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Original Research

Monitoring and Characterization of Waterlogged Irrigation Fields in the Fincha'a Watershed, Nile Basin of Western Ethiopia

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Abstract

Waterlogging is becoming the major threat to the sustainability of cultivated land in Fincha'a Valley Sugar Estate (FVSE). In the present study timely and accurate detection of waterlogged areas through piezometer monitoring and remote sensing indicators, along with their characterization and severity classification has been made. Accordingly, spatial maps of average GWT depth of the last 12 years (2000 to 2012) were produced in a Geographic information system (GIS) (ArcGIS 10.3) environment from 40 groundwater monitoring piezometer data. Results of the study revealed that FVSE, after nearly 20-25 years of irrigation, is experiencing a serious water logging problem. About 324.4 km^2 (75.5%) of the delineated sugarcane plantation fields are severely waterlogged and 105 km^2 (24.5%) are critically waterlogged. The study also revealed that the GWT depth for all selected sugarcane plantation fields is very shallow in summer (0.5m) compared to autumn (0.8m), spring (1.1m) and winter (1m) seasons. The groundwater depth is extremely shallow (<1m below ground) in most of the sugarcane plantation fields throughout the entire season and showed great spatio-seasonal variability. Despite the fact that winter is the driest season, GWT depth of the season kept shallow (1m) which shows factor that control GWT in the study area is not only rainfall. It was identified that GWT depth at FVSE was extremely shallow, at all seasons, exceeding the critical depth (1.5 m) recommended for sugarcane crop. The seasonal fluctuation and spatial variability of GWT in the sugarcane plantation fields is owing to excess irrigation water application, nature of the soil, topography and high seepage from water bodies and poor drainage system; hence are the main causes for water logging (GWT rise) problem in the study area. The rate of annual increment of groundwater rise, coupled with seasonal fluctuation, has obvious repercussions and grave consequences for the sustainability of Fincha'a Valley Sugar Estate. The serious problem of the rising GWT can be tackled by adopting improved irrigation water management practices, designing drainage system and further geological investigations. Therefore, it is highly suggested to critically study the causes, consequences and solutions of the waterlogging problem (GWT rise) in a concerted and integrated manner to get out of this vicious problem.

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INTRODUCTION

In cultivated terms, the soil should be considered waterlogged when the water table is within such a distance from the surface of the ground that it reduces the crop production below its normal yield that would be expected from the soil type of that area (Harshika, 2011). In physical context, an area is said to be waterlogged when the water table rises to an extent that the soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of air and decline in the level of oxygen that further increases the level of carbon dioxide. The actual depth of water table, which is considered to be harmful, would depend upon the type of crop, the type of soil and the quality of water and the period for which the water table remains high. The actual depth of water table when it starts affecting the yield of the crop adversity may vary over wide range from zero for the paddy to about 1.5 m for the other crops. The crops, which otherwise, would have grown in the wet season cannot be grown then due to high water table (Megersa *et al* 2013).

For sugarcane crop, the groundwater contribution increases as a function of increment in GWT depth (Kahlown *et al.* 2005). Kahlown and Azam (2004) recommended the critical depth resulting in a decrease of sugarcane yield is 1.5m below the ground. Harshika (2011) reported that the yield of sugarcane crop suffered when the water table depth is less than 1 m. Furthermore, the shallow GWT, in cultivated fields, can cause crops to perish and fields become inaccessible for machinery and harvesting operations (Asmuth and Knoters, 2004).

Waterlogging is often compounded by soil compaction. However, reduced tillage and permanent bed systems may alleviate soil compaction and the severity of waterlogging. Cloudy weather associated with wet seasons may enhance the waterlogging effect as well as the incidence of some cotton diseases. Low rates of evaporation and reduced radiation (sunshine) may encourage waterlogging and reduction in yield. Monitoring diagnosis and mapping of waterlogged area in irrigated agriculture is a perquisite for management of valuable land resources. GWT monitoring can reveal whether the GWT depth is rising, falling or remaining static and hence, used to identify the areas at risk of soil salinization (Megersa, 2010a). A trend of GWT under irrigated agriculture can provide an early indicator of an increased risk of soil salinity and vice versa (Harshika, 2011). A rise in groundwater results when irrigation induced recharge is greater than the natural discharge. Groundwater rise has subsequently led to waterlogging and the related salinity problems in many irrigated land around the world, which has happened where the pace of drainage development is not in balance with irrigation development, or where maintenance of drainage has largely been neglected (Tanji and Kielen, 2002).

The main factor challenging the sustainability of the sugar estate is the rise of GWT depth to the crop root zone. The major cause for the rise of GWT depth in the area is an intensive use of furrow irrigation system for long periods of time, coupled with poor drainage systems (Megersa, 2010b). GWT rising to the crop root zone is one of the most unfavorable effects of irrigation projects, which occur slowly, and its problem tends to emerge over years (Kahlown and Azam, 2005; Megersa, 2010a). The adverse impacts of shallow GWT depth to human health, environment, and crop production are well documented by different (local and international) studies (Kahlown and Azam, 2002; Khan *et al.*, 2005; Chaudhari *et al.,* 2008; Megersa, 2010a).

Geographic information system (GIS) offers an excellent alternative to conventional techniques in monitoring and assessing the extent of waterlogged and saline areas. In the past, several studies have demonstrated the usefulness of remote sensing and GIS techniques in detecting and monitoring waterlogged areas and saline/alkaline soils. Some scientists have used visual interpretation technique for the mapping of waterlogged areas and salt affected soils in IGNP Command areas (Mandal and Sharma, 2001). Mothikumar and Bhagwat (1989) studied the salt affected land using Landat at 1:50,000 scale by visual interpretation. According to FAO/UNEP (1984) guide lines GWT depth < 2 m are critically waterlogged areas: GWT depth which ranges from 2-3 m is considered to be potentially waterlogged, whereas GWT > 3 m is considered to be deep and hence, safe from waterlogging (Masoudi *et al.*, 2006; Megersa, 2010a).

High temperatures tend to exacerbate the negative effects of waterlogging. The GWT depth < 3 m is expected to contribute to the crop evapotranspiration (Kahlown *et al.,* 2005) and effect of GWT is increases when the depth is less than 1m. In waterlogged fields, sucrose inversion may result, which affects the sugar quality and quantity. Waterlogging also affects the nutrient and water uptake of roots by restricting root development, which is limited by moisture, aeration and temperature. Plant roots are susceptible for lack of oxygen for respiratory processes when drainage is inadequate (under anaerobic condition) or soils are heavily compacted (Megersa, 2004). Estimates of the global extent of irrigation-induced soil salinity vary, but there is widespread agreement that the twin menaces of waterlogging and salinization represent serious threats to the sustainability of irrigated agriculture in many arid and semi-arid regions (Mohamedin *et al.,* 2010). Therefore, this study was carried out with the objective to investigate waterlogged areas, along with their characterization and severity classification in the FVSE.

MATERIALS AND METHODS

Geographical Environment of the Study Area

Fincha’a Valley Sugar Estate (FVSE) is located in the western highland of Ethiopia, within the Nile basin, Ethiopia and bounded by the Amhara National Regional State in the north, Guduru District in the South and East, Horro District in the west and Jarte and Amuru District in the North West (Figure 1). It lies between 1055000 m and 1109500 m N and 302000 and 338000 m E. The elevation in the watershed varies from 892 to 2520 meters above sea level (masl). The littoral and alluvial deposits of recent sediments underlie the area (Getahun *et al*., 2013b). Fincha’a River originates from the Chomen and Fincha’a swamps on the highland and divides the scheme into west and east banks and joins the Nile River of Western Ethiopia. Many streams join the Fincha’a River, the main tributaries being Agamsa, Korke, Fakaree, and Boye from the western side and Sargo-Gobana, Aware, Sombo, and Andode from the eastern side (Getahun *et al*., 2013b).

The thirty two years (1979-2011) climatic data from the FVSE Meteorological Station recorded a yearly average rainfall of 1315 mm (Figure 3) which is characterized by unimodal rainfall pattern. About 80% of the annual rain falls between May to September. Its mean annual maximum and minimum temperatures are 30.5 and 14.8^0C, respectively (Figure 2). The average annual relative humidity is about 84 % (Seleshi *et al*., 2007). The FVSE has alternate wet (during May to October) and dry (during the rest of the months) seasons. Wind speed in the FVSE is low as the surrounding escarpments hinder wind movement. However, wind speed is high between the months of March to June (Worku, 1995; Ademe, 2001 and Amhed, 2007). The soils in the FVSE are made of alluvia land colluvial materials from the surrounding escarpments (Bezuayehu, 2008). Six major soil types were identified in the FVSE areas of which Luvisols and Vertisols are predominant (Getahun *et al*., 2013a). These soils account for more than 95 % of the cultivated and irrigated land.

As indicated in the figure 3, maximum rainfall in the area is obtained in July while minimum rainfall is on January. Furthermore, the rainy season in the area is summer while winter is the dries season.

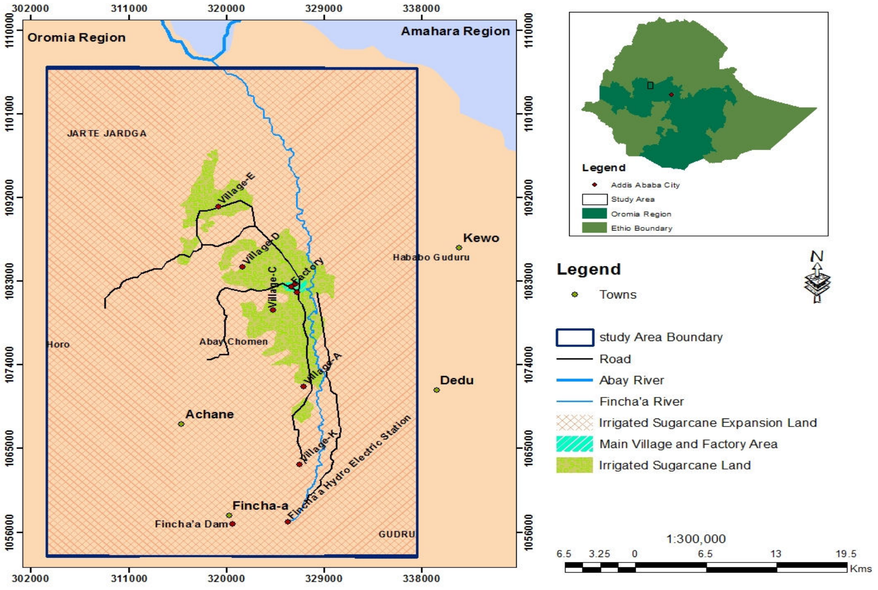

Figure 1: Location Map of the Study Area

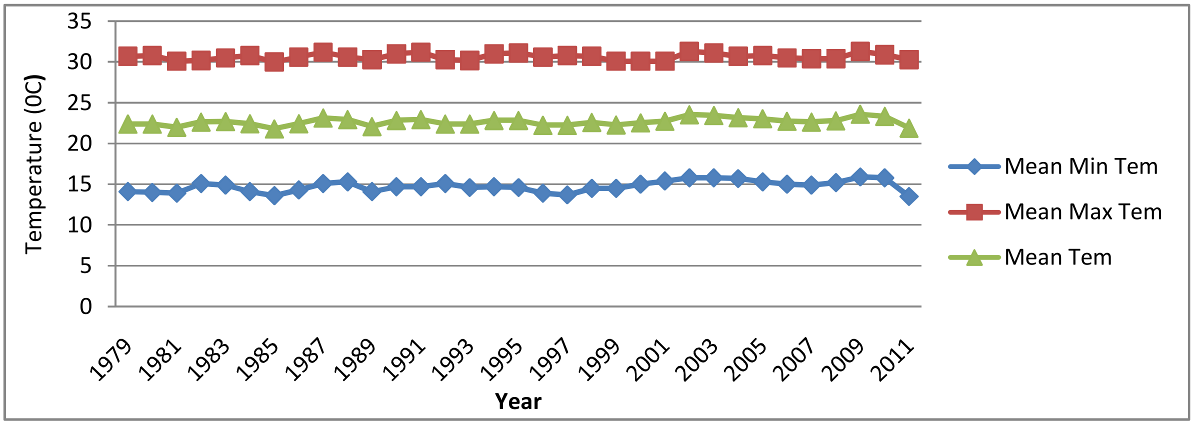

Figure 2: Mean, Mean Minimum and Mean maximum Temperature of the Study Area

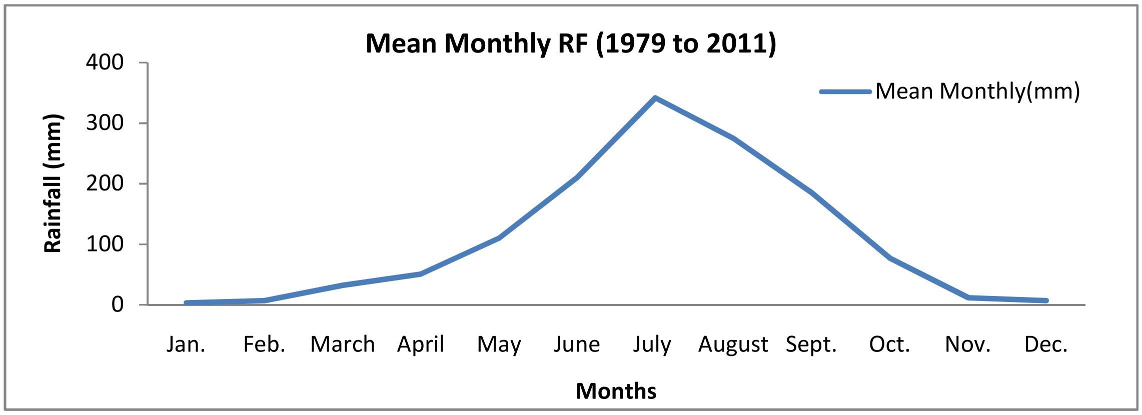

Figure 3: Mean Monthly Rainfall for the year 1979 to 2011.

Piezometer Installation and Groundwater Monitoring

A total of 28 piezometer tubes (F=80 mm and Length = 3 m) were installed in November 2010 to characterize the seasonal behavior and spatial variability of GWT depth of the study area. The piezometers are all PVC tubes and fairly distributed in the area. Different sources of water like (irrigation canals, streams and drainage canals), slope and soil type were taken into consideration for the selection of piezometer sites. The PVC tubes were installed manually using auger tubes. The locations (latitude, longitude and elevation) of each piezometer (Table 1) were registered using hand held GPS.

Table 1: Piezometer identification and coordinates

		Coordinates (UTM)		
Piezometer ID	**Field No**	**X**	**Y**	**Z**
PS	614	324770	1085353	1458
PS	604	324630	1083347	1461
PS	626	317112	1087492	1494
PS	115	327163	1069866	1465
PS	213	327239	1072310	1546
PS	205	325865	1071779	1591
PS	206	325878	1071933	1592
PS	356	320045	1091201	1446
PS	375	327007	1078071	1492
PS	412	327029	1078062	1456
GO	134	326714	1080603	1463
GO	216	324630	1083347	1468
GO	219	324517	1082446	1480
G0	207	323009	1084158	1477
GO	219	324517	1082446	1480
GO	227	326094	1084349	1418
GO	266	322454	1084656	1476
G0	311	327693	1080101	1459
GO	316	327922	1099667	1439
EGO	819	318010	1088821	1483
EPS	510	329783	1070440	1564
EPS	404	330413	1067462	1597
PS	114	327278	1069859	1534
PS	213	327239	1072310	1546
PS	220	322044	1084333	1486
PS	221	326804	1072774	1558
PS	320	327382	1074827	1508
PS	329	327183	1076187	1493
PS	358	327152	1078545	1462
GO	151	327019	1081228	1454
PS	227	326094	1084349	1418
GO	254	323156	1086264	1437
PS	111	327065	1068758	1458
PS	513	325645	1085546	1445

X = Longitude, Y = Latitude, Z = Altitude, UTM = Universal Transverse Mercator,
PS = Pump Station, GO = Gravity off take, EPS = East Bank Pump Station, EGO = East Bank Gravity off take

Data Analysis and Mapping

Monthly monitoring of groundwater depth monitoring was commenced as of January 2010, until December 2012; with the monitoring frequency of two readings per month. Water levels were monitored using a graded contact gauge that provides sound and light signals when it touches water in the tube. Care was taken to collect the GW levels in all tubes within a minimum possible time. The previous GW records (2000-2009) were obtained from the database of FVSE. The Digital Elevation Model (DEM) (30m resolution) was downloaded from Shuttle Radar Topography Mission (SRTM). Ground water table data of the year (2010-2012) were collected from the readings of the pre-installed piezometers and groundwater monitoring commenced which are spread all over the study area (Table 1). Topographic maps with sufficient accuracy to determine the expansion of Fincha'a Valley Sugar Estate are not available for the past decades. Therefore an attempt was made to use Landat imagery, which started observation in the early 1970's, for mapping currently irrigated sugarcane fields. The selected images were all cloud free and cover Fincha'a Valley Sugar Estate. A Digital CAD format Plantation (base) map showing all the roads, irrigation & drainage networks, field plots, Fincha'a river was collected from the Department of Civil Engineering of the Fincha'a Valley Sugar Estate and the 1980 Fincha'a top sheet (scale 1:50,000) was purchased from the Ethiopian Mapping Agency (EMA).

The DEM was processed in ArcGIS environment for the study and the surrounding area, assisted by topographic and plantation base maps. The piezometer readings were analyzed in an excel spreadsheet to monthly, seasonal, and annual values for each piezometer. Any missing data were filled by regression analysis. Then, the extent of waterlogging was mapped from point-monitored data showing the piezometric surfaces. The spatio-seasonal maps of GWT depth were produced in ArcGIS 10.3 using the Inverse Distance Weight (IDW) interpolation technique. With the help of these maps, detailed explanations were provided regarding the waterlogged condition of the area for each of the four Ethiopian seasons (winter, autumn, summer, and spring) represented by four months (winter, spring, summer, and autumn), respectively. Furthermore, water table depth ranges, area coverage and waterlogging condition of the study area were analyzed.

The DWDG is seamless GWT representation and reclassified into four distinct classes viz. most critical/severe (GWT< 1m), critical (1m < GWT < 2m), less critical (2 <GWT<3m) and not critical/moderate (GWT > 3m), following the FAO/UNEP (1984) guidelines (Masoudi *et al.,* 2006).

RESULTS AND DISCUSSION

Characterization and Severity Classification of Waterlogging in the FVSE

Pizometer data obtained from groundwater monitoring was used for the delineation of waterlogged sugarcane plantation fields. Waterlogged sugarcane plantation fields in the FVSE are delineated, the status of GWT depth and sensitive irrigation fields to waterlogging are shown in Table 4.2 and Figure 4.5. The study revealed that average GWT in the sugarcane plantation fields for ranges from -0.2 to 1.6 m. In general, the results showed that GWT depth of the sugarcane plantation fields is categorized as very shallow (< 2 m) and hence, varied from severe with GWT depth <1m (94.7%) to critical with GWT depth from 1 to 1.6 m (4.3%) waterlogging condition (Table 4.2). According to Kahlown *et al*., (1998) and Kahlown *et al.,* (2005) water table rises as a consequence of poor drainage design, poor water management and is expected to contribute to the crop evapotranspiration. The GWT depth for most of observed sugarcane plantation fields in the FVSE was < 1 m and this can affect the yield of sugarcane (Harshika, 2011).

Zhao *et al*. (2004) reported the importance of shallow GWT for soil salinization for other similar areas. It seems that the shallow perch GWT leads to high capillary movement of water in such areas and increases the risk of salinization and land degradation provided the water is saline. Kahlown and Azam (2002) reported the GWT depth 1.5m below the ground is the critical level recommended for sugarcane crop and shallower GWT will result in a decrease of sugarcane yield. This coincided with current situation in the FVSE**.** The delineated sugarcane plantation fields critically and/or severely waterlogged have low topography and the soils are heavy textured (Vertisols) with very high available water holding capacity and slow infiltration rate. This was implication of the effect of topography on GWT rise. The study also revealed that all of the delineated sugarcane plantation fields had the GWT depth value < 2 m below the ground. This condition of GWT depth will affect the plant available water and water productivity. As a principle, the lower the GWT depth impels water is available at shallow depth while the higher GWT depth value means water is at deeper level which shows available water in the study area is found at shallow depth and the study area is reach in groundwater. In general, GWT rise correlates negatively with the slope of the area.

Furthermore, intensive grazing, over population, intensive cultivation, the vegetation cover change, deforestation and land use/land cover changes, of the upstream area of the FVSE might be affected hap hazardously. This may trigger the cultivated runoff and soil erosion in the upstream areas. The cultivated runoff from the upstream may significantly worsen the downstream areas by polluting the quality of groundwater and rising water table of the plantation fields. The upstream farmers might use different inputs to cultivate various crops. These inputs such as fertilizers, herbicides, and insecticides might increase the ionization of the ionic constituents of the surface as well as GWT rise in the downstream.

Table 2: Severity classification of waterlogging at irrigation fields in the FVSE

WT depth (m)	Area (km^2)	Area (%)	Waterlogging condition
-0.2 to 0.2	8.7	2.1	Severe
0.2 to 0.5	67.5	15.7	Severe
0.5 to 0.8	248.2	57.7	Severe
0.8 to 1	82.4	19.2	Critical
1 to 1.6	22.6	5.3	Critical

Spatial and Seasonal Variability of GWT Depth for Selected Sugarcane plantation fields

Temporal (seasonal) and spatial variability of GWT depth for selected sugarcane plantation fields in the FVSE is displayed in Figure 4a/b and 5. Both on irrigation and off irrigation seasons were considered to identify the seasonal (monthly) fluctuations of GWT depth for these fields. The study revealed that the GWT depth for all selected sugarcane plantation fields is very shallow in winter compared to spring, autumn and summer seasons (Figure 6). The average GWT depth varies from 0.5 m in the summer to 1.1 m in the spring. During summer, almost all of the piezometers have very shallow GWT depth (<1.0 m) below the ground while, PS-513, PS 320 and PS-329 have shallower depth above the surface (-0.06, -0.04m and -0.02 m), respectively in almost all seasons and all of the selected piezometers sites have GWT depth below the critical (1.5 m) recommended depth for sugarcane yield crop reduction (Figure 41a/b). In general, the GWT depth of the area is very shallow and showed great seasonal and spatial variability. This implies that the selected sugarcane plantation fields fall under severe to critical waterlogging condition and exposed to sugarcane yield reduction. The average rainfall pattern of the study area (Figure 3) shows that winter is the driest season or has the lowest average monthly rainfall as compared to the other three seasons. The rising of GWT during this season may be an indicator of the change of GW flows from the upper stream, recharge from irrigation, phreatic GW, poor irrigation water management, nature of basement materials and drainage condition in the study area.

That means the contribution of salinity to the crop root zone is significant as the GWT depth is being becoming shallower and shallower. The sugarcane growth was observed to be stunted and out of production. Significant sugarcane plantation fields were abandoning, almost all Black cotton (Vertisols) because of their severe to critical waterlogging condition and GWT was rising to the surface in some sugarcane plantation fields (Table 1 and Figure 5). The result of the analysis showed that the average GWT depth in spring, summer, autumn and winter is about 1.1m, 0.5m, 0.8m and 1 m respectively. The result also revealed that GWT depth is very shallow in summer while relatively deep in winter, autumn and spring (Figure 6). However, the average GWT depth of the study area in all seasons is less than or equal to 1m which characterizes the selected sugarcane plantation fields as area with shallow water table.

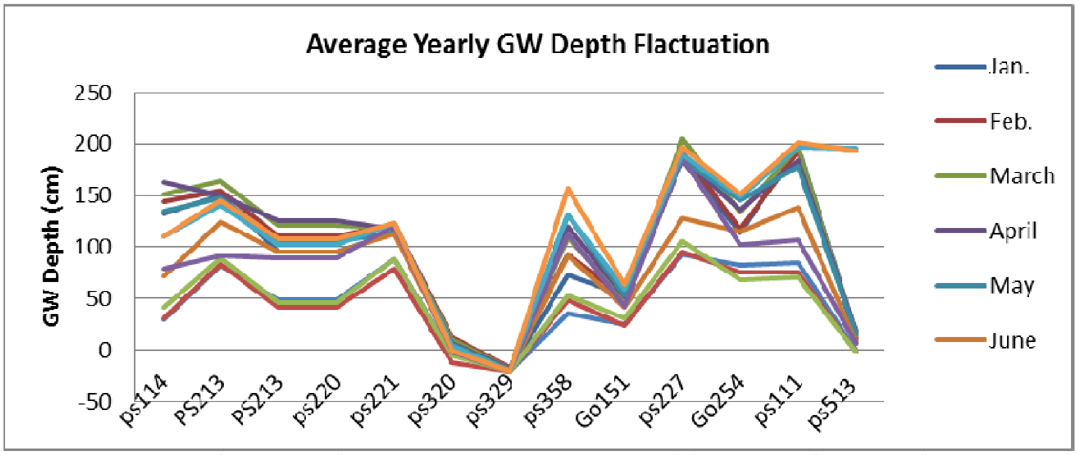

Figure 4a: Average yearly GWT depth fluctuation and spatial variation of GWT depth for some of the piezometer sites (2000-12). Piezometers are labeled by the field number of the plantation. Ps and Go refers to the Pump station and gravity off take, respectively for the piezometers installed in the FVSE.

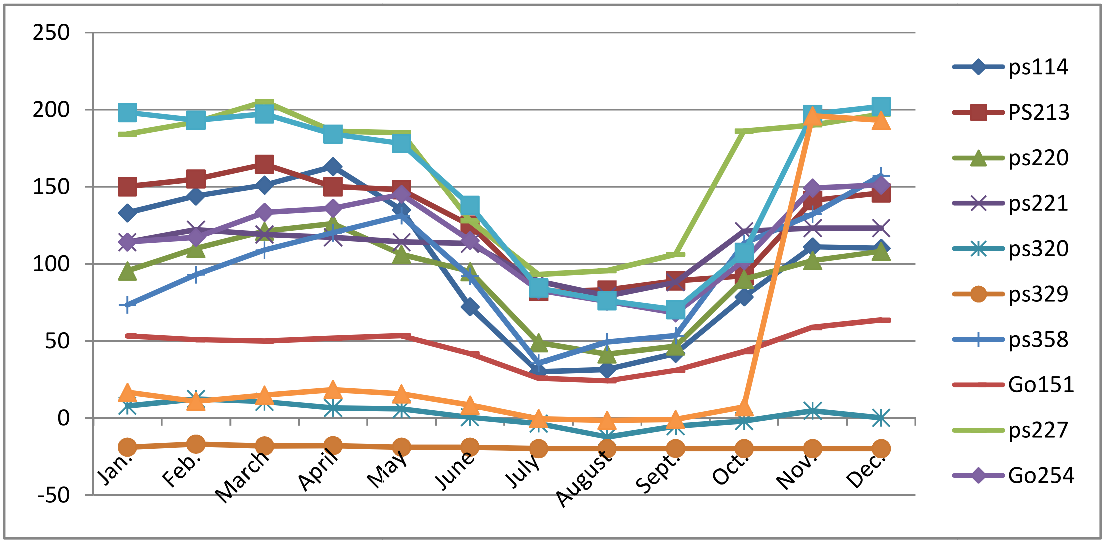

Figure 4b: Seasonal and spatial variation of GWT depth for some of the piezometer sites (2000-12). Piezometers are labeled by the field number of the plantation. Ps and Go refers to the Pump station and gravity off take, respectively for the piezometers installed in the FVSE.

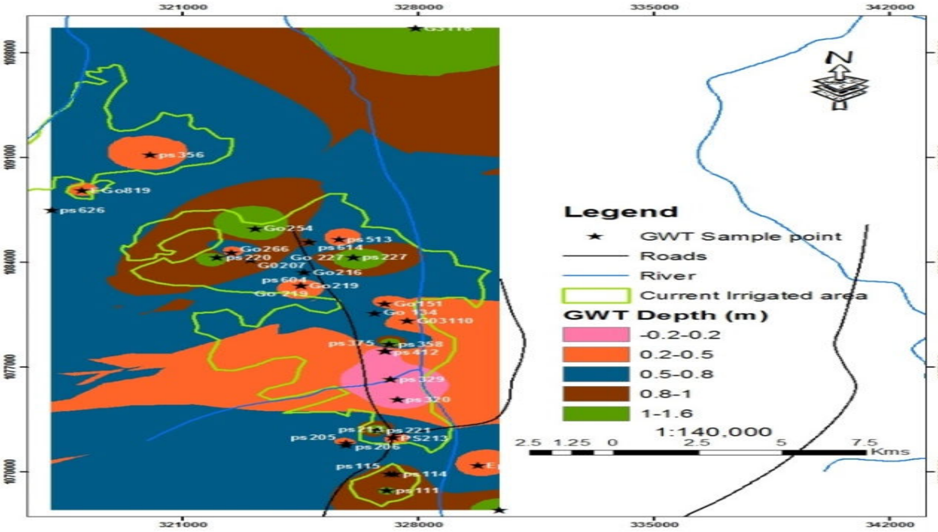

Figure 5: Spatial map of GWT in the FVSE indicating the waterlogging situation

During winter season the GWT depth varies from -0.2 to 2 m, with average value of 1 m (Figure 4a). About 62% of the selected sugarcane plantation fields have GWT depth < 1.0 m and have relatively had very shallow GW depth which are in line with the topographic feature of the area. From July to January, the GWT depth value in some selected sugarcane plantation fields or sugarcane plantation fields showed a slight increment (Figure 4b and 6) may be due to higher rainfall. Winter season is the dry period in the study area which is characterized by lowest rainfall (Figure 3). Hence, the plantation area is not under the influence of direct rainfall and runoff. Based up on this fact, a significant reduction in GWT depth has been inevitable during this period, which is actually not the case.

However, GWT depth of the study area, even in this dry season, is shallow (< 2m) and much less in some sugarcane plantation fields (PS-329 and PS-513) (Figure 4.4b). The possible sources for GW recharge during this season might be due to excess irrigation water, seepage from the irrigation and drainage canals and nature of the basement as identified (Getahun *et al*., 2013b). This was also mostly due to the poor performance of irrigation and drainage systems of the area. However, it is important to note that the minimum GWT depth significantly increased (from 0.47 m to 0.86 m), with the exception of (PS-329, PS-375, PS-513, PS-412, PS-320, GO-219, GO-3110, Go-266) which are with very shallow GWT depth during the main rainy season and remained shallower owing to their lower altitude (Figures 4a/b**)**. In spring season, the water table continued to decrease, but its magnitude is similar to that of the winter season and spring. The GWT depth varied from -0.2 to 1.96 m (Figure 4b), with average value of 0.8 m below the ground. About 50% of the plantation fields have GWT depth > 1 m and 8% of the plantation had GWT depth > 1.5 m and found to be safe from significant yield reduction. The sugarcane plantation fields (PS-114, PS-213, PS-220, and PS-111) have relatively deep GWT depth; whereas the sugarcane plantation fields (PS-320, PS-329 and PS-513) have relatively shallow GWT depth, which is in line with the topography of the area. During this season, sugarcane plantation fields (PS-154, PS- 227, PS-251, PS-111and PS-513), showed significant reduction in GWT depth (Figure 4a/b and4.6) compared to the preceding January (winter) season. This period, like spring and winter, is irrigation season, just prior to the summer (main rainy) season.

The Sugar Estate had difficulty in getting enough water for irrigation during this season; thus, sugarcane plant usually showed signs of wilting (moisture stress). The peak crop water demand and significant reduction of Fincha'a reservoir are the main reasons for the shortage of water at FVSE during this season; the later one is a major concern for sustainability of irrigation development in the Fincha'a valley, in general. The water shortage in the Fincha'a Reservoir, during this season was due to the harsh climatic conditions (high temperature, high ET, more sunshine hours, high humidity, low rainfall) and the peak water demand in the area in particular and most of the areas in the western region of the country.

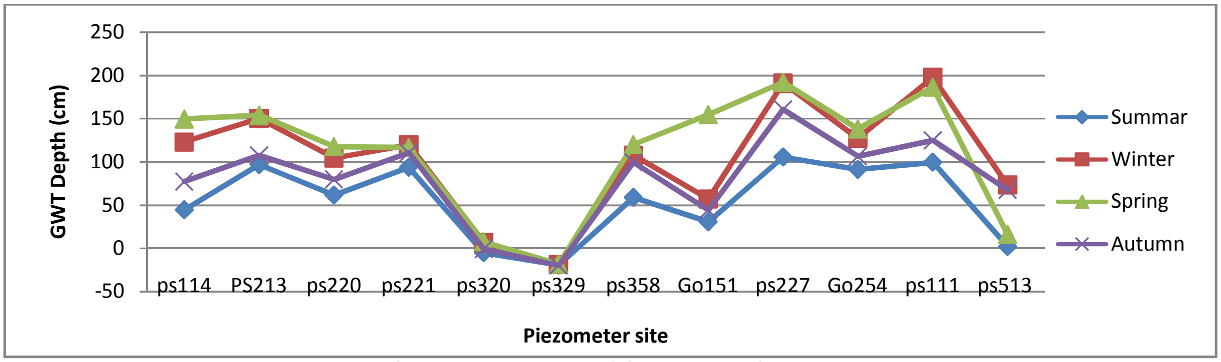

Figure 6: Seasonal Variability of GWT depth of the study area.

Climate change, ecological change and deforestation are expected to reduce water availability in the Fincha'a Reservoir in the near future and have negative effect on the sustainability of the irrigation development. Although this season is characterized by a small but occasionally appreciable amount of rainfall, it is compensated by the peak crop water demand, high evapotranspiration and reduced water application rates due to water shortage due to minimum effects of direct rainfall and the incoming runoff on GWT depth fluctuation. Furthermore, these areas are known to receive high magnitude of runoff coming from the upstream plateaus. From this result, it could be concluded that there was a change of GW flow pattern in this period, from the upstream to the downstream of the plantation; Thereby disturbing the normal drainage system of the area since water is usually drained toward the downstream.

This condition is especially challenging to water managers of the Sugar Estate. During the summer season**,** the GWT depth varied from -0.06 (at PS 513) to 1.4 (PS 111) m, with average value of 0.50 m below the ground surface (Figure 6). Almost more than half of the plantation has GWT depth< 0.50 m and the entire selected sugarcane plantation fields were severely waterlogged during this season. According to Table 2, more than 92% of the piezometers have GWT depth < 1 m below ground. This implies that the period is characterized by severe waterlogging conditions in the area (Figure 4b and 6) whereby GWT depth < 1 m above the ground surface has been recorded in PS-320, PS-329 and PS-513 with GWT depth -0.03, -0.2 and -0.-06 m, respectively mainly due to the basaltic nature of the basement rock.

Most irrigation fields have shown an extremely high rise in GWT depth compared to the preceding winter and autumn seasons (Figure 4b and 6). This might be the implication of the response of the GW depth to rainfall is quick and significant. Spring season**,** this period is the beginning of the irrigation season, following the dry season. The GWT depth varied from -0.18 to 1.97 m with an average of 1.1m below the ground surface (Figure 4b and 4.6). About 42% of the selected cane plantation fields have GWT depth < 1.0 m and hence are most critically (severely) waterlogged whereas 58% have the depth (1m < GWT < 2m) and critically waterlogged. The GWT depth was slightly reduced compared to the previous summer season. PS-151, PS-221, PS-358, PS-227, PS-251, PS-111and PS-231 have relatively shallow GWT depth compared with the other piezometer sites or cane plantation fields. During this period, PS-320, PS-329, PS-151and PS-513 had very shallow GWT depth (<2m) during the previous (summer) season. GWT depth during the summer season (Figure 4b), have shown greater reduction compared to the other parts. This showed that the GWT depth of the area would have been reduced significantly if drainage systems were effective. This ineffectiveness of the drainage system of the area, as discussed earlier, had an adverse effect on the GWT depth condition during the subsequent periods (winter and autumn).

The analysis of the data showed that the GWT depth in the FVSE was increasing during the spring season, which resulted in an average GWT rise of 1.5 m during this period throughout the selected sugarcane plantation fields. But the GWT decreased during the winter season. This was the implication of groundwater recharge. High GWT subsurface soil water in the FVSE has raised gradually near enough the nature of surface level to cause the moisture to move up by capillary action (the rate is high due to high evaporation rate). The magnitude and extent of waterlogging depends upon the soil structure which facilitates movement of soil water by capillary action. This can be observed from (Figure 4.4a) that the contribution of GW inflow in the study site lead to continuous accumulation of GW in the study area, which the GWT kept moving upward. Long-term monitoring provides evidence of this situation. Figure 7 shows the temporal variability of GWT during 2000-2012. It shows that GWT depth in 2000 and 2012 were at 0.64 and 0.7 m respectively, which indicates a rise in the GWT of 0.06 m in a span of 12 years. However, the maximum and minimum rises in the GWT were recorded at PS-320 and PS-329 (-0.2m) and PS-111and PS-227 (2.06 m), respectively. A continuously rising GWT caused waterlogging and enhanced flood problems in the studied piezometer sites, particularly during the summer season. These floods were further accented by man-made barriers such as roads, canals obstructing the natural flow of water. Waterlogging and flooding in the cultivated areas caused major damage to crops and soil fertility.

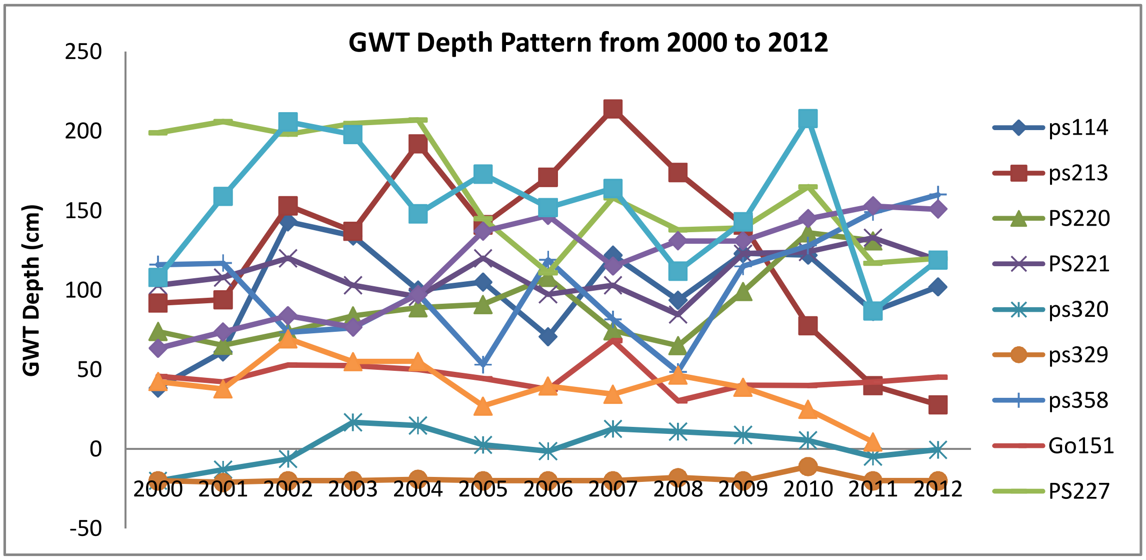

Figure 7: Temporal variability of GWT depth in the FVSE (2000-2012)

Trends in the Groundwater Depth in the FVSE of Piezometer Sites (2010-2012)

In Fincha'a Valley Sugar Estate problems due to irrigation were reported with regard to waterlogging. The GWT within the FVSE showed a rising tendency (Getahun *et al.,* 2013). This might be due to irrigation (seepage losses out of reservoirs and channels, over watering, etc) but also due to runoff from the upstream area. What has been reported before and confirmed in the field work are problems with a high water table and waterlogged fields. Especially on sugarcane plantation fields with heavy clayey soils problems with waterlogging have been discovered during the field study and soil analysis. The result showed that on some sugarcane plantation fields the GWT was very shallow (GWT < 2 m). The result also indicated that in some sugarcane plantation fields downward percolation of irrigation water below the root zone, especially in soils classified as heavy soils was so slow that it caused temporary storage within the root zone (in some places up to 10 days after irrigation). These drainage problems have even become one of the major factors in determining the composition of cane variety.

In sugarcane plantation fields located near irrigation canals and drains suppressed, stunted cane growth owing to waterlogging (seepage and GWT rise) were observed. The measurement of GWT of the FVSE showed the maximum GWT depth values in all years and months. The results indicated that sugarcane plantation fields which are located at low topography and on Vertisols were affected by rising GWT depth more than fields near to the distribution canals and nearby drains. Even this short measurement time series of 2010 to 2012 showed significant increasing trends of rising GWT. Sugarcane plantation fields of low topography, Vertisols and flat slope (ps-329, ps-320) were the most affected sugarcane plantation fields. The major cause for the rise of GWT depth in the area might be due to seepage from unlined irrigation canals, geological conditions, agricultural runoff, low topography and soil type, coupled with poor drainage systems.

The GWT depth within the FVSE showed a rising tendency (Table 3). This might be due to irrigation (seepage losses), agricultural runoff and over use of irrigation water. The average GWT depth for selected sugarcane plantation fields varied from -0.27 to 1.54 m (Ps-320), which had been observed during the field works and confirmed from the results as there were problems with a high GWT rise and waterlogging condition. Especially on sugarcane plantation fields with heavy clayey soils problems with waterlogging have been discovered during the field observation and its trend or extent was confirmed from the results of analyses. However, the lighter soils in relation to the heavy soils of the Sugar Estate seem to be of very good quality and not prone to negative impacts of waterlogging under the given conditions.

The investigation showed that most of selected sugarcane plantation fields had very shallow (GWT < 2 m) and in some sugarcane plantation fields downward percolation of irrigation water below the root zone, especially in soils classified as heavy soils was so slow that it caused temporary storage within the root zone in some places after irrigation (PS-205, PS-206, PS-375, PS-329 and Ps-320). These drainage problems have even become one of the major factors in determining the composition of cane variety. In sugarcane plantation fields located down irrigation canals and drains suppressed cane growth due to seepage and ground water table rise were observed. The measurement of GWT in the FVSE showed the maximum GWT depth values in all years and months. The results indicated that fields which are located at lower topography are affected by rising GWT depth more than sugarcane plantation fields nearby distribution canals and sugarcane plantation fields nearby drains. Even this short measurement time series of 2010 to 2012 showed significant increasing trends of rising GWT (Table 3).

Table 3: Spatial Trends in the GWT depth in the FVSE over two years (2010-2012)

		Coordinates (UTM)			**Average Yearly GW Depth (cm)**
Piezometer ID	**Field No**	**X**	**Y**	**Z**	
PS	614	324770	1085353	1458	82.08
PS	604	324630	1083347	1461	74.71
PS	626	317112	1087492	1494	66.54
PS	115	327163	1069866	1465	78.29
PS	213	327239	1072310	1546	34.67
PS	205	325865	1071779	1591	55.79
PS	206	325878	1071933	1592	41.13
PS	356	320045	1091201	1446	41.29
PS	375	327007	1078071	1492	-23.42
PS	412	327029	1078062	1456	6.31
GO	134	326714	1080603	1463	70.04
GO	216	324630	1083347	1468	72.25
GO	219	324517	1082446	1480	15.00
GO	207	323009	1084158	1477	101.13
GO	219	324517	1082446	1480	24.63
GO	227	326094	1084349	1418	146.25
GO	266	322454	1084656	1476	10.29
GO	311	327693	1080101	1459	25.42
GO	316	327922	1099667	1439	117.21
EGO	819	318010	1088821	1483	47.58
EPS	510	329783	1070440	1564	35.75
EPS	404	330413	1067462	1597	113.88
PS	114	327278	1069859	1534	94.08
PS	213	327239	1072310	1546	33.71
PS	220	322044	1084333	1486	133.42
PS	221	326804	1072774	1558	125.67
PS	320	327382	1074827	1508	-2.67
PS	329	327183	1076187	1493	-20.00
PS	358	327152	1078545	1462	154.58
GO	151	327019	1081228	1454	43.63
PS	227	326094	1084349	1418	118.54
GO	254	323156	1086264	1437	152.23
PS	111	327065	1068758	1458	102.92
PS	513	325645	1085546	1445	14.75

GO = Gravity off take, PS = Pump station, EGO = East bank gravity off take, EPS = East bank pump station

CONCLUSION

This study result clearly revealed that GWT depth in the FVSE was extremely shallow, at all seasons, exceeding the critical depth (1.5 m) recommended for sugarcane. It was characterized by a rise during summer and autumn, and a gradual decline in winter and spring due to water uptake by plants, decreased rainfall, increased GW discharge to streams and wetland. Consequently, the direction of GW flow pattern in the sugarcane plantation fields, as suggested earlier, was subject to change in summer and autumn based upon the seasonal GWT depth status and topography of the area. In post season the rise of GWT depth during the rainy season was not compensated by the fall of GWT depth during the non-rainy periods.

This was mostly due to the failure of the surface drainage system of the area to drain excess water from the fields. An attempt was made through application of geophysical (resistivity) method, in addition to topography, soil, poor water management and drainage, the basaltic nature of the basement rock and the recharge from direct irrigation and runoff from surrounding upstream escarpments could be the main causes responsible for the rise and fluctuation of GWT depth. Therefore, detailed investigations that include the entire possible causes of GWT rise and adoption of a feasible management strategy to limit a further rise of GWT depth in the area was highly suggested.

Long-term over irrigation had a cumulative effect on the rise of the GWT and could cause waterlogging and associated problems even if the border drains were effective in stopping the incoming runoff. Thus, efforts on the management of water resources, especially irrigation and drainage, in such areas were extremely important for the sustainability of irrigated agriculture. Moreover, reducing canal water releases into non-cane fields could also reduce net recharge to aquifer and integrated watershed management via understanding the physiographic, soil and hydrological differences in the irrigation fields is very useful to carry out further investigations.

Conflict of Interest

None declared.

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