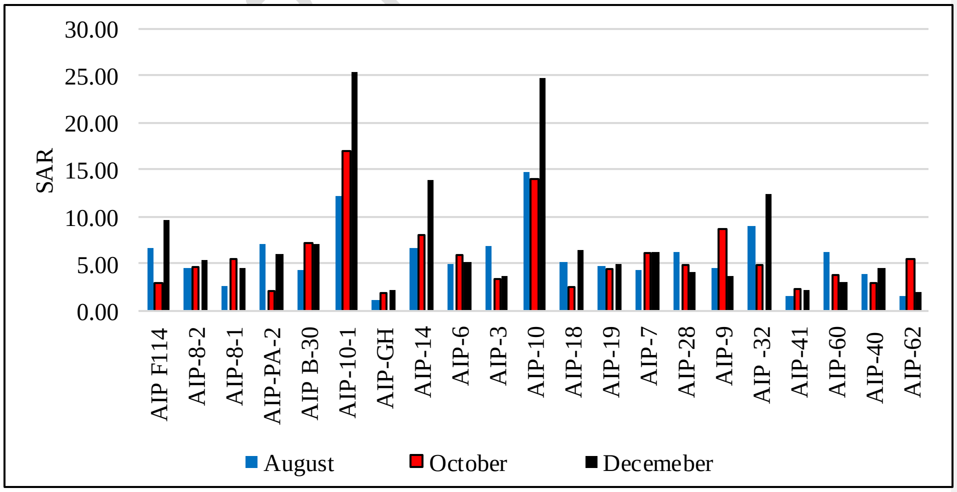
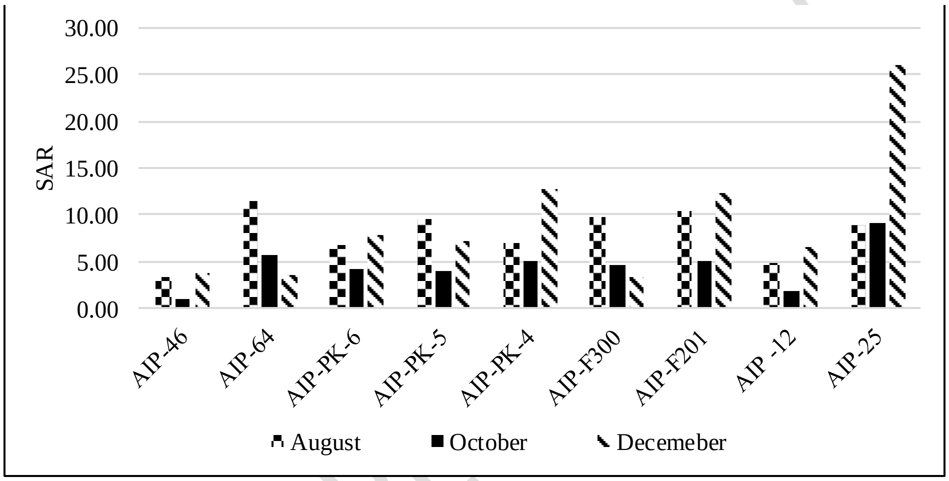


Figure 5 Temporal trend of soil SAR values at 0-30 cm soil depth in Fluvisols areas

Commented [D13]: Table 4 shows higher SAR values for piezometric points AIP-10 and AIP-1-10 according to first soil sampling

Similar to that in Fluvisols, the temporal trend of three months SAR values for the soil samples taken at the surface layer of soil (0-30 cm) from Vertisols areas of Amibara irrigation scheme is presented in Figure 6. The result showed, the SAR values for the samples collected from fields covered by sugarcane revealed an increasing trend at the samples taken near piezometers AIP-46, AIP-PK-6, AIP-PK-4, AIP-12 and AIP-25, while it revealed a decreasing trend near AIP-64 and AIP-PK-4. The soil samples collected from field covered by cotton, the SAR value revealed an increasing trend near AIP-F201, while it showed a decreasing trend for the soil samples collected from grass field near AIP-F300 along the sampling seasons from August to December.



compared with figure 5.

Figure 6 Temporal trend of soil SAR values at 0-30 c m soil depth in Vertisols areas

3.14 Impact of irrigation on soil properties

Commented [D14]: I suggest including irrigation frequency and depth of applied irrigation water

The change in percentage of each soil chemical properties indicates the higher positive increment in irrigated farm as compared to non-irrigated land (Table 1). Higher increment of each soil chemical properties in irrigated farm compared to non-irrigated farm may be due to development of salt affected soils in irrigated farm due to addition of different cations and anions from irrigation water and upward movement of these cations and anions through capillary rise from the soil parent material. This result is in agreement with the findings of [34] who stated that irrigation salinity occurs due to increased rates of leakage and groundwater recharge causing the water table to rise. Rising water tables can bring salts into the plant root zone which affects both plant growth and soil structure. The salt remains behind in the soil when water is taken up by plants or lost to evaporation.

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Higher changes were observed for most soil chemical properties in surface than that of the subsurface soil depth except for HCO_3^-, Cl^-, Ca and Mg in Fluvisols and for HCO_3^-, Cl^- and Ca in Vertisols. This may be associated with the accumulation of basic cations and water soluble anions on the surface of the earth through high evapotranspiration and low leaching of salts from the surface (low rainfall) that added from irrigation water and capillary rise from saline shallow ground water. The result is in agreement with the findings of [28] who indicated that capillary action brings saline groundwater to the surface, where evaporation and plant transpiration removes soil water, causing salt to precipitate and deposit in the upper layers of the soil profile.

Higher changes in percentage of each parameter were observed in Fluvisols than in Vertisols and the higher accumulation of these soil parameters in Fluvisols as compared to Vertisols may be associated with its soil texture. The result is in line with the findings of [11] who reported that Fluvisols have more silt and sand than Vertisols and the formation of salt affected soils was associated with high silt and sand fractions which could be due to larger pore sizes that favors more permeability for solute transport and easy for evaporation under Fluvisols.

Table 1 Mean comparison of soil properties between non-irrigated and irrigated areas

Soil properties	Non-irrigated farm		Irrigated farm				Change in percentage from the non-irrigated farm			
			Fluvisols		Vertisols		Fluvisols		Vertisols	
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
pH	7.80	7.90	8.14	8.08	8.17	8.12	4.36	2.28	4.74	2.78
ECe	0.72	1.60	3.11	3.81	2.35	1.90	331.94	138.13	226.3	18.75
HCO_3	3.50	2.00	8.57	7.73	8.47	8.56	144.86	286.50	142	328
Cl	3.00	1.50	25.93	32.08	20.75	17.22	764.33	2038.6	591.6	1048
SO_4	0.21	0.52	2.56	2.70	1.54	1.44	1119.0	419.23	633.3	176.9
Ca	1.50	1.00	10.28	11.39	6.81	5.49	585.33	1039	354	449
Mg	2.00	2.00	4.62	5.67	3.00	2.81	131.00	183.50	50	40.50
Na	2.55	6.29	15.97	19.35	15.59	12.76	526.27	207.63	511.3	102.8
K	0.32	0.59	1.19	0.89	0.80	0.88	271.88	50.85	150	49.15
SAR	1.34	1.83	6.28	6.75	7.28	6.73	368.66	268.85	443.2	267.7

4. CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to investigate the impact of depth of water table and groundwater quality on the occurrence of salt affected soil in Amibara irrigation scheme. A total of 182 soil samples were collected at (0-30 cm and 30-60 cm) depths from irrigated and non-irrigated fields. Based on the laboratory analysis result, higher spatial variability in salinity and sodicity of soil samples observed. Generally the soil revealed existence of high content of calcium carbonate. The soil is moderately alkaline to strongly alkaline in reaction, and significant points of the area have an ECe values ranging in saline and the other points have a potential to be changed to saline conditions in a short time. High values of SAR were recorded in the sampling points. The trend of soil electrical conductivity and sodium adsorption ratio were also varied temporally. In fields which were not continuously covered by field crops, an increasing trends were observed towards dry season. Higher increment of each soil chemical properties were observed in irrigated farm compared to non-irrigated farm, at surface than subsurface soil depth and in Fluvisols than in Vertisols. The irrigation water and saline ground water may be a potentially contributing factors for the occurrences of salt affected soils in the study areas along the sampling seasons. Therefore the amount of water that applied to the field should be based on the crops water requirement, soil types and properties to reduce ground water recharge and continuous maintenance of surface and subsurface drainage structures should be implemented to remove excess water from the system and to regulate ground water fluctuation.

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COMPETING INTERESTS

Authors have declares that no competing interests are exist.

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APPENDICES

Appendix Table 1 Long-term average climatic data of the study area (1970-2017) obtained from Werer Station

No.	month	Total Rainfall (mm)	Minimum Temperature (°C)	Maximum Temperature (°C)	Mean Temperature (°C)	Evapo-transpiration (mm)
1	January	9.9	14.2	29.3	21.8	214.6
2	February	22.7	15.4	34	24.7	194.1
3	March	133.1	18	36.6	27.3	255.2
4	April	31.5	20.1	37.7	28.9	235.4
5	May	105.2	17.1	35.6	26.4	247.6
6	June	16.1	17.8	36.8	27.3	282.2
7	July	165.7	14.9	23.6	19.3	224.2
8	August	159.1	14.4	22.5	18.5	193
9	September	72.4	21.1	35.6	28.4	191.6
10	October	11.9	19.6	34.8	27.2	222.7
11	November	6.5	15.9	33.8	24.9	255.4
12	December	2.4	13.5	31.3	22.4	192.7
	Sum	736.5	202	391.6	296.8	2708.7
	Average	61.4	16.8	32.6	24.7	225.7

Appendix Table 2 The percentage content of calcium carbonate and soil textural class in Fluvisols areas

No.	Piezometer points	Depth(cm)	% of $CaCO_3$	Rating	Individual particles content (%)			Textural class
					Clay	silt	sand	
1	AIP-F114	0-30	13	very high	41.2	33.6	25.2	clay (C)
		30-60	16	very high	39.2	35.6	25.2	clay loam (CL)
2	AIP-8-2	0-30	8	high	41.2	29.6	29.2	clay (C)
		30-60	9	High	47.2	31.6	21.2	clay (C)
3	AIP-8-1	0-30	5.5	high	41.2	33.6	25.2	clay (C)
		30-60	9.5	High	47.2	27.6	25.2	clay (C)
4	AIP-PA-2	0-30	36	very high	67.2	15.6	17.2	clay (C)
		30-60	37.5	very high	69.2	13.6	17.2	clay (C)
5	AIP-B-30	0-30	16.5	very high	65.2	15.6	19.2	clay (C)
		30-60	21	very high	71.2	13.6	15.2	clay (C)
6	AIP-10-1	0-30	9	high	37.2	41.6	21.2	clay loam (CL)
		30-60	10	High	13.2	67.6	19.2	silt loam (SiL)
7	AIP-GH	0-30	8	high	35.2	35.6	29.2	clay loam (CL)
		30-60	7.5	High	31.2	41.6	27.2	clay loam (CL)
8	AIP-14	0-30	9.5	High	50.4	14.4	35.2	clay (C)
		30-60	11	very high	44.4	20.4	35.2	clay (C)
9	AIP-6	0-30	11	Very high	56.4	28.4	15.2	clay (C)
		30-60	12	very high	56.4	30.4	13.2	clay (C)
10	AIP-3	30-60	4.5	medium	40.4	24.4	35.2	clay (C)
		0-30	7.5	High	52.4	24.4	23.2	clay (C)
11	AIP-10	0-30	7.5	High	36.4	40.4	23.2	clay loam (CL)
		30-60	8.5	High	48.4	36.4	15.2	clay (C)
12	AIP-18	0-30	9.5	High	66.4	18.4	15.2	clay (C)
		30-60	10	High	66.4	18.4	15.2	clay (C)
13	AIP-19	0-30	8	high	60.4	24.4	15.2	clay (C)
		30-60	8	high	46.4	38.4	15.2	clay (C)
14	AIP-7	0-30	3.5	medium	54.4	26.4	19.2	clay (C)
		30-60	3.5	medium	60.4	18.4	21.2	clay (C)
15	AIP-28	0-30	2.5	medium	62.4	22.4	15.2	clay (C)
		30-60	3	medium	64.4	22.4	13.2	clay (C)

16	AIP-9	0-30	2.5	medium	62.4	20.4	17.2	clay (C)
		30-60	3	medium	68.4	18.4	13.2	clay (C)
17	AIP-32	0-30	3	medium	50.4	26.4	23.2	clay (C)
		30-60	3.5	medium	36.4	40.4	23.2	clay loam (CL)
18	AIP-41	0-30	3	medium	66.4	20.4	13.2	clay (C)
		30-60	5.5	high	64.4	20.4	15.2	clay (C)
19	AIP-60	0-30	5.5	high	44.4	36.4	19.2	clay (C)
		30-60	6.5	high	38.4	38.4	23.2	clay loam (CL)
20	AIP-40	0-30	3	medium	58.4	24.4	17.2	clay (C)
		30-60	3.5	medium	48.4	28.4	23.2	clay (C)
21	AIP-62	0-30	2.5	medium	62.4	22.4	15.2	clay (C)
		30-60	3	medium	64.4	22.4	13.2	clay (C)
22	Non-irrigated.	0-30	9.5	high	28.4	30.4	41.2	clay loam (CL)
		30-60	10	high	38.4	26.4	35.2	clay loam (CL)

Appendix Table 3 The percentage content of calcium carbonate and soil textural class in Vertisols areas

No.	Piezometer points	Depth (cm)	% of $CaCO_3$	Rating	Individual particles content (%)			Textural class
					Clay	silt	sand	
1	AIP-46	0-30	9	high	61.2	19.6	19.2	clay (C)
		30-60	13	very high	61.2	19.6	19.2	clay (C)
2	AIP-64	0-30	23.5	very high	55.2	25.6	19.2	clay (C)
		30-60	25.5	very high	55.2	23.6	21.2	clay (C)
3	AIP-PK-6	0-30	7.5	high	65.2	19.6	15.2	clay (C)
		30-60	10	high	67.2	11.6	21.2	clay (C)
4	AIP-PK-5	0-30	8	high	67.2	9.6	23.2	clay (C)
		30-60	8.5	high	67.2	15.6	17.2	clay (C)
5	AIP-PK-4	0-30	7	high	61.2	21.6	17.2	clay (C)
		30-60	7.5	high	65.2	15.6	19.2	clay (C)
6	AIP-F300	0-30	2	medium	66.4	20.4	13.2	clay (C)
		30-60	6	high	70.4	16.4	13.2	clay (C)
7	AIP-F201	0-30	6.5	high	58.4	28.4	13.2	clay (C)
		30-60	7	high	56.4	30.4	13.2	clay (C)
8	AIP -12	0-30	2	medium	66.4	22.4	11.2	clay (C)
		30-60	2.5	medium	70.4	16.4	13.2	clay (C)
9	AIP-25	0-30	2.5	medium	64.4	22.4	13.2	clay (C)
		30-60	3.5	medium	62.4	22.4	15.2	clay (C)

Appendix Table 4 Mean values of soil chemical characteristics in Fluvisols areas

No.	Piezometer points	Depth (cm)	pH	ECe (ds/m)	All water soluble cations and anions (meq/l)									Exchangeable cations and CEC [cmol$_{(+)}$kg^{-1}]				
					Ca	Mg	Na	K	HCO_3	Cl	SO_4	SAR	RSC	Ca	Mg	Na	K	CEC
1	AIP-F114	0-30	7.7	4.9	16.3	6.3	22.7	1.1	9.2	32.0	2.5	6.5	-13.4	45.0	7.3	8.3	3.4	47.0
		30-60	7.7	3.4	19.4	9.1	19.6	1.1	11.0	23.5	3.0	5.2	-17.5	45.3	6.0	7.0	2.6	45.4
2	AIP-8-2	0-30	7.9	5.5	27.5	13.5	22.4	3.1	9.5	53.7	4.4	4.8	-34.5	52.3	11.0	5.1	4.6	54.0
		30-60	7.9	6.3	29.2	13.5	35.3	1.9	7.3	61.8	5.8	7.7	-35.3	52.3	7.3	8.8	2.7	53.0
3	AIP-8-1	0-30	8.0	6.7	23.7	15.0	18.9	4.3	8.7	70.3	8.7	4.2	-51.2	53.0	8.0	5.2	5.5	51.5
		30-60	7.9	5.9	22.9	15.0	29.8	1.6	6.3	60.7	10.2	6.7	-31.6	49.0	8.3	6.8	2.7	50.0
4	AIP-PA-2	0-30	8.3	1.0	4.2	2.7	9.0	0.7	13.0	13.2	0.2	5.1	7.1	52.3	10.3	6.7	3.2	52.9
		30-60	8.2	1.0	3.9	1.8	8.1	0.6	7.6	12.3	0.3	5.1	2.3	54.0	12.7	9.1	2.8	65.2
5	AIP-B-30	0-30	8.1	2.3	11.9	1.3	16.0	1.2	7.3	16.3	1.6	6.2	-5.8	49.0	11.0	8.7	4.9	52.9
		30-60	8.0	3.6	10.8	4.2	21.4	1.1	6.8	32.3	2.9	7.9	-8.2	45.3	11.0	12.7	3.6	53.2
6	AIP-10-1	0-30	7.9	15.7	19.2	9.5	65.4	2.3	12.7	106.8	9.7	18.2	-16.0	60.7	12.3	25.7	4.6	64.3
		30-60	8.1	21.8	22.4	11.5	88.8	1.7	13.8	158.7	9.0	21.7	-20.0	61.7	13.0	32.5	4.1	85.2
7	AIP-GH	0-30	7.8	5.4	45.1	18.1	9.5	2.7	13.7	63.0	4.1	1.7	-49.6	53.3	6.7	4.9	5.5	50.0
		30-60	7.6	9.1	58.8	24.9	16.3	1.6	7.2	106.5	3.3	2.5	-76.5	58.0	7.3	6.7	3.3	55.6
8	AIP-14	0-30	8.5	1.4	3.1	1.2	14.4	0.8	9.0	20.8	3.2	9.6	4.6	46.7	9.3	12.6	4.2	52.9
		30-60	8.3	1.2	3.6	1.3	10.4	0.9	8.4	8.6	3.0	6.4	3.5	45.3	10.7	8.6	4.1	50.5
9	AIP-6	0-30	8.4	1.0	4.4	1.7	9.5	0.7	12.0	15.0	1.3	5.4	5.9	43.7	18.0	8.3	3.8	54.0
		30-60	8.4	0.9	5.0	4.2	10.7	0.8	17.7	12.7	0.8	5.0	8.4	43.0	11.3	11.3	3.8	49.6

Appendix Table 4 Continued

No.	Piezo-meter points	Depth (cm)	pH	ECe (ds/l)	All soluble cations and anions (meq/l)									Exchangeable Cations and CEC [$cmol_{(+)}kg^{-1}$]				
					Ca	Mg	Na	K	HCO3	Cl	SO4	SAR	RSC	Ca	Mg	Na	K	CEC
10	AIP-3	0-30	8.1	0.9	4.8	2.2	7.7	0.7	8.1	7.6	0.7	4.6	1.7	49.7	13.0	5.4	3.1	52.5
		30-60	8.2	0.7	7.2	4.1	6.0	0.7	7.7	7.8	1.1	2.5	-3.7	46.7	12.7	3.4	2.3	46.6
11	AIP-10	0-30	7.9	8.0	16.2	5.6	56.8	2.4	5.8	54.8	7.3	17.8	-16.0	41.7	12.7	14.1	3.4	51.1
		30-60	7.9	15.1	20.4	7.6	83.3	2.4	6.2	91.6	7.7	22.3	-21.8	39.0	7.3	24.7	3.7	68.2
12	AIP-18	0-30	8.3	0.7	4.9	1.5	8.0	0.7	10.1	11.1	2.4	4.7	3.7	51.7	12.0	6.8	3.5	53.1
		30-60	8.2	0.9	2.4	1.1	9.8	0.4	5.2	5.7	0.9	7.6	1.7	51.0	7.0	7.1	3.0	48.8
13	AIP-19	0-30	8.4	0.79	6.5	4.3	0.7	2.9	0.7	6.2	0.3	4.7	3.0	48.0	14.7	4.8	3.7	50.3
		30-60	8.3	0.82	6.9	5.6	1.6	2.8	0.8	7.3	0.4	5.6	3.2	46.7	10.3	4.0	3.0	43.6
14	AIP-7	0-30	8.2	0.70	9.6	7.9	0.6	2.7	0.8	7.4	0.4	5.5	6.1	45.3	9.0	4.4	3.7	42.6
		30-60	8.2	1.11	9.4	10.2	1.2	3.2	1.5	7.6	0.5	5.2	4.1	48.7	12.3	4.4	3.0	48.5
15	AIP-28	0-30	8.0	1.20	6.6	7.7	1.0	3.4	2.1	8.2	0.4	5.1	1.1	47.3	8.3	5.7	4.1	46.4
		30-60	8.2	0.95	5.1	8.0	1.0	3.2	0.8	8.0	0.4	6.3	2.3	46.7	6.7	5.4	3.4	43.5
16	AIP-9	0-30	7.9	2.71	7.2	15.4	1.0	3.7	1.3	9.2	0.8	5.7	2.2	46.0	15.0	6.7	4.1	51.0
		30-60	8.1	1.56	8.5	19.7	1.4	3.9	1.7	7.6	0.7	5.0	2.6	37.3	12.0	6.2	3.5	40.0
17	AIP-32	0-30	8.1	2.57	5.4	18.0	0.8	7.3	2.5	19.6	0.7	8.8	-4.4	48.0	9.3	6.1	2.4	47.4
		30-60	8.1	1.76	5.2	12.7	0.6	4.8	4.6	12.2	0.6	5.8	-4.2	49.3	10.3	4.2	1.8	48.5
18	AIP-41	0-30	8.5	0.69	8.3	6.7	0.9	2.6	3.1	3.4	0.3	2.1	2.6	52.7	10.3	4.8	3.3	51.4
		30-60	8.0	0.56	4.8	6.9	0.6	3.1	2.4	6.6	0.3	4.0	-0.7	48.3	12.3	4.3	2.5	48.0
19	AIP-60	0-30	8.2	1.15	5.6	7.3	1.0	5.7	3.8	9.7	0.5	4.4	-3.9	43.0	10.7	3.9	3.0	41.5
		30-60	8.2	1.38	4.5	13.2	0.7	5.7	2.2	7.3	0.5	3.6	-3.5	47.7	5.7	3.9	2.9	42.2
20	AIP-40	0-30	8.2	1.28	3.5	5.1	1.0	2.3	2.1	5.6	0.4	3.8	-0.8	47.7	12.0	4.1	3.5	48.5
		30-60	8.1	0.48	5.0	8.8	0.7	3.7	5.1	5.2	0.3	2.5	-3.8	50.0	6.3	2.9	2.4	42.7
21	AIP-62	0-30	8.5	0.70	8.4	7.6	0.8	3.9	2.2	5.7	0.5	3.0	2.3	48.7	7.3	4.6	3.0	45.3
		30-60	8.2	1.48	7.9	6.4	0.8	2.9	1.8	4.9	0.2	3.2	4.2	46.7	11.7	5.2	2.5	47.7
22	Non-	0-30	7.8	0.72	3.5	3.0	0.2	1.5	1.0	2.5	0.3	1.3	1.0	57.0	3.0	2.0	0.7	56.0
	irrigated	30-60	7.9	1.60	2.0	1.5	0.5	2.0	2.0	6.3	0.6	1.8	-2.0	58.0	3.0	2.8	0.6	60.7

Appendix Table **5** Mean values of soil chemical characteristics in Vertisols areas

No.	Piezometer points	Depth (cm)	pH	ECe (ds/m)	All soluble cation and anions (meq/l)									Exchangeable cation and CEC [$cmol_{(+)}kg^{-1}$]				
					Ca	Mg	Na	K	HCO_3	Cl	SO_4	SAR	RSC	Ca	Mg	Na	K	CEC
1	AIP-46	0-30	8.4	0.7	3.2	3.2	5.7	0.7	15.3	10.8	1.3	2.8	9.0	49.0	15.0	6.7	3.2	54.8
		30-60	8.3	0.7	5.5	1.7	6.5	0.7	15.7	12.2	0.7	4.2	8.5	52.7	14.0	6.3	2.4	57.3
2	AIP-64	0-30	8.1	3.9	4.7	1.6	16.1	0.9	8.3	18.0	0.8	6.9	2.0	47.0	12.0	7.1	3.1	50.0
		30-60	8.0	2.3	2.6	2.1	14.0	0.9	6.3	15.7	2.3	8.9	1.7	52.0	8.7	7.4	2.1	51.0
3	AIP-PK-6	0-30	8.3	1.5	4.7	3.5	12.5	0.8	6.1	12.2	2.5	6.3	-2.1	48.0	10.3	10.3	3.9	53.2
		30-60	8.0	1.5	4.1	2.4	13.3	0.7	4.8	14.0	2.1	7.4	-1.7	50.3	10.7	9.9	3.2	54.3
4	AIP-PK-5	0-30	8.0	1.8	8.9	2.2	16.6	0.7	4.5	16.9	2.9	7.0	-6.7	51.0	13.0	11.5	4.1	60.4
		30-60	8.0	3.0	8.9	5.1	23.9	0.8	6.0	24.3	3.4	9.0	-8.0	51.3	13.3	11.8	3.8	60.2
5	AIP-PK-4	0-30	8.3	1.0	2.0	0.6	8.9	0.8	7.5	9.9	0.3	8.3	4.9	52.0	12.7	10.6	3.4	59.8
		30-60	8.1	1.7	1.8	0.7	7.7	0.6	5.3	9.1	0.4	6.9	2.8	54.3	9.7	11.8	2.9	58.5
6	AIP-F300	0-30	8.1	4.3	14.7	7.9	15.0	1.1	5.5	57.9	0.6	5.9	-10.6	46.3	10.0	9.7	4.0	50.4
		30-60	8.1	1.8	10.1	5.8	7.3	0.8	5.0	22.8	0.8	3.0	-6.4	42.7	9.3	7.0	3.0	43.1
7	AIP-F201	0-30	8.2	1.7	3.3	2.6	15.7	0.6	12.5	19.0	2.4	9.3	6.6	41.7	13.7	10.9	3.7	49.6
		30-60	8.2	1.6	4.1	2.0	13.3	0.8	16.2	18.3	0.4	7.6	10.1	42.3	10.0	8.0	2.7	46.0
8	AIP -12	0-30	8.3	0.8	4.8	1.4	6.7	0.4	9.2	7.8	0.6	4.4	3.0	42.0	17.3	5.6	3.3	48.4
		30-60	8.4	1.1	2.7	2.8	9.0	0.7	10.5	12.2	0.9	5.4	5.0	45.7	13.7	6.1	2.3	50.2
9	AIP-25	0-30	7.9	5.4	14.9	4.0	43.1	1.0	7.3	34.3	2.3	14.6	-11.7	51.3	7.7	12.6	2.9	55.0
		30-60	8.0	3.4	9.9	2.7	19.9	1.9	7.3	26.3	2.0	8.1	-5.3	54.7	8.7	4.8	2.5	51.1

NB. Carbonate is in the trace range at all sampling points

Appendix Table 6 Guidelines for classification of salt affected soils adapted from USSLS (1954)

Salt-affected soil classes	EC (dSm^{-1})	Soil pH	SAR	Soil physical condition
Non-saline non-sodic	< 4	< 8.5	< 13	Normal
Saline soil	> 4	< 8.5	< 13	Normal
Saline-sodic soil	> 4	> 8.5	> 13	Normal
Sodic soil	< 4	> 85	> 13	Poor