

*Full Length Research Paper*

# **Spatial and temporal fluctuation of groundwater depth in Amibara, middle Awash, Ethiopia**

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**Soil salinity is a threat for agriculture under irrigation as it affects the growth and development of plants and the problem is widespread in middle Awash where Amibara irrigated farms are present. Therefore, Measurements of groundwater depth were taken from thirty piezometers in the months of August, September, October, November and December to investigate spatial variability and temporal fluctuation of groundwater depth in Amibara irrigation scheme. Based on the field measurement, relatively shallow water levels were recorded in Vertisols area as compared to that in Fluvisols area with a mean values of 1.47 m and 3.01 m, respectively. On the other hand groundwater depth was influenced by the type of field cover and irrigation practices taken place during the sampling periods. Relatively deep water table was recorded in fields covered by shrubs and tree plants as compared to cotton and sugarcane fields with mean groundwater depth values of 4.87, 2.48 and 1.78 m, respectively. Seasonal fluctuation of groundwater depth was influenced with the climatic condition and irrigation practices occurred at the study area. In general shallower water tables were recorded at most piezometers in both soil types in the study area, which is resulted from poor irrigation management and destruction of surface and subsurface drainage structures to drain and remove excess water. Therefore Regular monitoring and evaluation of groundwater depth is required to reduce the accumulation of salt and to protect the irrigated land from abandonment.**

**Key words:** groundwater, depth, spatial, temporal, fluvisols and vertisols.

## **INTRODUCTION**

In the hot and dry regions of the world the soils are frequently saline with low agricultural potential. In these areas most crops are grown under irrigation, and to exacerbate the problem, inadequate irrigation management leads to secondary salinization. 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).

The water table is the surface below which all the spaces in soil and rock are filled with water. Water in this saturated zone is called groundwater. Above this is the unsaturated zone where the spaces are dry or only partially filled with water. Water moving downwards pass the plant root zone is called leakage (Cynthia, 2009).

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Shallow water tables are a common feature of many irrigation areas due to high recharge rates and, frequently, reduced drainage rates.

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). 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 (Halcrow and Partners, 1982). The soils at the farm area were generally non-saline and groundwater table in the area was below 10 m (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 (Fentaw et al., 2006).

In most soils with a shallow water table, water rises into the active root zone through capillarity, and if the water table contains salt, it becomes a continuous source of salt to the root zone as water is used by the crop or evaporates at the soil surface. Salinization caused in this way can accelerate as time goes on, especially in hot climates and clayey soil conditions. Therefore a shallow water table should be continuously monitored and held within tolerable limits in order to control salinity and to maintain successful sustainable irrigated agriculture (Ayers and Westcot, 1994). In order to surmount these problems with groundwater, it is crucial to know the depth and salinity of the groundwater and their variation over time, and to take the necessary measures in line with the data obtained (Kara and Arslan, 2004).

Adequate knowledge on the status of groundwater depth and its temporal fluctuation 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 (Georgis et al., 2006; Tsige, 2000). However, information on spatial variability and temporal fluctuation of ground water depth in Fluvisols and Vertisols condition of the project area has not been reported sufficiently. Therefore, this study was conducted with the following objectives.

## Objective

(i) To study the spatial variability and temporal fluctuation of groundwater depth, under Fluvisols and Vertisols

areas of Amibara area, middle Awash, Ethiopia.

## MATERIALS AND METHODS

### Description of the study area

#### Location

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, including Melka Sedi, Melka Werer and Ambash-Sheleko irrigated farms with a gross command area of more than 15,000 ha. The elevation 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" 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).

#### 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, carbonatite, volcanic ash, tuff, pumice, and rhyolite parent materials (Italconsult, 1969; Heluf, 1985). 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 (Italconsult, 1969; Halcrow and Partners 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).

#### 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 (Yibeltal, 2009). 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°C, respectively. 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.

#### Land use/land cover

Since the establishment of irrigated agriculture, fragments of forest,

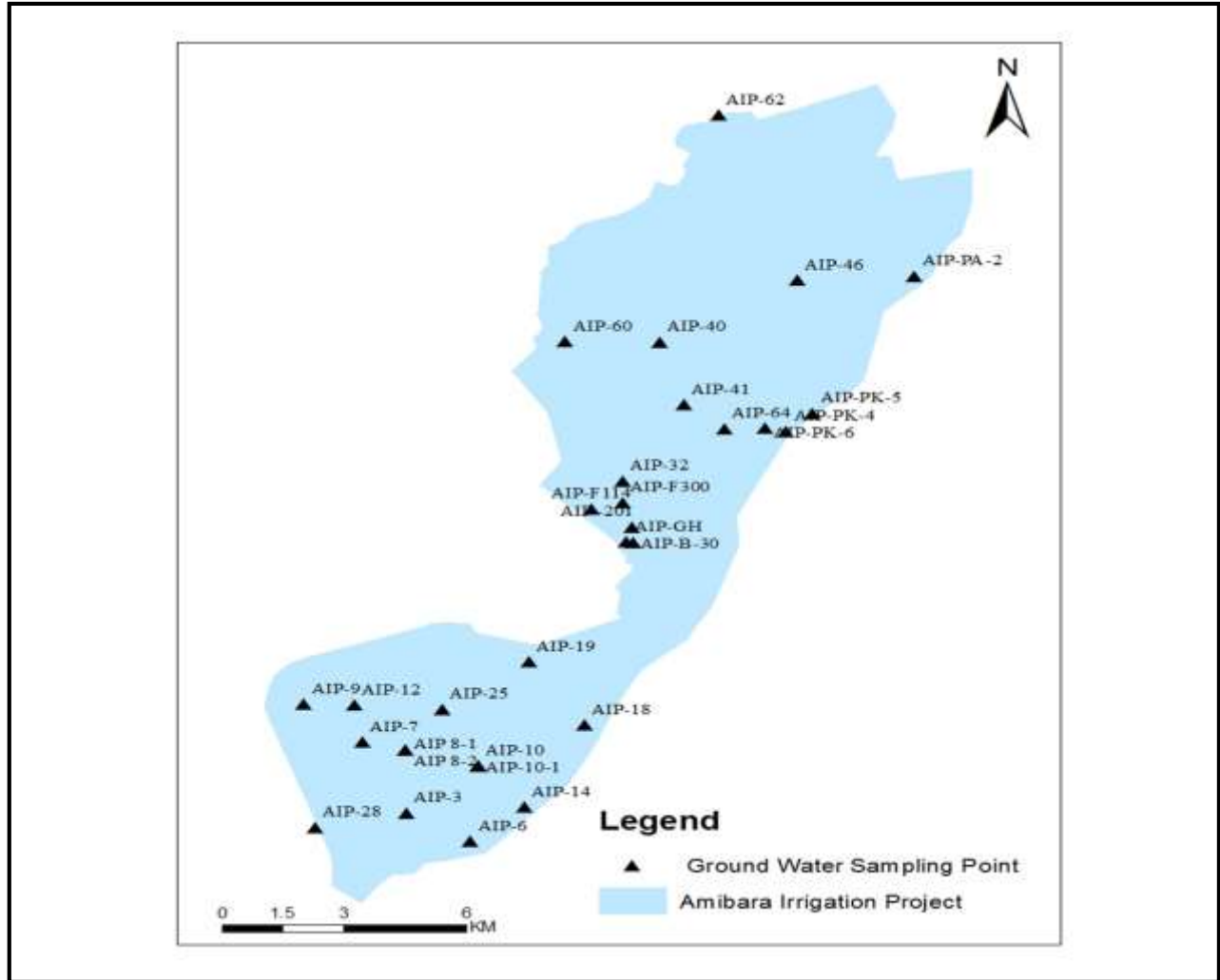


Figure 1. Location map of the study area.

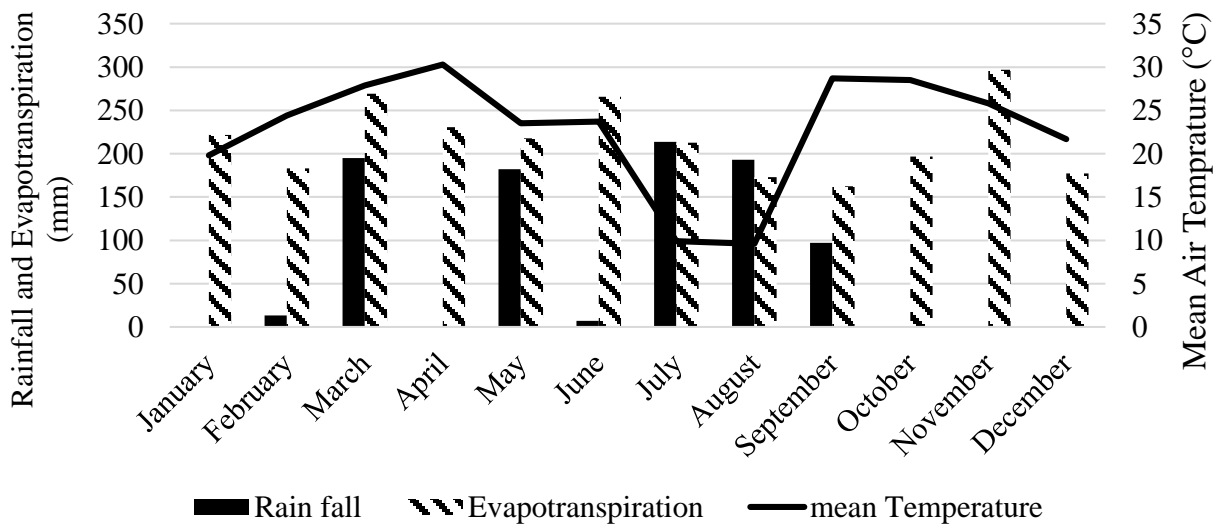


Figure 2. Mean annual rainfall, evapotranspiration and air temperature in the study area (January to December, 2017).

**Table 1.** Main land covers in the study areas and their management.

S/N	Field covers	Soil types	Piezometer points found in	Management
1	Sugarcane	Fluvisols	AIP-PA-2, AIP-14, AIP-3, AIP-18, AIP-19, AIP-7, AIP-28, AIP-9	All points Received irrigation water throughout the sampling periods except AIP-9 and AIP-28, which were not get in some months due to damage of the crop with animal attack
		Vertisols	AIP-46, AIP-64, AIP-PK-6, AIP-PK-5, AIP-PK-4, AIP-12 and AIP-25	All points Received irrigation water throughout the sampling periods
2	Cotton filed and forage	Fluvisols	AIP-F114, AIP-6, AIP-32, AIP-41, AIP-60, AIP-40, AIP-62	All points received irrigation water for some months except AIP-32, which get irrigation at all sampling months due to planting of onion after harvesting of cotton
		Vertisols	AIP-F300 and AIP-F201	Both of them get irrigation water in some months
3	Trees and shrubs field	Fluvisols	AIP-8-2, AIP-8-1, AIP-B30, AIP-10-1, AIP-GH and AIP-10	All the points in this field covers did not get any irrigation water except rain water during the sampling periods

mainly *Acacia neolithica*, are found along both sides of the Awash River bank (Chekol and Mnalku, 2012). Nowadays, an exotic tree species called *Prosopis juliflora* 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 found either in abandoned lands or simply they are non-irrigated land (Table 1).

#### **Irrigation water source and management**

Irrigated agriculture in the Middle Awash Valley started in the late sixties. When irrigation was introduced, the soils of the farmed area were non-saline and the ground water table was below 10 m. An excess of even small amounts of some salts, but when applied for a long time, coupled with poor agricultural practices and drainage, may radically affect soils (Inayathulla and Paul, 2013). 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 irrigated 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 areas, 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. The destruction and inadequate drainage facilities are among the main causes of soil salinity problems and water-logging especially near the irrigation canals and in low-lying areas. Even on those lands developed by Amibara Irrigation Project with properly designed field, tertiary, secondary and main surface drains, the system is not properly functional and did not remove the excess water from the fields to the drain canals then to the river downstream of the farms, due to lack of proper maintenance of the drainage canals.

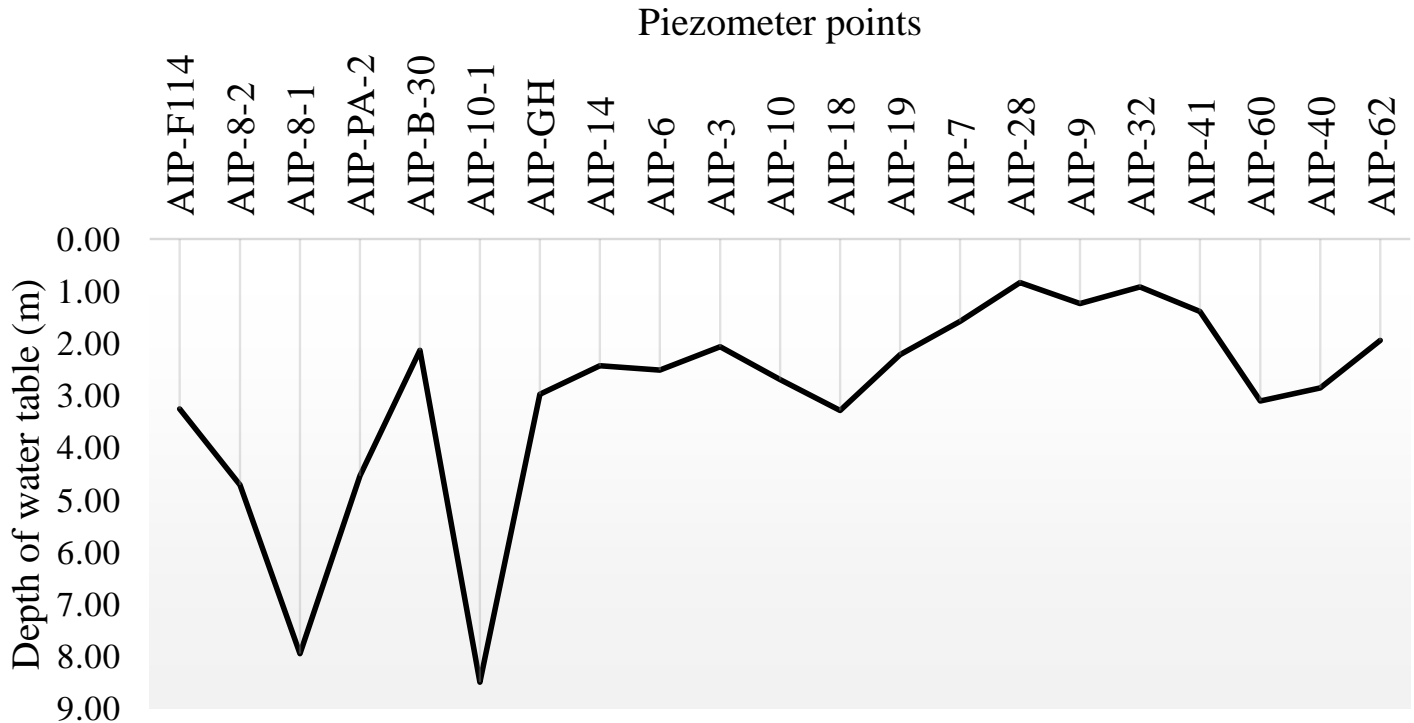
#### **Assessment, maintenance and installation of piezometers**

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, additional, 14 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 using auger tubes. A hole having around 6 cm in diameter down to below the lowest expected water table level was augured. A section of PVC pipe was placed into the hole. The diameter of the pipe was 4 cm. 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 cm in the pipe, slots were made with a drill over the distance where the water table might fluctuate. Finally, the space 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 Hanson et al., (2006).

#### **Groundwater table measurement**

Depth of water tables from each of the thirty piezometers were



**Figure 3.** Mean ground water table values of different piezometers in Fluvisols areas.

recorded for five consecutive months (August to December, 2017) to see its seasonal fluctuation. A steel tape (calibrated in mm), with a weight attached to it, was lowered into the pipe to below the water level. The tape was then pulled up and the length of its wetted part was measured. The water level below the reference point was obtained by subtracting the wetted depth from the total lowered length (Jerry, 1989).

#### Data analysis

All collected data were subjected to descriptive statistics and their range and mean were determined in excel sheet. Based on the mean values spatial variability while using five months data recordings, temporal fluctuation of groundwater depth was discussed. To show the spatial variability and temporal fluctuation of groundwater depth the data were presented using different form of graphs.

## RESULTS AND DISCUSSION

### Groundwater depth in fluvisols and vertisols

The mean value of groundwater depth data for different piezometers of AIS are presented in Figures 3 and 4 for Fluvisols and Vertisols, respectively. According to the values recorded at different location of Fluvisols, the ground water level varied from minimum value of 0.83 m at AIP-28 to maximum value of 8.5 m at AIP-10-1 with a mean value of 3.01 m from the ground surface. This highest variation could be due to differences in irrigation

management where, irrigation was applied throughout the year at AIP-28 located near the main canal, whereas there was no application of water in AIP-10-1 because this area was covered by tree plants. Similarly based on the values recorded at different locations of Vertisols, the ground water level varied from 0.86 m at AIP-25 to maximum value of 2.28 m depth at AIP-F201 with a mean value of 1.47 m from the ground surface. Similar as in Fluvisols, shallower water table were recorded in all piezometer found in areas covered by sugarcane crop as compared to one piezometer AIP-F201 (2.28) found in the field covered by cotton crops.

Generally shallow groundwater depth less than 2 m from the ground surface was recorded in six (29%) piezometers found in Fluvisols and eight (89%) piezometer points located in Vertisols. Relatively deep groundwater depth greater than 2 m from the ground surface was recorded in fifteen (71%) and one (11%) piezometers found in Fluvisols and Vertisols, respectively. Similar results was reported by Olumana et al. (2009), stated that groundwater table depth in Metehara sugar estate area, in general, is categorized as shallow (< 3 m). It is under severe condition (< 1 m) at the Abadir extension (South of Lake Basaka), North, East and Awash sections of the plantation and in moderate range (1- 3 m) in the other areas (away from water bodies).

The five months mean values revealed occurrence of deeper water table in Fluvisols (3.01 m) than in Vertisols (1.47). This variation could be due to higher water holding

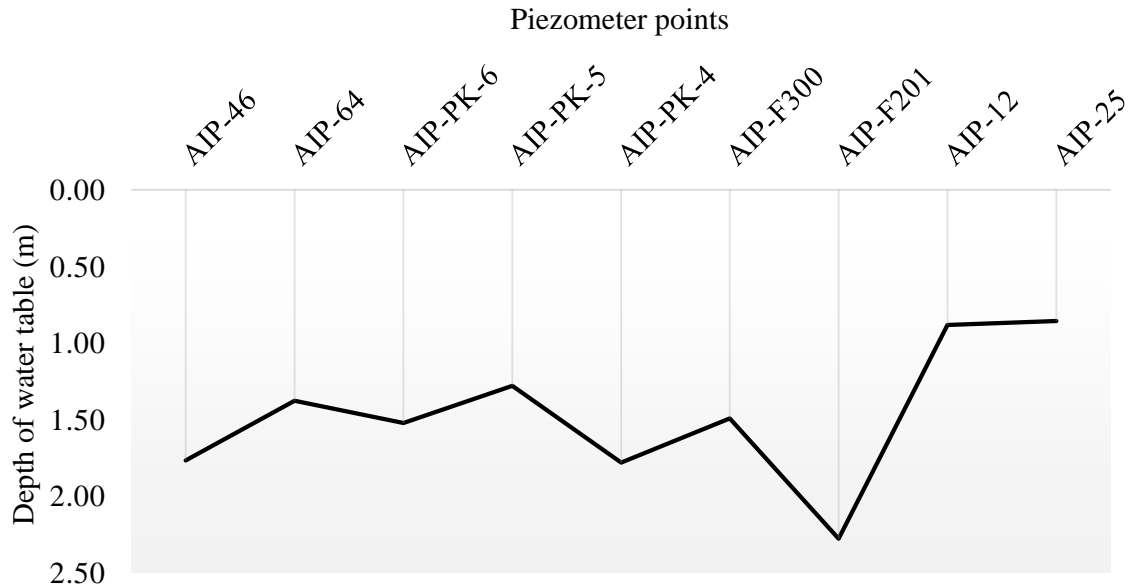


Figure 4. Mean ground water table values of different piezometers in vertisols areas.

capacity and low permeability of Vertisols as compared to Fluvisols which have high infiltration rate and low water holding capacity because of their coarse texture. The result agreed with the findings of Rengasamy (2006) who suggested that Vertisols (clay) 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. According to Campbell (1985) report the upward movement of water in fine textured soil (clay) is slow but covers a long distance. On the other hand, in coarse textured soil (sand), the upward movement of the water is quick but covers only a short distance. The author suggested that in fine clay soil water move more than 80 cm up to several meters through capillary system, as compared to 20 to 50 cm and 50 to 80 cm in coarse and medium textured soil, respectively

#### Spatial variability of groundwater depth in different field covers

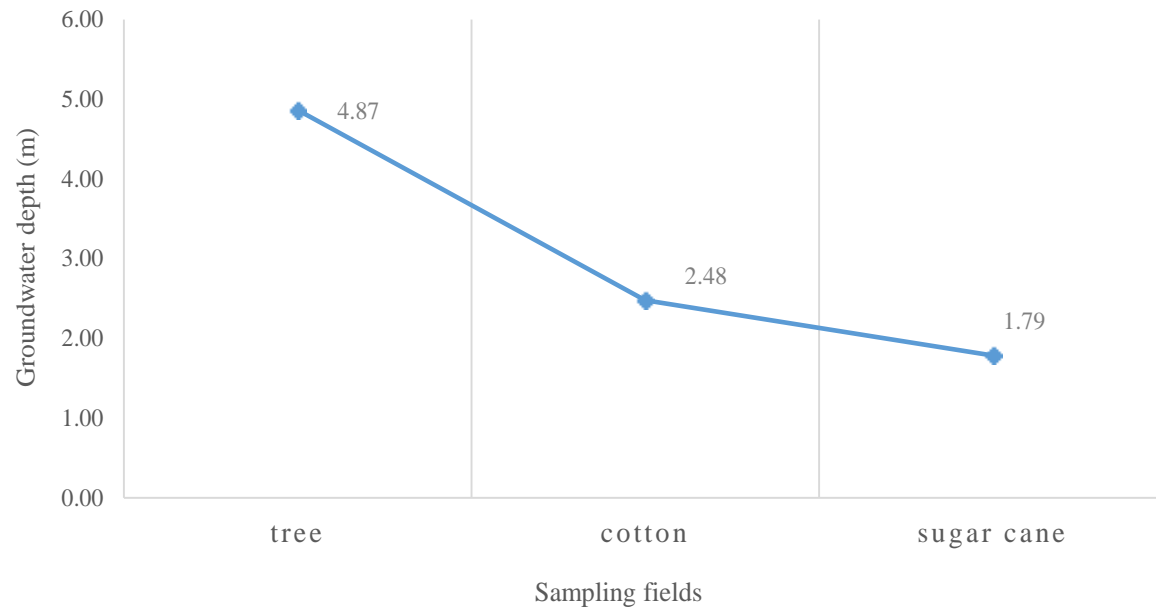
The mean groundwater table showed variation in depth according to the field cover. Relatively shallower water table was recorded in cultivated land than tree and shrub fields (Figure 5). Shallow water table below 2 m was recorded in sugarcane field located near primary and secondary canals, receiving irrigation water throughout the year compared to cotton and tree fields. However, relatively deep water table of greater than 2 m was recorded in most piezometers found in fields covered by cotton crops and tree plants. Similar results was reported by Paulo et al. (2016) stated land use and land cover changes have the potential to modify the groundwater

recharge rates. The author reported that replacement of dense cerrado area with cropland increased groundwater recharge. On the other hand, replacement of open cerrado area with forest trees such as eucalyptus may reduce recharge rates. Similarly Foster et al. (2000) and Leduc et al. (2001) stated irrigated crop-cultivation practices change the soil-water regime and modify groundwater recharge rate, where flood irrigation techniques with surface water are practiced on permeable soils, they are a major source of groundwater recharge and often the predominant one in arid terrains.

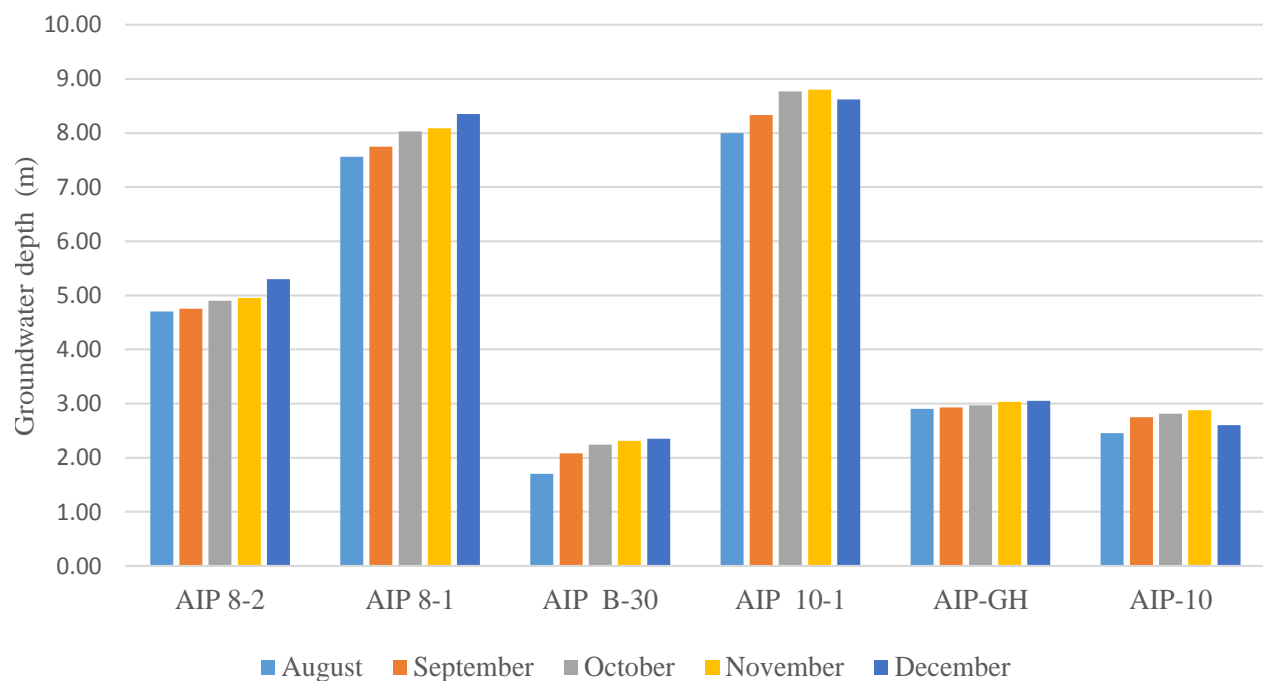
Generally, piezometers which were found in fields covered by tree plants showed deepest water table as compared to those which were located in fields covered by sugarcane and cotton crops. The reason for deep water table in those piezometers which were located in tree plants may be associated to low application of irrigation water and their high ground water uptake through their deep root system than field crops. The result agreed with the findings of Wood et al. (1998) who indicated that with no irrigation, the water table depth draws down significantly compared to irrigation field which showed rise in water table level. Heuperman et al. (2002) also suggested that biological drainage uses the transpirative capacity of vegetation and especially trees, to cope with elevated ground water table (GWTs) in the landscape by enhancing their discharge or/and reducing their recharge.

#### Temporal fluctuation of groundwater depth in different field covers

The five months temporal trend of groundwater table



**Figure 5.** Mean ground water table values of different piezometers in different field covers.



**Figure 6.** Temporal trend of groundwater table in trees and shrub fields.

observation data for different piezometers of AIS are presented in Figures 6, 7 and 8 for fields covered by shrubs and trees, cotton and sugarcane crops in soils of amibara irrigated schemes, respectively. The temporal trend of the groundwater depth was mostly influenced by the field cover and irrigation practices undertaken on

each fields covers. As explained in Table 1, the fields covered by shrubs and trees never get irrigation water throughout the year. However the fields covered by sugarcane get irrigation water throughout the year while cotton field irrigated some months of the year during the cotton growing periods. Most of the piezometers revealed

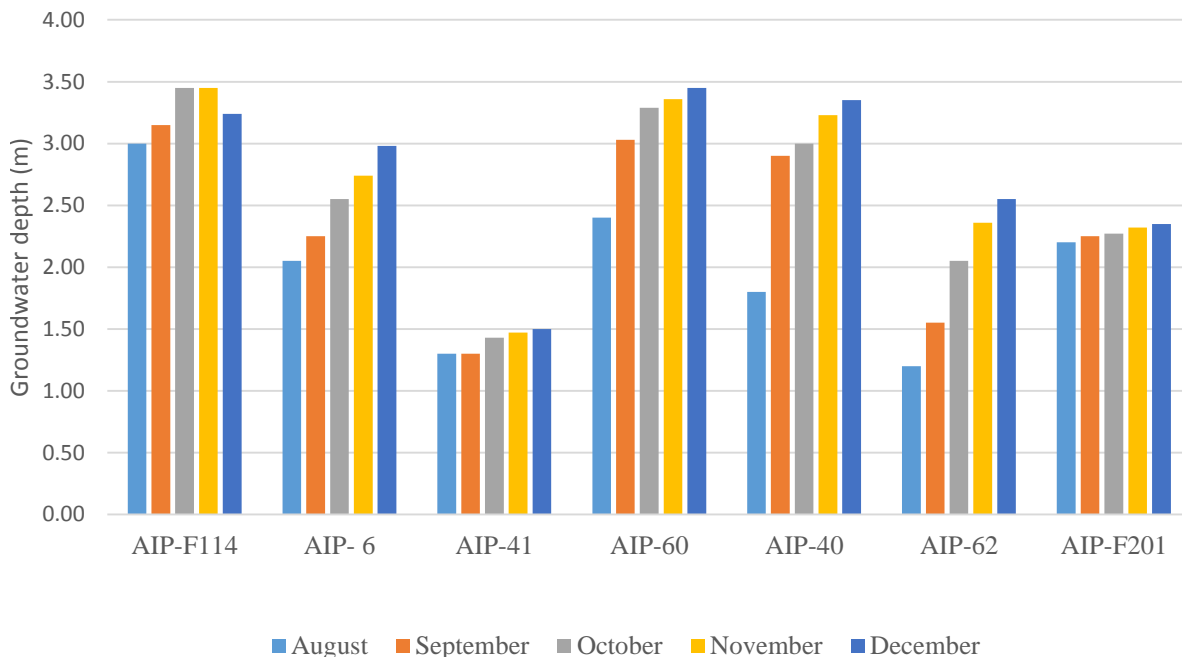


Figure 7. Temporal trend of groundwater table in cotton fields.

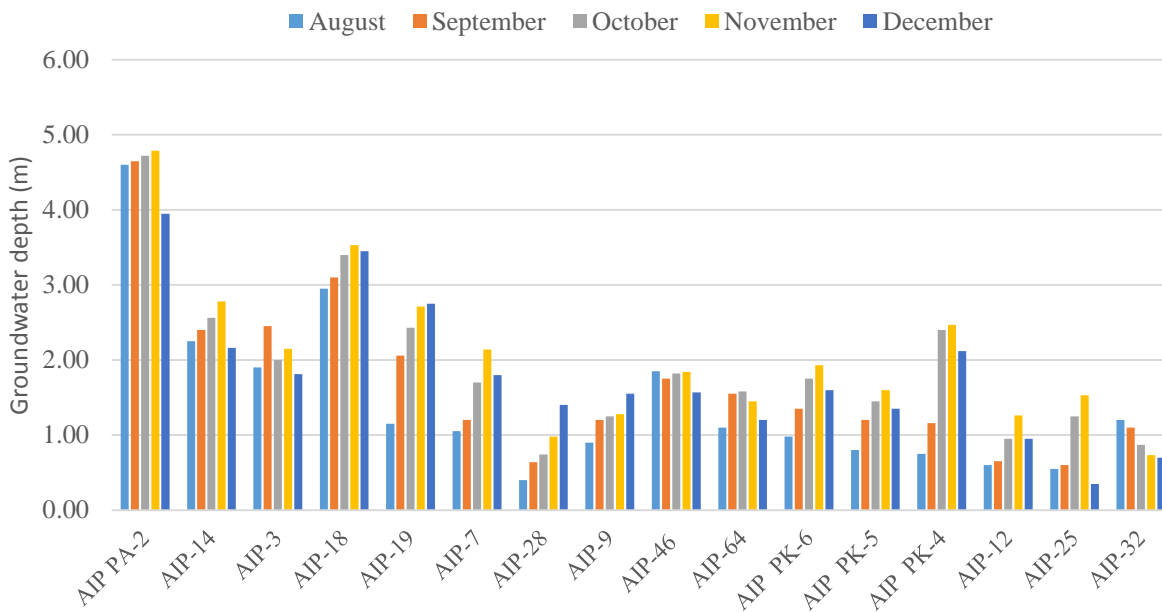


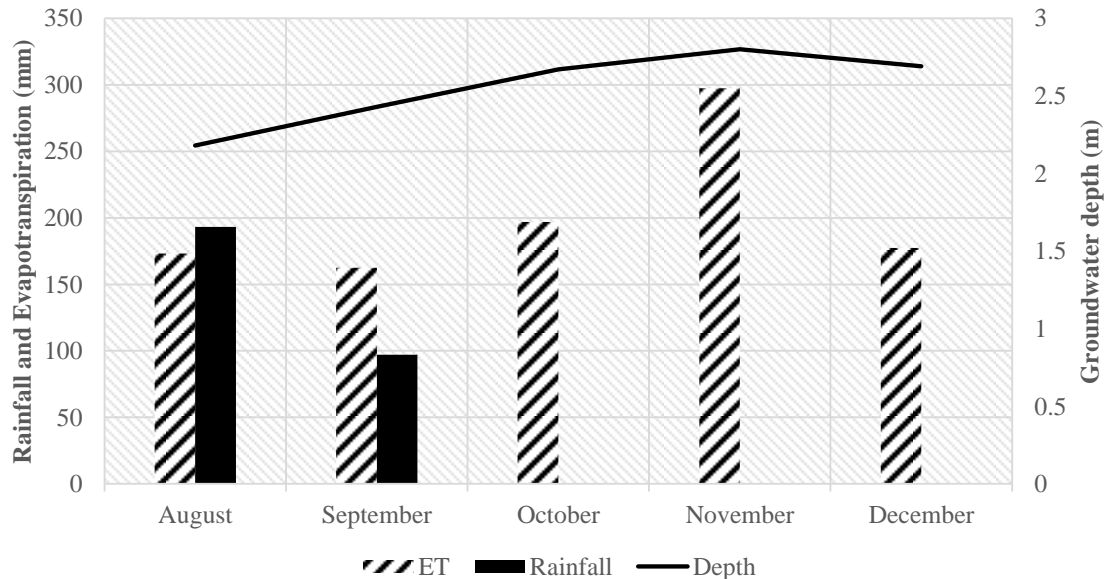
Figure 8. Temporal fluctuation of groundwater depth in sugarcane field.

a marked change in water table from September to December. The depth groundwater decreased from the surface along the sampling months, due to reduction of in the amount of rainfall, irrigation water application to the fields and increasing trend of temperature and evapotranspiration.

Based on the above scenario in all piezometers points

found in in filed covered by trees, shrubs and cotton crop field showed a straight increasing trend (Figure 7) in the depth of groundwater from the surface to the lower part (that is, the level of the groundwater reduced and lowered). The reasons for straight decrease in water table in piezometers found in areas covered by tree plants may be related to the decrease in rainfall, an





**Figure 9.** Groundwater level trend with varying rainfall and evapotranspiration.

increasing trend of evapotranspiration and also high water usage property through the deep root system of the trees. Similar trends also observed in some points found in sugarcane but failed due to different reasons. However all other piezometer points located in sugarcane field showed a non-uniform (increasing or decreasing) trend in groundwater depth fluctuation (Figure 8). But one piezometer (AIP-32) which was found in the field covered by onion crop after the harvesting of cotton crop showed a straight rising trend to the ground surface.

The reason for decrease in water table for the piezometers found in cotton field, may be due to stoppage in the application of irrigation water after the month of October to these fields. But for the case which showed an increasing trend in water level to the ground surface was associated with excess and frequent application of irrigation water throughout the sampling months, since the field was covered by onion after the harvesting of cotton crop. Non-uniform trend of water table could be associated with the variation and coinciding of irrigation water application and time of recording the water table along the investigation periods. Water table data recorded soon after the application of irrigation water showed an increasing trend towards the surface while for those points recorded when the irrigation water in the soil is depleted showed a decreasing trend from the ground surface.

In general out of 30 sampling points found throughout the Amibara irrigation scheme, about 56.7, 3.3, and 40% showed a straight decreasing trend from the ground surface, straight increasing trend towards the ground surface and non-uniform trend, respectively.

Generally, the Amibara irrigation system receives a huge amount of water recharge from rainfall, surface

runoff and irrigation, but the latter is responsible for the rising of groundwater levels. The reason for rapid rate of rise in water table is due to lack of adequate subsurface and surface drainage systems used to discharge the excess water which is not used by the crops, out of the irrigated area. This agreed with the causes for the ground water fluctuation and soil salinity study in central and southern Iraq as reported by Qureshi and Al-Falahi (2015). Similarly, an inefficient on-farm and off-farm management of irrigation water has contributed to a water table rise in the AIS. This is in line with the findings of Mills (1989), who concluded that conveyance losses from the water distribution system and deep percolation losses from croplands contribute more to a water-table rise than rainfall.

#### **Relationship between groundwater depth and climatic data**

The groundwater level is governed by various factors. Climate change, as reflected in precipitation and evaporation rates, influences the groundwater level fluctuation (Chen et al., 2004). In this study shallower water table were recorded during occurrence of high rainfall and low evapotranspiration in August and September (wet season), however the opposite occur during November and December, resulting recording of deep water table. The groundwater level increased after the precipitation events and then decreased gradually with evaporation. The groundwater tables varied within the period from wet to dry seasons and showed seasonal variations because of the seasonal distribution of precipitation and evaporation (Figure 9). Chen et al.

(2002) also found that climate trends have high correlations with groundwater level variations in southern Manitoba. Precipitation infiltration was a key recharge source of shallow groundwater as well as the major recharge source of groundwater (Yong et al., 2011). Shao-feng et al. (2015) also reported, occurrence of shallowest water level due to frequent and sufficient rainfall during the wet season. While during the dry season, the groundwater level fluctuated within a narrow range with low precipitation.

## Conclusion

Effective control of salt affected soil requires a good knowledge of the causes, extent and degree of surface soil salinity/sodicity. Reliable and up-dated information on the spatial variability and temporal fluctuation of groundwater depth, is required to effectively manage the limited natural resources. Therefore, this study was conducted to study the spatial variability and temporal fluctuation of groundwater depth under Fluvisols and Vertisols areas of Amibara area, Middle Awash, Ethiopia. Thirty monitoring piezometers found in both Fluvisols and Vertisols areas were used in this study. Depth of water table from the ground surface were recorded for five months. Data recording of the groundwater depth were conducted for five consecutive months from August to December 2017, once a month to evaluate the seasonal fluctuation of groundwater from the surface of the soil.

Based on the five months field measurement of groundwater depth, shallow water table were observed in all sampling points. The mean ground water level values indicate the occurrence of spatial variability in depth of water table from the ground surface at the sampling points. Generally about 29 and 71% of the piezometers in fluvisols and 89 and 11% in vertisols, revealed water table from the ground surface shallower than 2 m and deeper than 2 m, respectively. From this, most of the piezometer in Vertisols areas had groundwater depth shallower than 2 m as compared to those found in Fluvisols area. On the other hand groundwater depth was influenced by the type of field cover and irrigation practices taken place during the sampling periods. Relatively deep water table was recorded in fields covered by shrubs and tree plants as compared to cotton and sugarcane. Seasonal fluctuation of groundwater depth also seen during the study period. From the study groundwater depth was influenced seasonally with the climatic condition and irrigation practices occurred at the study area. Variation in rainfall and evapotranspiration along the sampling period influenced the depth of water table. The depth of groundwater from the surface of the earth decreased with increasing in evapotranspiration and decreasing amount of precipitation. In general from the study, shallower water tables were recorded in most piezometer points in both soil types (Fluvisols and

Vertisols) in the Amibara irrigated project area, which is resulted from poor irrigation management and destruction of surface and subsurface drainage structures to drain and remove excess water. Generally groundwater depth varied with soil type, irrigation water management and climatic condition (Rain fall and Evapotranspiration).

## RECOMMENDATIONS

Therefore, based on the present findings the following recommendations can be drawn;

- (i) Regular monitoring and evaluation of groundwater depth is required to control the accumulation of salt and to protect the irrigated land from abandonment derived from groundwater salinity through capillary rise
- (ii) Proper maintenance and construction of secondary and tertiary canals to protect seepage and lateral losses
- (iii) The amount of water applied to the field should be based on the crops water requirement and soil properties to reduce ground water recharge
- (iv) Maintenance of surface and subsurface drainage structures should be implemented to remove excess water from the system and to regulate and maintain ground water level at optimum level
- (v) Implementing crop rotation to control rising of groundwater depth using deep rooted crops.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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