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Severity Classification and Characterization of Waterlogged Irrigation Fields in the Fincha' a Valley Sugar Estate, Nile Basin of Western Ethiopia

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Abstract

Waterlogging is becoming the major threat to the sustainability of irrigated agricultural lands 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 groundwater table (GWT) depth were produced in a Geographic information system (GIS) (ArcGIS 10.2) 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 waterlogging problem. About 324.4 km^2 (75.5%) of the delineated 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 irrigation fields is very shallow in winter compared to spring, autumn and summer seasons. The seasonal fluctuation and spatial variability of groundwater table in the irrigated 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 waterlogging (GWT rise) problem in the study area. The groundwater depth is extremely shallow (<1 m below ground) in most of the piezometer sites (about 94.7% of the study area) throughout the entire season and showed great spatio-seasonal variability. 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 groundwater table 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.

Keywords: Waterlogging; Groundwater table; GIS; Piezometer; Drainage; Topography

Introduction

In agricultural 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 DIRU (Department of Irrigation, Uttar Pradesh) (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.

For sugarcane crop, the groundwater contribution increases as a function of increment in GWT depth Kahlown and Azam [1,2] recommended the critical depth resulting in a decrease of sugarcane yield is 1.5 m below the ground. Harshika [3] reported that the yield of sugarcane crop suffered when the water table depth is less than 1 m. Furthermore, the shallow groundwater table, in agricultural fields, can cause crops to perish and fields become inaccessible for machinery and harvesting operations [4].

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. Groundwater table monitoring can indicate whether the groundwater table depth is rising, falling or remaining static and hence, used to identify the areas at risk of soil salinization DNRE [5]. A rising trend of GWT under irrigated agriculture can provide an early indicator of an increased risk of soil salinity and vice versa [3]. 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 lands 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 [6].

The main factor challenging the sustainability of the sugar estate is

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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 [7]. Groundwater table 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 [1,2,7]. The adverse impacts of shallow GWT depth to human health, environment, and crop production are well documented by different (local and international) studies [2,7-9].

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 [10].

Mothikumar and Bhagwat [11] studied the salt affected land using Landsat at 1:50,000 scale by visual interpretation. According to FAO/UNEP [12] guide lines groundwater table depth <2 m are critically waterlogged areas; groundwater table depth which ranges from 2-3 m are considered to be potentially waterlogged, whereas groundwater table >3 m is considered to be deep and hence, safe from waterlogging [7,13]. High temperatures tend to exacerbate the negative effects of waterlogging. The GWT depth <3 m is expected to contribute to the crop evapotranspiration [1] and its effect is maximum when the depth is less than 1 m.

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 [14]. 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 [15]. 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 highlands 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 Fincha'a River originates from the Chomen and Fincha'a swamps on the highlands 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.

The thirty two years (1979-2011) climatic data from the FVSE Meteorological Station recorded a yearly average rainfall of 1316 mm 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 31 and 15ºC, respectively (Figure 2). The average annual relative humidity is about 84% 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 [16,17]. The soils in the FVSE are made of alluvia land and colluvial materials from the surrounding escarpments. Six major soil types were identified in the FVSE areas of which Luvisols and Vertisols are predominant. These soils account for more than 95% of the cultivated and irrigated lands.

As indicated in the Figure 3 above, 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.

Data source and analysis

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. Monthly bimonthly monitoring of groundwater depth monitoring commenced as of January 2010, until December l 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

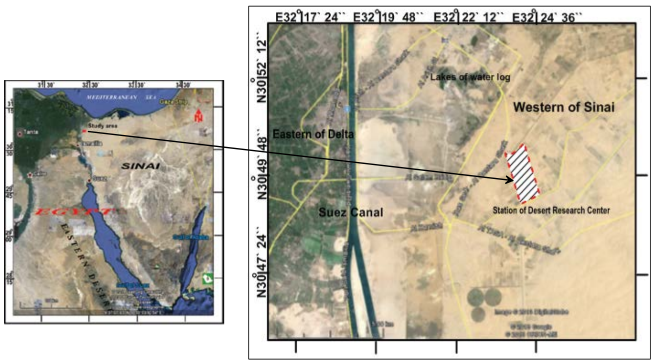

Figure 1: Location map of the study area.

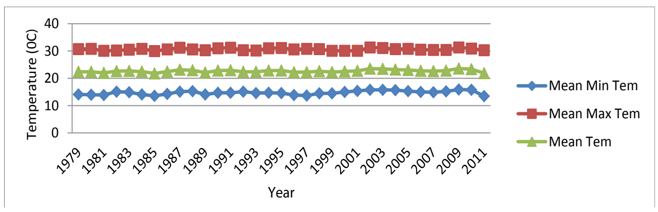

Figure 2: Mean, mean minimum and mean maximum temperature of the study area.

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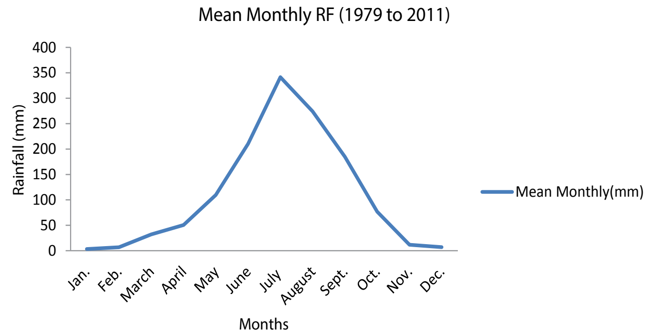

Figure 3: Mean monthly rainfall for the year 1979 to 2011.

WT depth (m)	Area (km²)	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

Table 1: Severity classification of waterlogging of sugarcane irrigation fields in the FVSE.

minimum possible time. The previous GW records (2000-2009) were obtained from the database of FVSE. The Digital Elevation Model (DEM) (30 m resolution) was downloaded from Shuttle Radar Topography Mission (SRTM). Ground water table data of the year (2011-2012) were collected from the readings of the pre-installed piezometers and groundwater monitoring commenced which are spread all over the study area (Figure 1). Topographic maps with sufficient accuracy to determine the expansion of Fincha'a Sugar Estate are not available for the past decades. Therefore an attempt was made to use Landsat imagery, which started observation in the early 1970's, for mapping current and expansion sugarcane fields. The selected images were all cloud free and cover Fincha'a Sugar Estate. A Digital CAD format Plantation (base) map showing all the roads, irrigation and drainage networks, field plots, Fincha'a river was collected from the Department of Civil Engineering of the Fincha'a 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 10.2 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 (January, April, July, and October), respectively. Furthermore, water table depth ranges, area coverage and waterlogging condition of the study area were analyzed (Table 1). The DWDG is seamless groundwater table representation and reclassified into four distinct classes viz. most critical/severe (GWT<1 m), critical (1 m<GWT<2 m), less critical (2<GWT<3 m) and not critical/moderate (GWT>3 m), following the FAO/UNEP [12] guidelines [13].

Results and Discussion

Characterization and Severity Classification of Waterlogging in the FVSE

Waterlogged plantation fields in the FVSE are delineated, the status of GWT depth and sensitive irrigation fields to waterlogging are shown in Figure 4. The study revealed that groundwater table of the study area ranges from -0.2 to 1.6 m. In general, the results shows that GWT depth of the field is categorized as very shallow (<2 m) and hence, varied from severe with GWT depth <1 m (94.7%) to critical with GWT depth from 1 to 1.6 m (4.3%) waterlogging condition (Table 1). According to Kahlown and Hutchinson [18-20] 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 plantation fields in the FVSE was <1 m and this can affect the yield of sugarcane [3] 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 [2] reported the GWT depth (1.5 m) 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 plantation critically and/or severely waterlogged fields 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 fields had the GWT

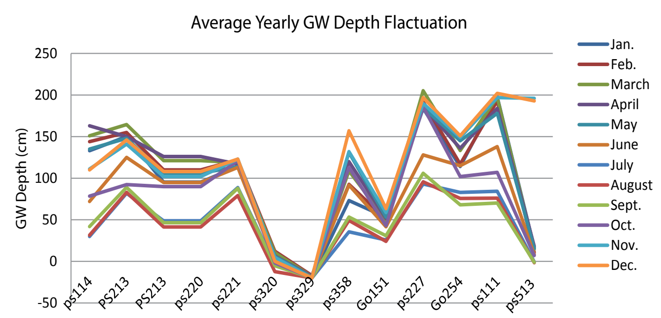

Figure 4: Seasonal and spatial variation of GWT depth for piezometers (2000-12).

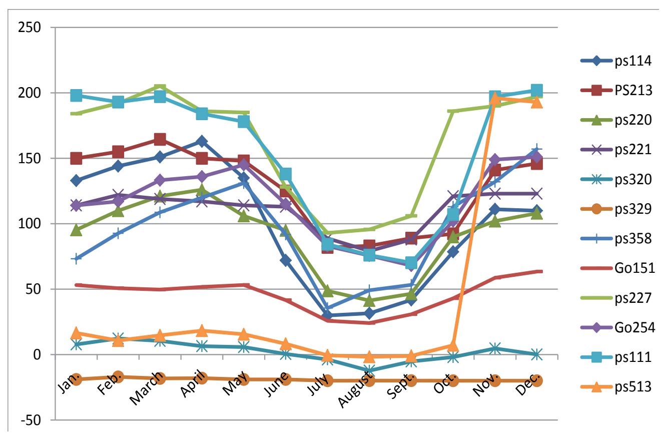

Figure 4A: Seasonal GWT depth of the study area.

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.

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 agricultural runoff and soil erosion in the upstream areas. The agricultural 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.

Spatial and seasonal variability of groundwater table depth for piezometer sites

Temporal (seasonal) and spatial variability of GWT depth for selected irrigated fields in the FVSE is displayed in Figures 4 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 irrigation fields is very shallow in winter compared to spring, autumn and summer seasons (Figure 4 and summary of Table 2). The GWT depth varies from 0.5 m in the summer to 1.09 m in the autumn. During summer, almost all of the piezometers have very shallow GWT depth (<1.0 m) below the ground while, Ps-513 and Ps-329 have shallower depth above the surface (-0.06 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.

In general, the GWT depth of the area is very shallow and showed great seasonal and spatial variability. This implies that the selected irrigation 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.

The above table shows the spatial and seasonal variability of some piezometer sites which have groundwater table depth from the year 2000 to 2012. The result of the analysis shows that the average GWT depth from March to May, June to August, September to November and December to February is about 1 m, 0.5 m, 0.8 m and 1 m respectively. The result also reveals that GWT depth is very shallow in summer while relatively deep in both winter and spring. However, generally, the average GWT depth of the study area is less than 1 m which characterizes the area as area with shallow water table.

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.

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 irrigated 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 irrigated fields (Table 1 and Figure 5).

During winter season the GWT depth varies from -0.2 to 2 m, with average value of 0.50 m (Figure 4C). About 62% of the selected piezometer sites have GWT depth <1.0 m and have relatively had very shallow GW depths (Table 2), which is in line with the topographic feature of the area. From July to January, the GWT depth value in some selected piezometer sites or irrigated fields showed a slight increment (Table 2) may be due to higher rainfall. Winter season (January, February and December) is the dry period in the study area, 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 GW levels 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 (<2 m) and much less in some piezometer sites (ps-329 and ps-513) as revealed in Table 2. 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 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) with very shallow GWT depth during the main rainy season and remained shallower owing to their lower altitude (Figure 4 and Table 2).

In autumn season, the water table continued to decrease, but its magnitude is similar to that of the winter season. The GWT depth varied from -0.2 to 1.84 m (Figure 4 and Table 2), with average value of 1.16 m below the ground. GWT depth is relatively less shallow in this season compared with all the other seasons. About 69% of the plantation fields have GWT depth >1 m and 24% of the plantation had GWT depth >1.5 m and found to be safe from significant yield reduction. The irrigated fields (Ps-114, Ps-213, Ps-220, Go-251 and Ps-111) have relatively deep GWT depths; whereas the irrigated fields (Ps-221, Ps-320, Ps- 329, Ps-154) have relatively shallow GWT depth (Figures 4A and 4B), which is in line with the topography of the area. During this season, irrigation fields (Ps-154, Ps- 227, Ps-251, Ps-111 and Ps-513), showed significant reduction in GWT depth (Figure 4C) 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.

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

Depth in (cm)		Coordinate			Months											
Year	**Field**	**X**	**Y**	**Z**	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct.**	**Nov.**	**Dec**
2000	ps114	327278	1069859	1534	74	70	78	60	60.5	42	3	4	6	4	54	5
2001	"				74	70	81	67.5	60.5	51	3.5	30	40	69.5	96.5	90
2002	"				198	155	147	257	141	116	27	28	72	129	221	224
2003	"				135	255	260	266	185	153	29	26	47	153	49	50
2004	"				44	92	254	266	177	61	17	16	26	65	90	92
2005	"				194	216	194	178	95	56	15	45	46	69	77	80
2006	"				107	19	18	17	35	65	6	4	0	145	212	220
2007	"				222	250	250	260	110	52	30	20	46	32	93	95
2008	"				128	130	152	147	150	107	62	24	28	37	79	80
2009	"				170	258	160	90	88	82	80	90	106	108	118	120
2010	"				169	171	164	233	254	80	80	77	70	79	42	45
2011	"				40	85	108	140	194	36	16	22	26	60	152	160
2012	"				174	101	97	135	200	40	20	24	30	70	160	168
Average					133	144	151	163	135	72	29.9	31.538	41.8	78.5	111	110
2000	PS213	327239	1072310	1546	42	90	158	154	133	57	48	76	33	14	145	150
2001	"				50	98	150	153	153	54	17	14	82	46	153	155
2002	"				184	177	130	193	130	193	108	105	102	108	204	206
2003	"				243	240	242	140	158	150	35	34	60	80	126	130
2004	"				245	245	245	245	245	245	108	105	102	108	204	209
2005	"				243	240	242	143	158	108	28	62	70	105	145	150
2006	"				145	145	187	180	195	200	193	129	80	215	187	190
2007	"				214	229	231	231	225	219	218	174	185	201	210	225
2008	"				132	141	195	206	208	183	183	177	154	159	171	178
2009	"				195	193	235	229	231	133	53	64	71	73	104	110
2010	"				103	74	71	59	63	63	65	62	59	64	121	126
2011	"				126	109	20	11	13	6	3	38	79	12	29	30
2012	"				25	28	33	12	14	10	6	40	80	15	30	40
Average					150	155	164.5	150	148	125	81.9	83.077	89	92.3	141	146
2001	ps220	322044	108433	1486	30	56	96	118	112	76	21	21	34	100	110	115
2002	"				91	82	80	98	90	28	19	18	24	118	65	70
2003	"				71	40	100	180	97	12	17	10	19	104	116	118
2004	"				112	130	122	99	55	130	19	27	25	110	84	92
2005	"				119	140	143	140	109	107	6	31	30	88	75	80
2006	"				114	110	173	170	131	126	8	6	6	95	75	78
2007	"				84	140	160	165	120	114	49	85	88	80	100	112
2008	"				92	102	120	110	113	105	39	23	26	39	60	65
Depth in (cm)		**Coordinate**			**Months**											
Year	Field	X	Y	Z	Jan.	Feb.	March	April	May	June	July	August	Sept	Oct.	Nov.	Dec
2009	"				80	104	98	88	76	45	11	20	32	33	96	98
2010	"				114	105	110	106	108	155	154	10	32	80	106	109
2011	"				98	158	144	138	157	121	121	120	120	112	168	178
2012	"				138	155	107	105	105	120	120	125	122	120	170	180
Average					95.3	110	121.1	126	106	94.9	48.7	41.333	46.5	89.9	102	108
2000	ps221	326804	1072774	1558	53	73	67	93	111	109	120	94	133	173	103	105
2001	"				59	60	61	121	117	110	153	84	107	179	119	120
2002	"				103	115	118	109	121	125	112	73	105	133	163	165
2003	"				127	103	115	101	94	71	77	82	103	150	107	109
2004	"				146	94	100	99	94	71	40	60	87	149	104	105
2005	"				142	162	151	132	163	120	56	104	63	84	127	130
2006	"				120	145	140	103	100	89	78	69	52	53	108	110
2007	"				113	154	183	149	93	105	81	42	31	100	89	90
2008	"				93	98	127	134	107	127	60	44	62	37	61	65
2009	"				95	98	139	129	97	158	97	82	136	138	153	156
2010	"				119	123	118	130	124	121	117	116	110	137	133	143

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2011	"				190	256	118	118	131	139	83	89	54	118	163	135
2012	"				128	108	109	104	125	130	80	90	100	120	165	163
Average					114	122	118.9	117	114	113	88.8	79.154	87.9	121	123	123
2000	ps320	327382	1074827	1508	-40	-11	-5	-10	-15	-40	-13	-30	-20	-13	-23	-20
2001	"				-8	-13	-4	-6	-14	-13	-28	-32	16	-5	-21	-24
2002	"				-10	-2	-6	-9	-1	-12	-9	-20	-16	9	6	-6
2003	"				12	24	40	41	40	-2	9	-7	6	21	9	10
2004	"				4	10	22	41	42	37	0	-9	-1	13	7	12
2005					15	-3	0	9	21	-1	-13	-8	-14	-6	14	18
2006	"				7	4	-11	-4	-6	-4	0.3	-10	-2	-9	9	10
2007	"				36	40	33	10	2	26	1	-3	-5	-1	6	8
2008	"				17	11	24	18	18	32	32	-4	-5	-8	-2	-1
2009	"				17	18	14	10	7	11	0	-2	5	8	8	10
2010	"				35	18	11	9	8	6	4	3	0	-10	-10	-8
2011	"				-13	40	-8	-10	-12	-14	-20	-18	-16	-12	29	-4
2012	"				29	24	26	-15	-15	-20	-12	-20	-16	-12	29	-4
Average					7.77	12.3	10.46	6.46	5.77	0.46	-3.7	-12.31	-5.23	-1.9	4.69	0.08
2000	ps329	327183	1076187	1493	-23	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2001					-20	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
2002					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2003					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Depth in (cm)		**Coordinate**			**Months**											
Year	Field	X	Y	Z	Jan.	Feb.	March	April	May	June	July	August	Sept	Oct.	Nov.	Dec
2004					-20	-20	-20	-20	-11	-12	-20	-20	-20	-20	-20	-20
2005					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2006					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2007					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2008					-20	-4	-16	-20	-20	-20	-20	-20	-20	-20	-20	-20
2009					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2010					0.5	0.4	0.8	0.7	-13	-15	-16	-18	-18	-20	-20	-20
2011					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
2012					-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Average					-19	-17	-18.2	-18	-19	-19	-20	-19.92	-19.9	-20	-20	-20
2000	ps358	327152	1078545	1462	0	33	122	165	192	183	8	6	47	145	242	245
2001	" "				19	46	147	180	169	25	16	10	118	162	252	258
2002	" "				18	80	141	130	177	70	22	12	24	170	17	20
2003	" "				110	198	235	41	108	32	21	9	32	89	18	24
2004	" "				37	57	112	130	164	158	31	16	32	110	162	165
2005	" "				11	25	55	25	14	8	6	42	10	9	212	220
2006	" "				230	240	231	230	224	12	18	12	8	87	68	70
2007	" "				165	200	26	130	68	54	11	13	15	59	118	120
2008	" "				23	26	54	33	22	28	12	10	9	16	170	180
2009	" "				183	34	69	160	165	115	28	61	129	131	150	160
2010	" "				123	130	148	180	216	126	129	121	109	153	45	50
2011	" "				32	30	73	80	190	192	160	167	160	171	266	267
2012	" "				120	106	79	78	180	190	145	160	160	171	266	267
Average					73.2	92.7	108.7	120	131	91.8	35.5	49.154	53.3	113	132	157
2000	Go151	3227019	1081228	1454	52	49	57	63	58	55	18	20	34	48	46	50
2001	" "				50	56	18	36	55	38	26	24	45	50	53	55
2002	" "				50	48	48	50	72	43	24	23	24	55	98	100
2003	" "				74	60	85	74	50	19	39	17	38	62	55	58
2004	" "				71	67	74	65	72	27	10	26	32	52	50	55
2005	" "				46	52	60	80	46	57	16	18	40	20	46	50
2006	" "				46	24	47	56	60	28	16	15	16	42	46	54
2007	" "				69	42	51	49	45	45	42	46	51	69	151	160
2008	" "				42	40	44	48	25	28	12	11	9	18	41	45
2009	" "				40	46	40	68	66	51	30	26	24	23	32	35
2010	" "				40	41	38	48	42	51	36	30	28	38	41	46

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2011	" "				50	54	30	35	48	49	32	27	30	41	52	58
2012	" "				60	80	54		52	50	34	30	30	41	52	58
Average					53.1	50.7	49.69	51.7	53.2	41.6	25.8	24.077	30.8	43	58.7	63.4
Depth in (cm)		**Coordinates**			**Months**											
Year	Field	X	Y	**Z**	Jan.	Feb.	March	April	May	June	July	August	Sept	Oct.	Nov.	Dec
2000	ps227	326094	1084349	1418	193	204	215	235	235	195	114	155	170	214	220	240
2001	" "				220	204	230	238	225	163	146	160	210	225	222	230
2002	" "				235	234	210	232	160	178	138	131	134	240	244	245
2003	" "				240	224	212	232	240	166	208	138	153	220	210	220
2004	" "				188	212	214	185	226	205	168	170	172	210	268	270
2005	" "				212	227	243	228	214	70	14	130	98	105	96	100
2006	" "				210	206	190	17	13	19	16	8	8	208	215	220
2007	" "				195	160	190	200	220	200	80	97	92	110	176	180
2008	" "				185	193	230	213	106	93	56	41	34	150	172	178
2009	" "				-2	130	142	151	192	140	66	108	160	190	192	200
2010	" "				158	154	159	156	156	150	143	140	125	172	220	242
2011	" "				180	172	216	160	200	40	28	-20	9	184	115	117
2012	" "				175	182	216	165	214	50	32	-15	9	184	115	117
Average					184	192	205.2	186	185	128	93	95.615	106	186	190	197
2000	Go254	323156	1086264	1437	48	46	141	33	113	90	15	9	14	33	108	109
2001	" "				88	90	148	34	103	118	36	14	10	8	116	118
2002	" "				88	89	140	180	188	17	34	9	13	27	110	112
2003	" "				43	24	21	162	180	13	42	10	15	83	161	165
2004	" "				79	69	55	154	73	165	24	42	92	135	137	140
2005	" "				146	175	210	132	201	121	86	131	20	112	156	156
2006	" "				113	155	160	178	190	200	180	90	96	127	135	135
2007	" "				148	100	90	120	90	36	100	85	82	120	207	204
2008	" "				200	196	160	116	99	114	77	143	82	110	134	140
2009	" "				90	140	144	161	150	110	113	92	128	130	156	156
2010	" "				154	158	160	165	162	176	82	110	102	117	177	178
2011	" "				141	142	154	162	175	163	147	115	118	166	178	180
2012	" "				140	138	150	165	160	178	142	134	112	156	167	170
Average					114	117	133.3	136	145	115	82.9	75.692	68	102	149	151
2000	ps111	327065	1068758	1458	133	154	148	189	158	155	68	33	18	-8	123	124
2001					182	123	169	165	167	134	24	134	127	245	218	220
2002					230	215	200	220	273	278	250	136	124	84	218	241
2003					240	278	274	229	270	170	50	40	65	208	270	278
2004					226	266	172	167	123	93	53	24	22	100	260	270
2005					270	276	280	201	200	160	46	47	19	80	249	250
2006					278	280	280	172	115	50	48	46	30	67	228	229
2007					260	262	280	280	280	170	50	31	50	81	111	112
2008					140	156	162	164	151	47	64	51	63	71	138	140
Depth in (cm)		**Coordinate**			**Months**											
Year	Field	X	Y	Z	Jan.	Feb.	March	April	May	June	July	August	Sept	Oct.	Nov.	Dec
2009					138	170	176	145	143	143	134	126	123	132	140	142
2010					176	179	260	250	250	250	232	228	198	161	152	160
2011					94	31	34	76	80	77	32	36	38	90	227	228
2012					210	120	127	130	98	72	45	57	36	80	225	227
Average					198	193	197.1	184	178	138	84.3	76.007	70.2	107	197	202
2000	ps513	325645	1085546	1445	0	0	-3	42	-1	-1	-2	-3.5	-3.5	42.5	220	220
2001					39	-1.5	-3	-5	-4	-7.5	-9.5	-9	-1.5	2.5	222	231
2002					55.5	19.5	47.5	71	60.5	22	13	13.5	21.5	20	244	245
2003					27.5	26.5	28.5	24	34	30.5	15	13	15.5	16	210	220
2004					16.5	23	17.5	17.5	13.5	8	3	4.5	5.5	14.5	268	270
2005					16.5	23	18.5	18.5	16.5	8	3	4.5	5.5	14.5	96	100
2006					15.5	6	8.5	6	4	2.5	-1.5	-2	-1	3	215	220
2007					17.5	14.5	11.5	9	6.5	4.5	2	-3	-4	-0.5	176	180
2008					2	5.5	19	35	70.5	36.5	18	10	8	10	172	172

2009					10	10	10	7	5	40	0.3	0	0.5	0.5	192	192
2010					10	12	11	10	-13	-26	-28	-10	-26	-10	220	150
2011					-12	-10	10	-16	-7	-19	-20	-38	-33	-28	115	112
Average					16.5	10.7	14.67	18.3	15.5	8.21	-0.6	-1.667	-1.04	7.08	196	193

Table 2: Spatial and seasonal fluctuation of GWT Depth for selected Piezometer sites.

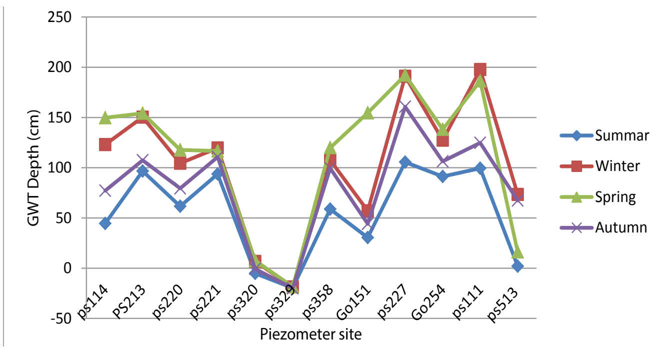

Figure 4B: Seasonal GWT depth of the study area.

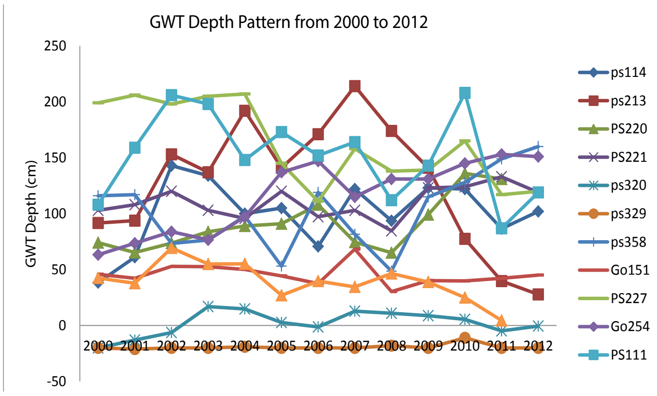

Figure 4C: Temporal variability of GWT depth in the FVSE (2000-2012).

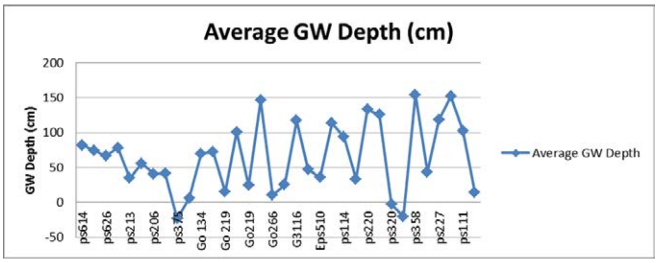

Figure 4D: Spatial Trends in the GWT depth in the FVSE over two years (2011-2012).

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 (Table 3).

During the summer (July) season**,** the GWT depth varied from -0.06 to 0.93 m, with average value of 0.50 m below the ground surface

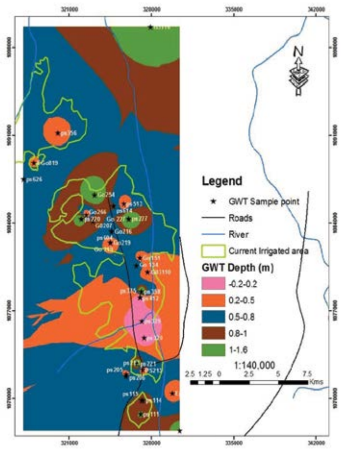

Figure 5: Spatial map of groundwater table in the FVSE indicating the waterlogging situation.

(Figure 4B). Almost more than half of the plantation has GWT depth <0.50 m and the entire selected cane plantation fields were severely waterlogged during this season. According to Figure 4B, 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 4C) whereby GWT depth as low as 0.05 m below the ground surface has been recorded in Ps-320 surprisingly Ps-329 and Ps-513 have GWT depth (-0.2 and -0.-06 m), respectively due to the 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 (Figures 4B and 4C). 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 main rainy (summer) season. The GWT depth varied from -0.02 to 1.86 m (average ˜ 0.99 m) below the ground surface and 0.11 m above the ground surface (Figure 4B). About 62% of the selected cane plantation fields have GWT depth <1.0 m and hence are most critically (severely) waterlogged whereas 39% have the depth (1 m <GWT<2 m) 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-111 and 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-151 and Ps-513 had very shallow GWT depths (<2 m) during the previous (summer) season. GWT depth during the summer season (Figure 3), have shown greater reduction compared to the other parts (Figure 4D). This showed that the GWT depths 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

FID	X	Y	Z	Average Yearly GW Depth (cm)
ps614	324770	1085353	1458	82.08
ps604	324630	1083347	1461	74.71
ps626	317112	1087492	1494	66.54
ps115	327163	1069866	1465	78.29
ps213	327239	1072310	1546	34.67
ps205	325865	1071779	1591	55.79
ps206	325878	1071933	1592	41.13
ps356	320045	1091201	1446	41.29
ps375	327007	1078071	1492	-23.42
ps412	327029	1078062	1456	6.31
Go 134	326714	1080603	1463	70.04
Go216	324630	1083347	1468	72.25
Go 219	324517	1082446	1480	15
G0207	323009	1084158	1477	101.13
Go219	324517	1082446	1480	24.63
Go 227	326094	1084349	1418	146.25
Go266	322454	1084656	1476	10.29
G03110	327693	1080101	1459	25.42
G3116	327922	1099667	1439	117.21
EGo819	318010	1088821	1483	47.58
Eps510	329783	1070440	1564	35.75
Eps404	330413	1067462	1597	113.88
ps114	327278	1069859	1534	94.08
PS213	327239	1072310	1546	33.71
ps220	322044	1084333	1486	133.42
ps221	326804	1072774	1558	125.67
ps320	327382	1074827	1508	-2.67
ps329	327183	1076187	1493	-20
ps358	327152	1078545	1462	154.58
Go151	327019	1081228	1454	43.63
ps227	326094	1084349	1418	118.54
Go254	323156	1086264	1437	152.23
ps111	327065	1068758	1458	102.92
ps513	325645	1085546	1445	14.75

Table 3: Average Yearly GWT depth of Piezometer sites of 2011 and 2012 years.

average GWT rise of 1.5 m during this period throughout the selected irrigation 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 hot moisture evaporates this moisture, leaving). 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 4C) that the contribution of groundwater 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 4C showed 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 table 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 (-0.2 m) and Ps-111 and PS-227 (2.06 m), respectively. A continuously rising GWT caused waterlogging and enhanced flood problems in the studied piezometer sites, particularly during the spring 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 agricultural areas caused major damage to crops and soil fertility.

Trends in the groundwater depth in the FVSE of piezometer sites (2010-2012)

In Fincha'a Valley problems due to irrigation are reported with regard to waterlogging. The ground water level within the FVSE showed a rising tendency. 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 fields with heavy clayey soils problems with waterlogging have been discovered during the field study and the analysis in a soil.

The result showed that on some plantation fields the GWT was very shallow (GWT <2 m). The same report indicated that in some fields downward percolation of irrigation water below the root zone, especially in soils classified as heavy black cotton 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 fields located near irrigation canals and drains suppressed cane growth due to seepage and GWT rise could be observed and cane loss due to this problem was economically significant. The measurement of GWT of the FVSE showed the maximum GWT depth values in all years and months.

The results indicated that 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 fields. The major cause for the rise of GWT depth in the area might be seepage from unlined irrigation canals, geological conditions, agricultural runoff, topography and soil type, coupled with poor drainage systems.

The GWT depth within the FVSE showed a rising tendency (Figure 4C). This might be due to irrigation (seepage losses), agricultural runoff and over use of irrigation water. The average GWT depth for selected irrigation fields varied from -0.27 to 1.54 m (Ps-320), (Figure 4D) what had been observed during the field works and confirmed from the results were problems with a high GWT rise and waterlogging condition. Especially on fields with heavy clayey soils (Vertisols) 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 (Luvisols) light 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 irrigation fields had very shallow (GWT <2 m) and in some irrigated fields downward percolation of irrigation water below the root zone, especially in soils classified as heavy black 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 fields located down irrigation canals and drains suppressed cane growth due to seepage and ground water table rise could be 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 fields nearby distribution canals and fields nearby drains. Even this short measurement time series of 2010 to 2012 showed significant increasing trends of rising GWT.

Conclusion

In the present study, waterlogged irrigation fields have been delineated using GIS and remote sensing and other ancillary information. From this study it inferred that GIS and remote sensing data, firsthand knowledge of waterlogging area can be obtained. To confirm the results obtained from image processing, other data such as topography and groundwater level information are very much required. Groundwater maps and satellite derived waterlogged maps may be used to zeroing in to sub areas for further investigation. Waterlogged area was verified in the field through ground truth at the selected irrigation fields/pizometer sites through field observation.

From this field visit and analysis result it was observed that a possible cause of waterlogging could be poor irrigation water management, nature of basement rock and/or geology, nature of soil, slope, poor and neglected drainage design condition of the plantation field. The entire selected sugarcane plantation fields (area) were under critical to severe waterlogging conditions. The study revealed that the GWT rise varied from 2.1 to 57.7% and are under severe and critically waterlogged, respectively. The severely affected areas are where drainage is not sufficiently designed. 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 spring, and a gradual decline in winter and autumn due to water uptake by plants, decreased rainfall, increased ET, increased relative humidity and GW discharge to streams and wetlands. Consequently, the direction of GW flow pattern in the cane fields, as suggested earlier, was subject to change in summer and spring 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. As attempt was made through application of geophysical (resistivity) method identified the root cause for the rise in GWT depth of the study area in addition to topography, soil, poor water management and drainage, the 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.

Intercropping with other low water crops like sorghum was suggested, as it could reduce percolation rates considerably. Long-term over irrigation had a cumulative effect on the rise of the GWT and could cause water logging 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 watershade management physiographic/soil/hydrological differences in the irrigation fields and thus is useful to carry out further investigations.

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References

1. Kahlown MA, Ashraf D, Haq Z (2005) Effect of shallow groundwater table on crop water requirements and crop yields.Journal of Agriculture and Water Management 76: 24-35.
2. Kahlown MA, Azam M (2002) Individual and combined effect of waterlogging and salinity on crop yields in the Indus basin.Journal of Irrigation and Drainage 51: 329-338.
3. Kaul Harshika A, Sopan T Ingle (2011) Severity Classification of Waterlogged Areas in Irrigation Projects of Jalgaon District, Maharashtra. Journal of Applied Technology in Environmental Sanitation 1: 221-232.
4. Asmuth JR, Knotters M (2004) Characterizing groundwater dynamics based on a system identification approach. Journal of Hydrology 5: 34-48.
5. DNRE (Department of Natural Resources and Energy) (2001) Victorian Catchment indicators. Our commitment to reporting on catchment condition. DNRE. Victoria.
6. Tanji KK, Kielen NC (2002) Agricultural drainage water management in arid and semi-arid areas. FAO of the UNS. Irrigation and Drainage paper 61, ISBN 92-5-104839-8. Rome. Italy.
7. Megersa Olumana, Dilsebo H (2010) Characterization of the responses of groundwater monitoring piezometers installed at WSSE. 2nd biannual conference of Ethiopian sugar industry on theme 'sugarcane production & climate'. Adama, Ethiopia.
8. Khan MN, Rastoskuev VV, Sato Y, Shiozawa S (2005) Assessment of hydro saline land degradation by using a simple approach of remote sensing indicators. Journal of Agriculture and Water Management 77: 96-109.
9. Chaudhari VM, Chaudhari Viru R, Neeti N, Bothale RV, Srivastawa YK, et al. (2008) Assessment of surface and sub-surface waterlogged areas in irrigation command areas of Bihar state using remote sensing and GIS.Journal of Agricultural Water Management 95: 754-766.
10. Mandal AK, Sharma RC (2001) Mapping of Waterlogged Areas and Salt affected soils in the IGNP Command Area.Journal of the Indian Society of Remote Sensing 29: 239-235.
11. Mothikumar KE, Bhagwat KA (1989) Delineation and Mapping of Salt Affected Lands in Pariej village of Kheda district (Gujarat) by Remote Sensing.Journal of the Indian Society of Remote Sensing 19: 40-57.
12. FAO/UNEP (Food and Agricultural Organization) (1984) Provisional methodology for assessment and mapping of desertification. Rome. p. 84
13. Masoudi M, Patwardhan A, Mand Gore SD (2006) A new methodology for producing of risk maps of soil salinity, Case study: Payab Basin, Iran. Journal of Applied Sciences and Environmental Management 10: 9-13.
14. Megersa Olumana (2004) Evaluation of the infield water application performance of sprinkler irrigation system at Fincha'a Sugar Estate. MSc Thesis Submitted to Arbaminch University, Ethiopia.
15. Mohamedin AAM, Awaad MS, Ahmed AR (2010) The Negative Role of Soil Salinity and Waterlogging on Crop Productivity in the Northeastern Region of the Nile Delta, Egypt.Research Journal of Agriculture and Biological Sciences 6: 378-385.
16. Adaman F, Madra Y (2003) A participatory Framework for Poverty Eradication in I.H. Unver, Rajiv. Gupta K, Kebaroglu A (eds.), Water, Development and Poverty Reduction, Kluwer Academic Publishers, London.
17. Ademe Adenew (2001) Summary of Metrological Data (1979 - 2000) Fincha'a Research Station, Agriculture, Ethiopia. pp. 272.
18. Amdihun A (2007) GIS and remote sensing integrated environmental impact assessment of irrigation project in Fincha'a Valley area, Ethiopia.Journal of Catchment and Lake Research.
19. Kahlown MA, Lqbal M, Skogerboe GV, Rehman SU (1998) Waterlogging, salinity and crop yield relationships. Mona Reclamation Experimental Project. WAPDA. Report (233).
20. Hutchinson MF (1989) A new procedure for gridding elevation and stream line data with automatic removal of spurious pits.Journal of Hydrology 106: 211-232.