Groundwater and Surface Water Quality Status and Its Spatial and Seasonal Fluctuation in Amibara irrigated area of Ethiopia

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Abstract

Irrigated agriculture is a major human activity, which often leads to secondary salinization of land and water resources in arid and semi-arid conditions. Soil salinity is an enormous problem for agriculture under irrigation as it affects the growth and development of plants in Ethiopia; the problem is widespread in the rift valley areas where middle Awash and Amibara irrigated farms are present. Therefore, this study was conducted to investigate spatial variability and seasonal fluctuation of ground and surface water quality. Based on the existing piezometers points, additional ground water monitoring holes were repaired and installed at the previous points. Totally, about thirty monitoring piezometers were used in this study, which are found in both Fluvisols and Vertisols areas. A total of 155 water samples were collected at the months of August, September, October, November and December from ground water monitoring piezometers and Awash River, to evaluate the spatial variability and seasonal fluctuation of groundwater and Awash River water quality. Then, for all water samples, all salinity and sodicity parameters were determined in the laboratory. Based on the laboratory analysis results, the Awash River water quality is in the medium range for irrigation with regarding mean values of 1 ds/m ECw and 6.65 SAR. For the water of groundwater samples, collected from fluvisols area, the pH, ECw and SAR values ranged from 7.3 to 9.1, 1.31 to 13.1 and 2.86 to 66.98 with mean values of 8, 5.4 and 17.6, respectively, while the pH, ECw and SAR values ranged from 7.5 to 8.3, 0.9 to 7.68 and 3.87 to 11.37 with a mean values of 7.9, 3 and 6.2, respectively for groundwater samples collected from vertisol areas.

***Key-words**: ground water salinity and sodicity, Fluvisols and Vertisols*

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 (Rozema and Flowers, 2008). Once groundwater is in close proximity to the ground surface, capillary up flow results in the movement of water and salts towards the soil surface potentially leading to salt accumulation in the root zone. Soil salinization above the water table is therefore affected by capillary up flow, groundwater position, groundwater salinity and soil and crop characteristics (Soppe and Ayars, 2003; Hutmacher et al., 1996; King et al., 1995; Prathapar et al., 1992; Prathapar and Meyer, 1992).

Inefficient irrigation and drainage systems are major causes of excess leakage and increase the risk of salinity and waterlogging in irrigation areas. Irrigating with saline water adds salt to the soil and increases the need for applying more irrigation water to leach salts past the plant root zone (Cynthia, 2009).

Irrigated agriculture at Amibara Irrigation Project, located in the Middle Awash region, was started towards late sixties (Halcrow, 1982). The soils at the farm area were generally non-saline and groundwater table in the area was below 10 meters (Halcrow, 1983). 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 (Kidane et a*l.*, 2006).

Adequate knowledge on the spatial variability and temporal fluctuation of surface and groundwater quality is required to effectively manage the limited natural resources and maintain a viable agricultural industry that is highly dependent on conjunctive use of surface and ground waters with varying salinity levels (Kidane et al., 2006).; Hailay *et al.*, 2000).

Recent information on spatial variability and temporal fluctuation of surface and groundwater quality in Fluvisols and Vertisols conditions of the project area has not been reported sufficiently. Therefore, this study was conducted with the objective.

- To study the spatial variability and temporal fluctuation of groundwater and surface water quality under Fluvisols and Vertisols areas of Amibara area, Middle Awash, Ethiopia.

Materials and Methods

Location of the Study Area

The study was conducted at Amibara irrigation scheme, in Amibara District, 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 Melkasedi, Werer and Ambash-Sheleko irrigated farms with a gross command area of more than 15,000 ha.

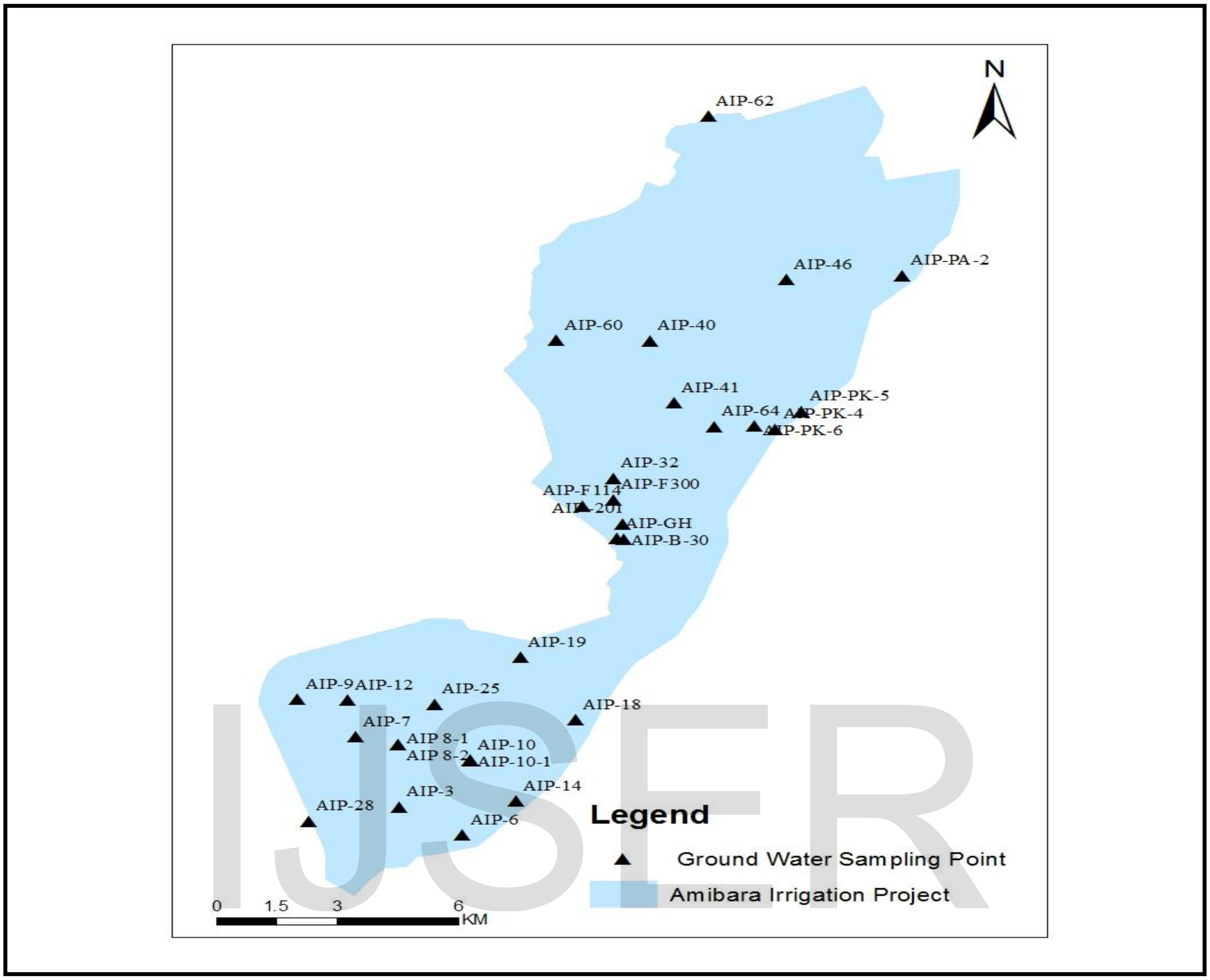

Figure 1. Location map of the study area

The elevations of the area ranged from 724 to 745 m with average of about 734.5 m above sea level. It is located at 9° 14’ 1.2" to 9°27’12.1" North latitude and 40° 6’ 19.2" to 40°14’26.1" East 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).

Topography, geology and soil type of the Study Area

The topography of the study area reflects the recent geomorphoological 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, carbonatite, volcanic ash, tuff, pumice, and rhyolite parent materials (Italconsult, 1969; Heluf, 1985). The soils of the study area are predominantly Eutric Fluvents, order Fluvisols followed by Vertisols occupying about 30% of the total area (Italconsult, 1969; Halcrow, 1982; Wondimagegne and Abere, 2012). 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 (Heluf, 1985; Wondimagegne and Abere, 2012). Fluvisols are constituted by muscovite/illite clay minerals and Vertisols are dominated by montmorillonite clay minerals (Girma, 1999).

Climate of the Study Area

According to the classification of Agro-ecological zones by the Ministry of Agriculture and Rural Development (MoARD), the area is classified as semi-arid (Yibeltal, 2009), whereas, according to Werer Agricultural Research Center, with regard to 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 ^{o}C and 32.6 ^{0}C, respectively (Appendix Table 1). As shown on the Figure 2, the mean evapotranspiration and temperature in the study periods showed an increasing trend, while rainfall decreases from August to December in the water sampling seasons which may affect the level of ground water in the study area.

Irrigation water source and management in the Study Area

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 linking 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 farms, especially in sugarcane fields (personal communication).

The Amibara irrigation schemes were provided with surface and sub-surface drainage facilities. An appropriate gravity outlet for these drainage flows away from the project area was available through a gravity flap gated outfall at Hassoba which enters to the Awash River. But now the sub-surface drainage system is totally closed throughout the system due to silting of buried drain pipes as a result of poor management and back flow of water from open drainage canals.

Assessment, Maintenance and Installation of Piezometers

The piezometers found in the study area which were used to collect water samples and measure the water table were assessed throughout the irrigation scheme. During the assessment, about 13 sampling piezometers were identified. Based on the existing numbers and distribution of these sampling holes, 14 additional Piezometers were installed and about 3 piezometers were repaired which were not previously working, at strategic points in both Fluvisols and Vertisols of the project area. The existing observation wells, for periodic observation of the groundwater table were established throughout the project area in 1970/80s. They were set out on a 2 km grid pattern and spaced to give a close approximation of the groundwater surface. A total of 30 piezometers were used for this study. Numbers and distribution of piezometers depend on the total area of each soil types.

The installation of piezometers was done manually by using auger tubes. A hole having around 6 centimeters in diameter down to below the lowest expected water table level was augured. A section of PVC pipe was placed into the hole and the diameter of the pipe was 4 centimeters. The bottom of the pipe was sealed with a rubber stopper to prevent materials from entering the bottom of the pipe. At every 2.5 centimeters in the pipe, slots were made with a drill over the distance where the water table might fluctuate. Finally, the cavity between PVC pipe and wall of the bore hole were backfilled with sand and red ash having a wide range of grain sizes. To prevent surface water from flowing into the well, the bore hole at the surface was packed with concrete made of cement and sand based on the method out lined by Blaine (2006).

Water Sampling

Water samples for determination of the water quality in terms of salinity and sodicity from each piezometer and Awash River (source of irrigation water) were collected with plastic bottles following standard methods (Greenberg et al., 1992). Before collecting the samples, the bottles were carefully washed and rinsed thoroughly with distilled water so as to avoid any contamination. A metal bottle tied with rope was dropped in to the piezometer to collect water sample. Water samples from all piezometers were collected starting from August to December, 2017 for five consecutive months to see seasonal fluctuations in water quality and its effects on soil salinity and sodicity

Sample Preparation and Laboratory Analysis

Sample preparation

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 water samples were conducted at soil and water analysis laboratories of Werer and Melkassa Agricultural Research Centers.

Laboratory analysis of water samples

Water samples collected from different piezometers and Awash River were analyzed for total dissolved solids (TDS), pH, ECw, dissolved cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anions (HCO_3^- and $CO_3^=$, Cl^- and $SO_4^=$) contents in the laboratory according to the method outlined for each parameter. Total Dissolved Solids (TDS) was determined from the filterable residue that passes through a standard glass filter disk and remains after evaporation and drying at 180°C according to the method set by Howard (1933). Water pH was measured by using a digital pH-meter according to the method outlined by USSLS (1954) and Electrical conductivity (ECw) by digital conductivity meter according to the method outlined by the Rhoades *et al*. (1999). carbonates ($CO_3^=$) and bi-carbonate (HCO_3^-) ions were determined by titration with standard hydrochloric acid (Singh *et al*., 1999); chloride ion was determined by silver nitrate titrimetion method (Jackson, 1967) and $SO_4^=$ turbidimetrically by spectrophotometer (Singh *et al.*, 1999). Ca^{++} and Mg^{++} ions were measured by using atomic absorption spectrophotometer, while Na^{+} and K^{+} were analyzed by using flame photometer (Singh *et al*., 1999). Sodium Adsorption Ratio (SAR), a useful index of the sodicity or relative sodium status of the water samples was calculated from the concentrations of soluble Na, Ca and Mg, by using the following equation:

$$SAR_{ss} = \frac{\left(Na^{+}\right)}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The Residual Sodium Carbonate (RSC) was calculated by subtracting the sum of Ca^{++} and Mg^{++} from the sum of $CO_3^=$ and HCO_3^- as:

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

Data Analysis and interpretation

All collected data were subjected to descriptive statistics and their range and average were determined in excel sheet of Microsoft Office. Finally, irrigation water and ground water quality were classified in different salinity and sodicity classes according to the guidelines for interpretations of water quality for irrigation (Table 1) and laboratory determinations needed to evaluate common irrigation water quality problems (Table 1) of FAO (1985).

Results and Discussion

Water Quality of Awash River at Melkasedi Weir site

The mean, minimum and maximum values of selected physical and chemical properties for Awash River water are presented in Table 1. The pH ranged from 8.1 to 8.7 which is mostly within the normal range (6.5 to 8.5), except for September and October sampling months which were beyond restricted range for major agricultural crops. Higher pH values were recorded during September and October which can be associated to the inflow of highly alkaline water with appreciable amount of bicarbonate ions from Beseka Lake to the Awash River (Megersa et al., 2009).

Table 1. Mean analytical results of the key physicochemical water quality parameters for Awash River

No.	Parameters	unit	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Min.	Max.	Usual range (FAO,1985)
1	pH	1-14	8.2	8.7	8.7	8.1	8.3	8.40	8.1	8.7	6.5 - 8.5
2	TDS	mg/l	524	752	688	496	452	582.4	452	752	0-2000
3	ECw	dS/m	0.71	1.1	1.1	0.9	0.97	0.9	0.71	1.1	0-3
4	CO_3	meq/l	0.60	3.8	2.4	2.0	0.50	1.9	0.5	3.8	0 - 1
5	HCO_3	meq/l	12.2	7.6	8.6	6.9	7.70	8.6	6.9	12.2	0 - 1
6	Cl	meq/l	4.60	8.0	6.0	6.0	3.70	5.7	3.7	8.0	0 - 1
7	SO_4	meq/l	0.9	0.7	0.6	0.6	0.5	0.7	0.5	0.9	0 - 1
8	Ca	meq/l	2.50	1.4	1.1	0.9	1.40	1.5	0.9	2.5	0 - 20
9	Mg	meq/l	3.22	1.2	2.2	1.3	1.60	1.9	1.2	3.2	0 - 2
10	Na	meq/l	6.49	8.0	8.3	8.2	9.97	8.2	6.49	9.97	0 - 20
11	K	meq/l	0.22	0.32	0.34	0.30	0.37	0.31	0.22	0.37	0 - 2
12	SARw	%	3.84	7.03	6.48	7.77	8.14	6.65	3.84	8.14	0 - 15
13	RSC	meq/l	7.11	8.80	7.70	6.70	5.20	7.10	5.20	8.80	0-2.5

N.B: Aug. = August, Sep. = September, Oct. = October, Nov. = November, Dec. = December, Min. = minimum, Max. = maximum

The TDS values ranged from 452 in December to 752 mg/l in September. The higher TDS in September may be due to flow of higher volume and more sediments associated with more rainfall and runoff in which decreases in December when the water becomes more pure during this time. The mean value (582.4 mg/l) recorded during the sampling period was above critical limits (500 mg/l) for irrigation purpose. Similar results were reported by Girma, (2006) who stated that the TDS results in most of analyzed water samples were above 500 mg/l in Amibara area. The electrical conductivity (ECw) ranged from 0.71 in August to 1.1 dS/m in September and October. Higher ECw values during September and October may be associated with the higher inflow of Beseka Lake to the Awash River beyond the recommended rate. According to (1985) FAO guidelines for interpretation of water quality for irrigation, the Awash River, at the sampling point, was rated within the slight to moderate range (0.7 to 3 ds/m) that can affect crop water requirements and sensitive agricultural crops. According to the classification of USSLS (1954), if the EC is lower than 250 μS cm^{-1}, between 250 and 750, 750 and 2250, and higher than 2250 μS cm^{-1}, salinity is low (C1), moderate (C2), high (C3), and very high (C4), respectively. Based on this, the samples taken from Awash River, the ECw was found to be moderate (C2) to high (C3) range to be used for irrigation purpose.

Sodium Adsorption Ratio (SAR) is used to determine the suitability of water for irrigation in terms of sodium hazard. The values of SAR ranged from 3.84 to 8.14. According to FAO (1985) guidelines for irrigation water, the SAR values obtained were above the critical levels (slight to moderate degree of restriction) to cause sodium toxicity to the plants and deteriorate the soil chemical properties. Residual Sodium Carbonate (RSC) gave an indication of whether bicarbonates and carbonates will increase the effects of sodium. It ranged from 5.20 in December to 8.8 meq/l in September. The mean value of RSC falls above the critical values to add an excess of Na^+ ions with a consequent increase in the SAR of the water (Table 2).

Among the cations, the water sample was dominated by sodium followed by magnesium and calcium whereas, among the anions, bicarbonate and chloride ions were dominant ions and the result was in agreement with the findings of Zeleke et al. (2014) who conducted a study in Kesem Kebena areas. According to FAO (1985), except carbonate all other anions were within the usual range for irrigation water and the chlorine was above the desired range while bicarbonate was under desired range. The sulfate ion causes no particular harmful effects on soils or plants; however, it contributes to increase salinity in the soil solution. Unlike sulfate, the chloride ion had a direct toxic effect on some plants, while also contributing to the salinity of the soil solution.

Seasonal Fluctuation of Selected Chemical Properties in Awash River Water

The electrical conductivity (ECw) ranged from 0.71 in August to 1.1 dS/m in September and October. Higher ECw values during September and October may be associated with the higher inflow of Beseka Lake to the Awash River beyond the recommended rate. Generally the EC values increased in the dry periods. The five months trends for major anions (carbonate, bi-carbonate, chloride and sulphate) showed a decreasing trend from August to December. This may be due to the reduction of Awash River water organic and inorganic materials coming through erosion from different sources of the surrounding highland areas during the rainy season.

The values of SAR revealed an increasing trend from August (3.84) to December (8.14). The reason for an increasing trend might be the inflow of Lake Beseka and other hot springs having high level sodium relative to calcium and magnesium, without considering the volume of Awash River water which declines from August to December associated with low rainfall in these seasons in the highland and the surrounding areas where the sample was taken. Increasing levels of ECiw and SAR values during the sampling months was due to increasing content of ions through evaporation of water, accumulation and concentration of ions in river water. Similar result was reported by (VIMS, 2005) who stated that conductivity and salinity values often increase in summer (low rain fall season) due to lower flow volume and evaporation.

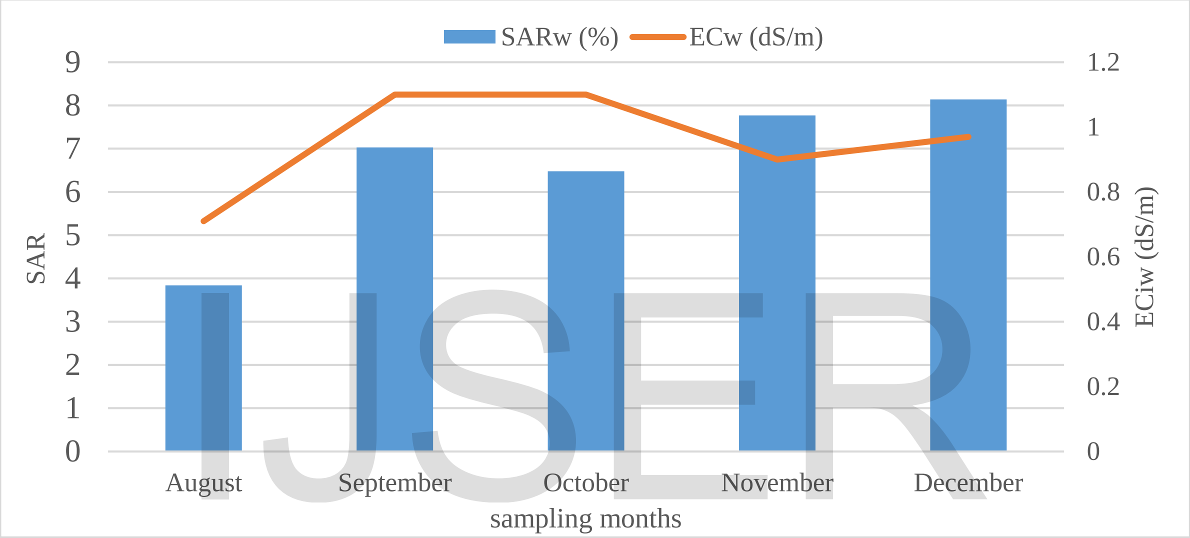

Figure 2. Seasonal trend of Sodium Adsorption Ratio and Electrical Conductivity

Generally, the Awash River water showed a deterioration trend in its quality through the sampling periods from August to December which may be due to addition of Lake Beseka to the Awash River. The result was in agreement with the findings of Elias et al. (2016) who suggested that the discharge rate of Lake Beseka water into Awash River will affect its quality and aggravate the soil salinity and reduce cotton yield. The same Authors also indicated that Beseka Lake was a great source of pollution for downstream agricultural farms and it is a great environmental concern that need close attention.

Spatial Variability of Ground Water Chemical Characteristics

Water Reaction (pHw)

The mean, minimum and maximum pH values for the groundwater collected from different piezometers in both Fluvisols and Vertisols areas of AIS is presented in Tables 2. The pH values varied from 7.3 to 9.1 and 7.5 to 8.3 in piezometers found in Fluvisols and Vertisols, respectively. Out of 21 piezometers which were found in Fluvisols, 90.5% of them had pH values within the normal range (6.5-8.5) while the remaining 9.5% falls under alkaline range which was greater than or equal to 8.5. Similarly, piezometers found in Vertisols areas showed pH values under acceptable range for irrigation with minimum and maximum value of 7.5 and 8.3, respectively.

Electrical conductivity (ECw)

The mean, minimum and maximum values of electrical conductivity of the sample collected from 30 different groundwater monitoring piezometers are presented in Table 2. The electrical conductivity of the water samples collected from piezometers located in Fluvisols, showed a great variation among different sampling points. It varied from 1.31 to 13.10 dS/m at AIP-F#114 and AIP-8-1, respectively.

Based on the guidelines for interpretation of water quality for irrigation (FAO, 1985), all the sampling points showed EC values greater than the lower limit (0.7 dS/m). From the total sampling points about 47.6% of them falls under class 2, which may have slight to moderate effect on soil and crop tolerance when used as irrigation water through capillary rise in crops root system, whilst the remaining 52.4% falls under severe irrigation water salinity class. Therefore these values may have a significant impact on soil properties and crop tolerance when it is transported through capillary rise and may come to surface when water is evaporated especially those that have groundwater which are found within 3 meters of depth from the surface of the terrain.

Similar to that in Fluvisols, the mean electrical conductivity of the water samples collected from piezometers found in Vertisols was higher than the lower limit (0.7) (Table 2). The EC showed a high variation among different sampling points. Minimum (0.98 dS/m) and maximum (7.68 dS/m) ECw values were recorded at AIP-PK-4 and AIP-25, respectively. According to FAO (1985) the EC in all the sampling point was above the critical limit (0.7 dS/m). From all points about 66.7% of them falls under class 2, which may have slight to moderate effect on soil properties and crop tolerance when used as irrigation water through capillary rise in crops root system, the remaining 33.3% falls under severe irrigation water class.

Table 2. Minimum, Maximum and Mean values of ground water chemical characteristics in Fluvisols and Vertisols areas of AIS

No.	Terms	pH	ECw (dS/m)	TDS (mg/l)	All cations and anions (meq/l)								SAR	RSC
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4		
Fluvisols														
1	Minimum	7.3	1.31	647.2	0.74	1.42	5.81	0.16	0	1.23	12.64	0.72	2.86	-76.95
2	Maximum	9.1	13.1	10493.6	45.1	66.72	74.32	1.02	6.68	27.47	154.44	2.92	66.98	31.06
3	Mean	8	5.4	3742.9	5.3	7.3	27.5	0.4	2.8	11.7	44	1.4	17.6	1.6
Vertisols														
1	Minimum	7.5	0.98	560	1.44	2.22	6.82	0.2	0.52	7.45	6.72	0.8	3.87	-8.16
2	Maximum	8.3	7.68	4339.2	40.32	22.16	25.01	0.66	4.24	15.93	87.54	1.52	11.37	14.96
3	Mean	7.9	3	2103.7	8.5	8.5	13.6	0.4	1.7	10.7	25	1.1	6.2	-4.7
Usual range in irrigation water (FAO,1985)		6.5 - 8.5	0 - 3	0 -2000	0 - 20	0 - 5	0 - 40	0 - 2	0 - 1	0 - 10	0 - 30	0 - 20	0 - 15	0 - 2.5

Total Dissolved Solids (TDS)

The study clearly indicated that the mean TDS values ranged from 647.2 to 10493.6 mg/l at AIP-F114 and AIP 8-2, respectively in Fluvisols areas (Table 3) and 560 to 4339.2 mg/l at AIP-PK-6 and AIP-F300, respectively in Vertisols areas (Table 4). The excess value of TDS was mainly due to high concentration of soluble Ca, Mg, K, Na, carbonates, bicarbonates, chlorides and sulfates in the analyzed water samples. According to standard of the acceptable range of TDS for irrigation water use (Hopkins *et al.,* (2007), 33.33% of the ground water samples, had TDS values ranging from 480 to 1280 mg/l that cause medium hazard and needed careful irrigation, good drainage and leaching and salinity may adversely affect plants and it requires selection of salt tolerant plants and 19.05% of the water samples had TDS values ranging from 1280 to 1920 mg/l that causes medium to high hazard and require careful management to raise most crops. The remaining 47.62% of the water samples had a TDS values above 1920 mg/l that brings high hazard. Generally unacceptable for irrigation, except for very salt-tolerant plants where there is excellent drainage, frequent leaching, and intensive management, in Fluvisols areas of the study area. Similar to the above in Fluvisols, about 55.6% of the ground water samples having TDS ranging from 480 to 1280 mg/l that cause medium hazard, 22.2% of the water samples had TDS values ranging from 1280 to 1920 mg/l that causes medium to high hazard and require careful management to cultivate most crops and the remaining 22.2% of the ground water samples have TDS values above 1920 mg/l to cause high hazard on plants and soil property in Vertisols areas (Ayers and Westcott, 1994; Hopkins et al., 2007).

Dissolved cations

The mean spatial variation of water soluble cations for ground water samples collected from different piezometers found in Fluvisols areas is presented in Table 3. As shown on the Table 3, maximum values of 45.10, 66.72, 74.32 and 1.02 meq/l for Ca^{++}, Mg^{++}, Na^{+} and K^{+} were recorded in piezometers AIP-32, AIP-8-2, AIP-8-1 and AIP-6, respectively, whilst minimum values of 0.74, 1.14, 5.81 and 0.16 meq/l for Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were recorded in piezometers AIP-19, AIP-10, AIP-6 and AIP-10-1, respectively in Fluvisols areas of AIS. Generally the mean content of those dissolved cations was in the order of $Na^{+} > Mg^{++} > Ca^{++} > K^{+}$ with their constituents of 27.5, 7.3, 5.3 and 0.4 meq/l. Similarly maximum values of 40.32, 22.16, 25.01 and 0.66 meq/l for Ca^{++}, Mg^{++}, Na^{+} and K^{+} were recorded in piezometers AIP-25, AIP-25, AIP-25 and AIP-F300, respectively, whilst minimum values of 1.44, 2.22, 6.82 and 0.20 meq/l for Ca^{++}, Mg^{++}, Na^{+} and K^{+} were recorded in piezometers AIP-F201, AIP-64, AIP-PK-6 and AIP-12, respectively which were found in Vertisols area (Table 4). Generally the mean content of those dissolved cations was in the order of $Na^{+} > Mg^{++} \geq Ca^{++} > K^{+}$ with their constituents of 13.6, 8.5, 8.5 and 0.4 meq/l in vertisol areas. The result agreed with the findings of Girma (2006), who reported occurrence of higher content of sodium in well water in middle Awash areas. Generally according to FAO (1985) except magnesium all other cations were within desired range for irrigation in both soil types.

Table 3. Mean values of ground water chemical characteristics in Fluvisols area of AIS

No.	Piezometer points	pH	ECw (ds/l)	TDS (mg/l)	All cations and anions (meq/l)								SAR	RSC
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4		
1	AIP-F114	7.7	1.31	647.2	1.18	6.46	10.31	0.37	1.44	10.29	6.64	1.13	5.76	3.93
2	AIP-8-2	7.3	12.42	10493.6	12.10	66.72	43.24	0.74	Trace	1.87	154.44	2.50	6.89	-76.95
3	AIP-8-1	7.4	13.10	9028.8	3.48	3.00	74.32	0.59	Trace	2.17	106.92	2.92	42.38	-4.32
4	AIP-PA-2	7.9	2.05	1214.4	1.90	4.96	15.85	0.39	2.24	9.83	13.06	0.95	10.06	6.28
5	AIP-B-30	8.4	2.61	1520	1.10	2.06	22.41	0.19	3.72	16.75	14.26	1.18	18.24	17.30
6	AIP-10-1	9.1	1.88	1350.4	2.48	3.96	17.18	0.16	6.68	7.99	12.64	1.48	9.66	9.79
7	AIP-GH	8.2	2.44	1514.4	1.46	5.04	19.10	0.19	3.32	14.39	14.24	1.19	10.75	11.20
8	AIP-14	8.5	3.92	2773.6	0.80	1.62	29.53	0.57	5.12	18.39	19.2	1.15	27.34	21.08
9	AIP-6	7.5	10.14	9620	7.00	1.42	5.81	1.02	Trace	1.23	130.42	1.36	2.86	-6.11
10	AIP-3	7.8	1.55	884	1.20	2.36	10.12	0.35	1.64	11.47	10.34	1.23	7.66	8.72
11	AIP-10	8.1	3.61	2396.8	1.36	1.14	28.31	0.25	2.92	15.03	29.76	1.60	26.82	15.44
12	AIP-18	8.2	11.91	8560.8	1.74	2.24	72.27	0.36	4.68	16.93	95.16	1.67	52.04	17.62
13	AIP-19	8.3	11.17	7361.6	0.74	1.50	68.97	0.25	5.92	27.47	93.94	2.10	66.98	31.06
14	AIP-7	7.7	2.29	1023.2	5.50	6.94	9.25	0.37	0.6	9.47	19.68	1.14	3.76	-2.38
15	AIP-28	8.0	2.59	1829.6	3.02	3.18	20.67	1.00	0.44	22.11	14.56	1.26	11.96	16.34
16	AIP-9	7.7	2.04	1109.6	5.42	4.70	9.55	0.78	0.56	7.33	18.76	1.23	4.31	-2.24
17	AIP-32	7.6	6.25	6168	45.10	15.44	20.64	0.52	0.2	7.21	52.8	0.88	3.76	-53.13
18	AIP-41	8.4	6.96	4898.4	1.30	3.28	45.97	0.21	5.72	17.19	50.98	0.72	34.50	18.33
19	AIP-60	8.1	2.98	845.6	2.98	3.46	11.79	0.22	1.6	9.29	10.76	1.03	7.04	5.47
20	AIP-40	8.0	4.68	971.2	4.68	4.72	7.49	0.24	1.2	8.05	19.28	1.14	3.61	-1.11
21	AIP-62	8.2	6.7	4389.6	6.70	9.36	35.25	0.40	2.6	10.81	35.28	0.91	12.55	-2.65
	mean	8.0	5.4	3742.9	5.3	7.3	27.5	0.4	2.8	11.7	44.0	1.4	17.6	1.6

Dissolved anions

The mean content of dissolved anions for water samples collected from different piezometers found in Fluvisols areas are presented in Table 3. Carbonates ranged from trace in AIP-8-2, AIP-8-1 and AIP-6 to 6.48 meq/l at AIP-10-1. Bi-carbonate ranged from 1.23 in AIP-6 to 27.47 meq/l in AIP-19. Chloride ranged from 6.64 in AIP-F114 to154.44 meq/l AIP-8-2. Sulfate ranged from 0.72 in AIP-41 to 2.92 meq/l in AIP-8-1. Generally, the mean contents of the dissolved anions were in the order of $Cl^- > HCO_3^- > CO_3^= > SO_4^=$ with their constituents of 44.01, 11.7, 2.8 and 1.4 meq/l. Similarly carbonate ranged from 0.52 in AIP-25 to 4.24 meq/l in AIP-F201. Bi-carbonate ranged from 7.45 in AIP-25 to 15.93 meq/l in AIP-F201. Chloride ranges from 6.72 at AIP-46 to 87.54 meq/l in AIP-25. Sulfate ranged from 0.8 in AIP-25 to 1.52 meq/l in AIP-PK4. Generally, the mean contents of the dissolved anions were in the order of $Cl^- > HCO_3^- > CO_3^= > SO_4^=$ with their constituents of 25.0, 10.7, 1.7, and 1.1 meq/l. Generally according to FAO (1985) except sulphate all other anions were above desired range for irrigation purpose in Fluvisols. Carbonate and bicarbonate were above desired range while chlorine and sulphate were within the desired range for irrigation in Vertisols area (Table4)

Sodium Adsorption Ratio (SAR)

The mean values of Sodium Adsorption Ratio (SAR) for ground water samples collected from different piezometers found in Fluvisols (Table 2) showed that minimum and maximum values of 2.86 and 66.98 were recorded at AIP-6 and AIP-19, respectively. Similarly, piezometers located in Vertisols areas (AIP-PK-6 and AIP-F201) revealed a minimum and maximum SAR values of 3.87 and 11.37, respectively. Generally, 4.76%, 38.10% and 57.14 % of the ground water sampling points revealed that SAR values fell under none, slight to moderate and severe sodicity hazard, respectively on soil and plants.

According to Ayers and Westcott (1985), water samples collected from most of the piezometers, such as AIP-PK-6, AIP-PK-5, AIP-46, AIP-25, AIP-12, AIP PK-4, AIP-F300 and AIP-64 which were found in Vertisols areas of the AIS were grouped under slight to moderate sodicity classes with SAR values of 3.87, 3.94, 4.46, 4.49, 5.78, 6.61, 7.14, 8.28 and, respectively. While only one sample collected from AIP-F201 with a SAR value 11.37, was grouped under sever sodicity class (Table 4). Generally, 88.89% and 11.11% of the ground water sampling points revealed SAR values that fell under slight to moderate and severe sodicity hazard, respectively on soil and plants.

Residual Sodium Carbonate

The monthly mean values of calculated residual sodium carbonate (RSC) for the piezometers found in Fluvisols and Vertisols (Table 3 and 4). According to Rengasamy et al., (2010); FAO and ITPS (2015), RSC values greater than 2.5 meq/l has a very high impact on SAR. Generally, if the RSC is less than zero (negative), there is no impact on SAR. If RSC is positive, it may increase SAR. However, a measurement of RSC on its own is not a useful indicator of sodicity hazard as waters may have a high SAR and a negative RSC because sodium chloride is the dominant salt. When both SAR and RSC are high, then soil sodification rates are likely to be greater. In this case for the RSC values ranging from 0 to 1.25 meq/L, 1.25 to 2.5 meq/L and greater than 2.5 meq/L, the RSC impact on SAR is moderate, high and very high, respectively (Rengasamy *et al*., 2010; FAO and ITPS, 2015). Based on the above topic, out of 21 piezometers found in Fluvisols areas, 38.1% and 61.9% of the sampling points showed RSC values less than zero and greater than 2.5 meq/l, which could introduce zero and very high impact respectively, on soil sodium content,. However among nine piezometers located in Vertisols areas, about 33.33%, 11.1% and 55.56% of the sampling piezometers could result in high and very high impact respectively, on soil sodium.

Generally, according to FAO (1985)., all the water samples collected from all piezometer points both in Fluvisols and Vertisols areas indicated high level of electrical conductivity and TDS values beyond the permissible range. Regarding the SAR values, some points ranged within none, slight to moderate and severe sodicity classes to introduce sodium hazard on crop plants and impede infiltration rate of the soil.

Table 4. Mean values of groundwater chemical characteristics in Vertisols area of AIS

No.	sampling points	pH	ECw (ds/m	TDS (mg/l)	All cations and anions (meq/l)								SAR	RSC
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4		
1	AIP-46	7.5	1.53	744.00	2.60	4.36	8.60	0.46	0.68	13.09	6.72	1.15	4.46	6.22
2	AIP-64	8.2	1.43	793.60	1.88	2.22	11.80	0.26	2.28	11.35	8.28	0.86	8.28	9.52
3	AIP-PK-6	7.9	3.02	560.00	1.86	4.90	6.82	0.31	2.00	10.25	9.04	0.87	3.87	5.50
4	AIP-PK-5	7.8	2.09	1741.60	8.06	15.78	13.62	0.47	1.96	8.09	24.24	1.27	3.94	-3.45
5	AIP-PK-4	8.0	0.98	1116.80	3.10	4.16	12.62	0.29	2.32	11.69	13.82	1.52	6.61	5.94
6	AIP-F#300	7.7	5.94	4339.20	14.44	13.58	14.44	0.66	0.72	9.15	46.7	1.38	7.14	-8.16
7	AIP-F#201	8.3	2.27	1372.80	1.44	3.76	18.38	0.39	4.24	15.93	14.74	1.21	11.37	14.96
8	AIP-12	8.0	1.86	1049.60	2.98	5.46	11.02	0.20	0.92	9.33	13.50	1.19	5.78	1.81
9	AIP-25	7.6	7.68	7216.00	40.32	22.16	25.01	0.37	0.52	7.45	87.54	0.80	4.49	-4.51
	Mean	7.9	3.0	2103.7	8.5	8.5	13.6	0.4	1.7	10.7	25.0	1.1	6.2	- 4.70

Temporal fluctuation of groundwater chemical characteristics

Temporal fluctuation of electrical conductivity

The five months trend of electrical conductivity of ground water is presented in Figures 3 and 4 for the piezometers found in Fluvisols and Vertisols of AIS, respectively. As shown on Figure 3 below, the electrical conductivity revealed an increasing trend in most of the piezometers except some points such as AIP-8-2, AIP-8-1, AIP-PA-2, AIP-14, AIP-6 and AIP-9, which showed a decreasing trend from August to December. In contrary to the above cases, piezometers including AIP-GH, AIP-18, AIP-19 and AIP-28 revealed an irregular trend during the sampling months. Inayathulla and Paul (2013) reported that, groundwater is more affected in summer season than during rainy and winter season. Water quality index in summer season falls in class III of poor water quality in the case of some sampling stations and the seasonal variations of index values were due to variation in physicochemical characteristics of groundwater.

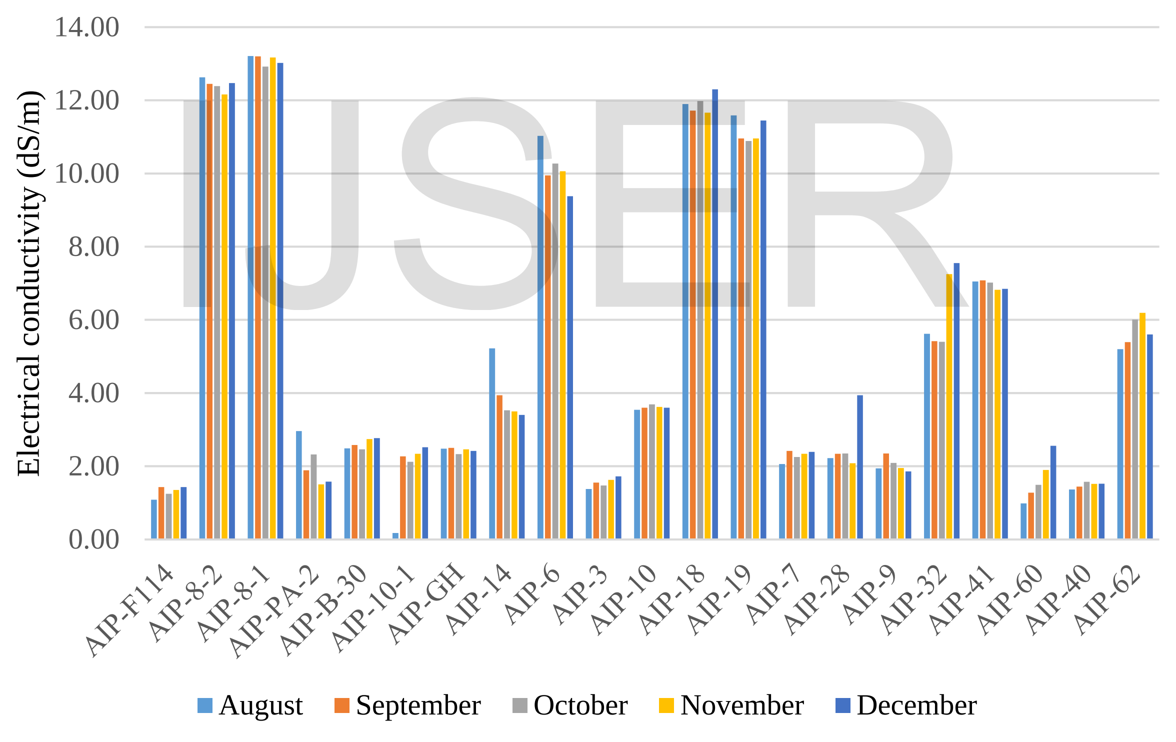

Figure 3. Temporal trend of groundwater electrical conductivity in Fluvisols areas

Similarly, the electrical conductivity for most piezometers found in Vertisols areas of AIS (Figure 4) showed an increasing trend for AIP-46, AIP-64, AIP-PK5, and AIP-F201 while it revealed a decreasing trend at AIP -12 and AIP-25 from August to December. In contrary to the above cases AIP-PK4 and AIP-300 revealed an irregular trend during the sampling months. In both soil types, the reason for increasing and decreasing in ground water salinity could be correlated with the decreasing and increasing of water table from the ground surface and to the ground surface, which came from the dissolution of water soluble cations from the lower soil profile.

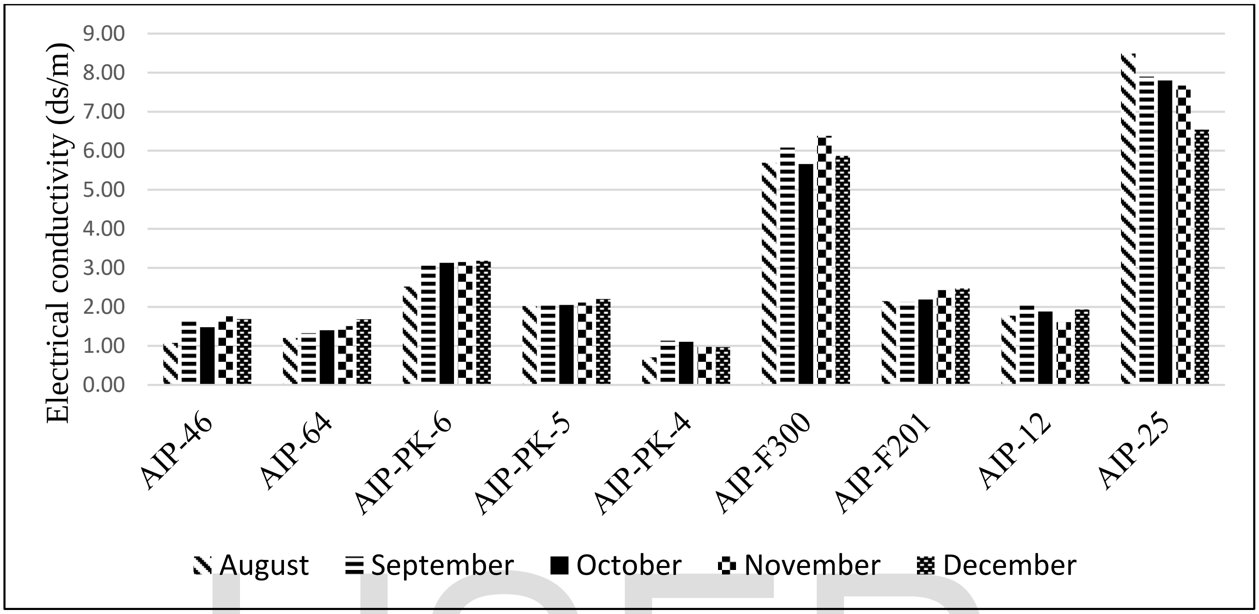

Figure 4. Temporal trend of groundwater electrical conductivity in Vertisols areas

Temporal fluctuation of Sodium Adsorption Ratio (SAR)

The temporal fluctuation of SAR values of water samples collected from piezometers found in Fluvisols areas of AIS (Figure 5) showed an increasing trend of SAR values from August to December at all points except AIP-32 which showed a decreasing trend.

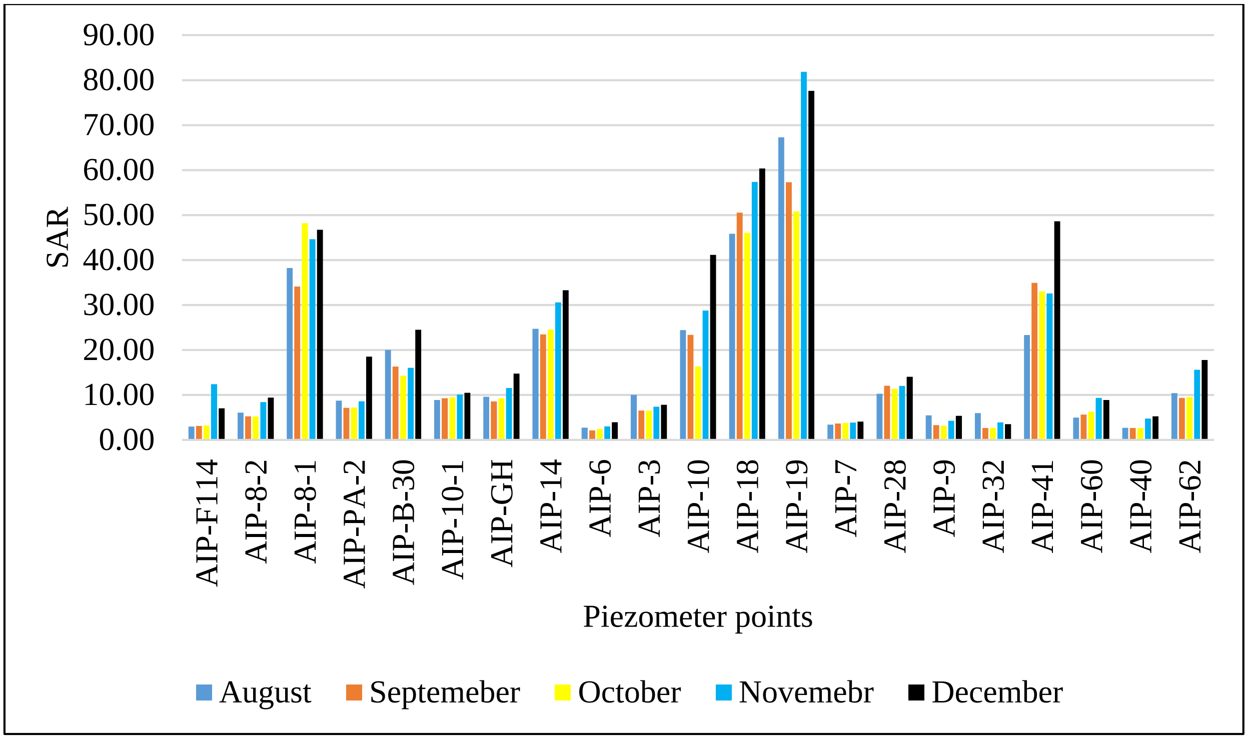

Figure 5. Temporal trend of ground water sodium adsorption ratio in Fluvisols areas

The temporal fluctuation of SAR values of water samples collected from piezometers located in Vertisols areas (Figure 6) revealed that out of the nine piezometers, eight of them showed an increasing trend of SAR values from August to December except AIP-PK-4 which showed a decreasing trend. The occurrence of an increment trends at both soil types could be associated with the dissolution of cation (sodium) as the water table decreases from the surface long the sampling months. The result was in agreement with the findings of (Ramsis and Claus, (1999) and Northey et. al., 2005) who suggested that as the water table fall corresponds to an increase in salinity/sodicity relative to water table rise at each depth.

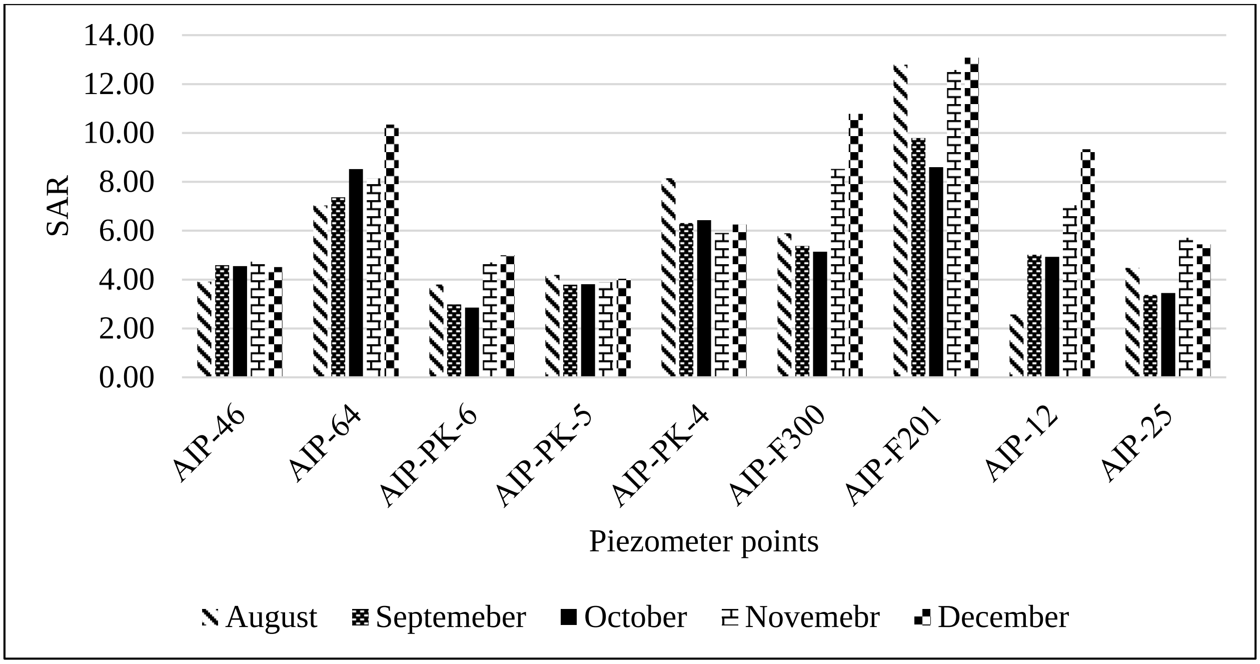

Figure 6. Temporal trend of ground water sodium adsorption ratio in Vertisols areas

Conclusion

Reliable and up-dated information on the spatial variability and temporal fluctuation of groundwater and surface water quality is required to effectively manage the limited natural resources and maintain a viable agricultural industry that is highly dependent on conjunctive use of surface and ground waters with varying salinity/sodicity levels. Therefore, this study was conducted to study the spatial variability and temporal fluctuation of groundwater and surface water quality under Fluvisols and Vertisols areas of Amibara area, Middle Awash, Ethiopia.

Then, for all water samples, all salinity and sodicity parameters were determined in the laboratory according to standard methods recommended for pH, EC, TDS, soluble anions and cations in Werer Agricultural Research Center’s Agricultural and nutritional research laboratory. SAR and RSC were calculated.

Regarding the quality of Awash River water for irrigation purpose, the mean values of electrical conductivity and SAR obtained were within slight to moderate classes of restriction while TDS and RSC values were above the critical limit for irrigation purpose. Generally, the mean content of dissolved cations were in the order of $Na^+ > Mg^{++} \geq Ca^{++} > K^+$ while the anions were in the order of $Cl^- > HCO_3^- > CO_3^= > SO_4^=$.

The analytical result for the groundwater salinity and sodicity parameters revealed higher variability among different sampling piezometer points. Out of 21 sampling points found in Fluvisols, 90.5% of them had pH values within the normal range while the remaining 9.5% fell under alkaline range. While all the sampling points located in Vertisols area revealed pH values of within acceptable range.

The mean electrical conductivity values were fell under class 2 in most sampling points at both soil types, which had slight to moderate effects on soil and crop tolerance while the remaining points were fell under severe irrigation water salinity class. Generally, highest mean ECe values of 5.10 and 2.98 dS/m in Fluvisols and Vertisols areas, respectively.

Regarding the TDS values about, 33.33%, 19.05%and 47.62% of the ground water samples in Fluvisols areas and 55.6%, 22.2% and 22.2% % of the ground water samples in Vertisols area, their TDS content could cause introduce medium, medium to high and high hazard, respectively on plants and soil property, unless appropriate management options are implemented. The mean values of the cations were in the order of $Na^+ > Mg^{++} \geq Ca^{++} > K^+$ while anions were in the order of $Cl^- > HCO_3^- > CO_3^= > SO_4^=$ in both soil types. Generally except magnesium, all other cations fell within desired range for irrigation in both soil types. Among the anions, except sulphate all others were above desired range in Fluvisols while carbonate and bicarbonate were above desired range but chlorine and sulphate were within the desired range for irrigation in Vertisols area. About, 4.76%, 38.10% and 57.14% of the ground water sampling points revealed SAR values that fall under none, slight to moderate and severe sodicity hazard classes, respectively in Fluvisols. However, about 88.89 and 11.11% of the ground water sampling points revealed a SAR values that fell under slight to moderate and severe sodicity hazard, respectively in Vertisols area. Out of 21 piezometers found in Fluvisols areas, about 38.1% and 61.9% of them showed RSC values less than zero and greater than 2.5 meq/l, which could cause none and very high impact on soil sodium content, respectively. However among nine piezometers located in Vertisols areas, about 33.33%, 11.1% and 55.56% of them, their RSC values could result in high and very high impact on soil sodium content, respectively.

In both soil types, the electrical conductivity revealed an increasing and decreasing trends in the sampling months, due to the fluctuation of groundwater depth from the ground surface and to the ground surface, which came from the dissolution of water soluble cations from the lower soil profile. Generally about 62% of the ground water sampling piezometer points showed a decreasing trend of TDS while the remaining 38% of the samples revealed an increasing trend in Fluvisols areas. However at all sampling points in Vertisols area, the TDS revealed a decreasing trends during the sampling months. The SAR values revealed an increasing trends at both soil types associated with the dissolution of cation (sodium) as the groundwater depth decreases from the surface during the sampling months.

In general, quality reduction has been observed in the irrigation water during the sampling seasons in relation to salinity. Higher spatial variability in salinity and sodicity of ground water was observed due to variation in depth and relative existing positions from the irrigation and surface drainage canals.

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Appendices

Appendix Table 1. Long-term average climatic data of the study area (1970-2017) obtained from Werer meteorological 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. Guidelines for interpretation of water quality for irrigation (Ayers and Westcott, 1985)

Potential Irrigation Problem		Degree of Restriction on Use		
Salinity	unit	None	Slight to Moderate	Severe
ECw	ds/m	< 0.7	0.7 - 3.0	> 3.0
TDS	mg/l	< 450	450 - 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using ECW and SAR together)				
SAR = 0 - 3 and ECw		> 0.7	0.7 - 0.2	< 0.2
= 3 - 6		> 1.2	1.2 - 0.3	< 0.3
= 6 - 12		> 1.9	1.9 - 0.5	< 0.5
= 12 - 20		> 2.9	2.9 - 1.3	< 1.3
= 20 - 40		> 5.0	5.0 - 2.9	< 2.9
Specific Ion Toxicity Sodium (Na) surface irrigation Sprinkler irrigation	SAR	< 3	3 - 9	> 9

Appendix Table 3. Coordinate points of soil and groundwater sampling points in both soil types

No.	Piezometer points	Description of field codes	Northing	Easting	Altitude
			Degree decimal		
1	AIP-F114	Amibara Irrigation Project- Field number 114	9.341944444	40.16922222	733
2	AIP 8-2	Amibara Irrigation Project-8-2	9.273666667	40.12800000	737
3	AIP 8-1	Amibara Irrigation Project-8-1	9.273694444	40.12800000	743
4	AIP-46	Amibara Irrigation Project-46	9.406638889	40.21461111	727
5	AIP-64	Amibara Irrigation Project-64	9.364694444	40.19841667	733
6	AIP-PA-2	Amibara Irrigation Project-Piezometer in Arage	9.40775000	40.24027778	731
7	AIP-PK-6	Amibara Irrigation Project-Piezometer in kifil-sosit	9.364722222	40.20750000	733
8	AIP-PK-5	Amibara Irrigation Project- Piezometer in kifil-sosit	9.369055556	40.21791667	733
9	AIP-PK-4	Amibara Irrigation Project -Piezometer in kifil-sosit	9.363916667	40.21213889	733
10	AIP-B-30	Amibara Irrigation Project-near Block-30	9.332416667	40.17825000	736
11	AIP-10-1	Amibara Irrigation Project-10-1	9.269166667	40.14411111	740
12	AIP-GH	Amibara Irrigation Project-near green house	9.332666667	40.17686111	728
13	AIP-14	Amibara Irrigation Project-14	9.257583333	40.15436111	741
14	AIP-F300	Amibara Irrigation Project-Field number 300	9.343777778	40.17611111	733
15	AIP -201	Amibara Irrigation Project- Field number 201	9.336777778	40.17813889	732
16	AIP-6	Amibara Irrigation Project-6	9.247888889	40.14233333	742
17	AIP-3	Amibara Irrigation Project-3	9.255972222	40.12822222	749
18	AIP-10	Amibara Irrigation Project-10	9.269305556	40.14416667	745
19	AIP-18	Amibara Irrigation Project-18	9.280777778	40.16769444	740
20	AIP-19	Amibara Irrigation Project-19	9.298722222	40.15533333	734
21	AIP-7	Amibara Irrigation Project-7	9.275916667	40.11852778	740
22	AIP-28	Amibara Irrigation Project-28	9.251861111	40.10811111	744
23	AIP-9	Amibara Irrigation Project-9	9.286722222	40.10569444	740
24	AIP-12	Amibara Irrigation Project-12	9.286444444	40.11677778	737
25	AIP-32	Amibara Irrigation Project-32	9.349916667	40.17608333	736
26	AIP-41	Amibara Irrigation Project-41	9.371416667	40.18950000	728
27	AIP-25	Amibara Irrigation Project-25	9.285277778	40.13613889	740
28	AIP-60	Amibara Irrigation Project-60	9.389222222	40.16341667	726
29	AIP-40	Amibara Irrigation Project-40	9.389166667	40.18427778	742
30	AIP-62	Amibara Irrigation Project-62	9.453333333	40.19730556	727

Table 1. Guidelines for Interpretations of Water Quality for Irrigation

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*					
	EC$_w$	dS/m	< 0.7	0.7 – 3.0	> 3.0

	TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*[3]							
SAR	= 0 – 3	**And EC_w**	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)						
	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/l	< 3	> 3	
	Chloride (Cl)						
	surface irrigation			me/l	< 4	4 – 10	> 10
	sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements						
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				**Normal Range 6.5 – 8.4**		