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Groundwater Fluctuation and Its Implications along the Niger-Benue Confluence of Nigeria - A Pilot Study

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Abstract Rising water tables is one of the major problems affecting irrigation and agriculture in general, hence, regular investigation of the trend of groundwater fluctuation especially within 'fadama' lands is necessary to forestall incidences of flooding and salinization which are harmful to arable soils. Groundwater fluctuation was monitored between February and September, using chalk-dusted graduated steel tapes at five (5) piezometric locations in a small-scale *fadama* irrigation farm, in the Niger-Benue Confluence, Lokoja-Nigeria. It was observed that the mean monthly depth of water table fluctuates between 2.03m bgl and 0.022m agl in the period under review. Statistical analysis of data collected show that the trend of fluctuation obeys a third order hyperbolic function (with R^2= 0.98). Findings imply that the land is critically waterlogged between February and September, with rainfall depth significantly affecting groundwater fluctuation, and will be prone to salinity hazard overtime. There may be need to carry out further investigations on the hydrological characteristics such as hydraulic conductivity, infiltration and evapotranspiration for the area; these may inform the need to design appropriate measures for the water resources management in this area; such as installation of drainage structures/facilities to check the flooding and/or drilling of more shallow tubewells for irrigation purposes in months of less rainfall.

Keywords: *groundwater fluctuation, fadama, Niger-Benue confluence, salinization*

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1. Introduction

The significance of irrigation in agriculture cannot be overemphasized. As at the year 2013, [1] reported that only about half of the world is suitable for rain-fed agriculture even though 80% of global agricultural production come from these areas. Further, the ratio of area equipped for irrigation to cultivated area (AI) has been adjudged low globally by [2], more so in Africa where the AI has been forecasted to rise sharply above 50% of its original value between 2011 thorough 2035 to 2060 [3]. Ironically, only 17% of globally irrigated arable lands produce one-third of every edible crop harvested globally [4]. All of these data and trend greatly underscores the necessity for researchers and policy makers to pay greater attention to the encouragement and advancement of irrigated agriculture. Expansion of irrigation schemes in the mid to late 20th century led to over 50% increase in agricultural outputs [5].

One factor that poses great concern to the sustainability of irrigation is salinization [6]. In general, salinization has been linked to (1) rising groundwater tables due to excess irrigation and/or poor drainage in agricultural lands, with the consequent waterlogging resulting in deposits of salts on the top soil [7]; (2) direct use of poor quality water for irrigation [8,9] and (3) intrusion of sea or estuarine water, especially in coastal areas used for agriculture. Salt effects on soils are hazardous and lead to poor crop yield and subsequent loss of agricultural land.

With increasing global population, it is imperative that irrigated agriculture should expand commensurably to meet up with food and fiber needs. However, increasing population on the other hand leads to decrease in availability of good quality water resources to meet up with the competing demands for water allocation towards domestic, industrial and/or agricultural uses [10]. Groundwater, a major source of supplemental irrigation water, becomes an option for deeper exploration. The attendant technologies required for abstraction and utilization of groundwater for irrigation has witnessed appreciable level of improvement overtime. For instance, water lifting devices have evolved progressively from the early crude methods of utilizing water power for irrigation in Mesopotamia (about 4000BC) to the use of jet pumps and submersible sewage pumps developed in the mid-1950s to date [11]. It would be worthwhile, therefore, to seek out and explore areas where groundwater potentials are suitable for agricultural use, such as the reservoirs which lie within the alluvial formations of large rivers, where significant potential for higher yield of groundwater exists [7]. Groundwater table in these areas are suspected to be close to the surface thereby making them easily exploitable for irrigation through open wells and shallow tubewells [12] with the flip-side challenges of waterlogging and salinization as well.

2. Background

Lokoja, a small town in the North-Central region of Nigeria hosts the confluence of the two major rivers in the country – rivers Niger and Benue (Figure 1). This provides the agrarian community with the opportunity to establish farm settlements adjacent to the river banks in order to use the abundant and easily accessible groundwater resources for all year round crop production. Locals refer to this agricultural practice as: *fadama* farming. *Fadama* is a word in a Nigerian (Hausa) dialect which refers to relatively flat, low lying lands adjoining prenial water bodies or streamless depressions [13]. Soils in this area are classified as Eutric/Dystric Fluvisols [14,15].

The phenomenon of high water table (often during rainy seasons) and semi-arid weather condition (dry seasons) makes lands, like the fadama soils, prone to salinity/sodicity development [16]. Regular monitoring of groundwater table fluctuation and irrigation water quality in the fadama lands is therefore necessary in order to detect potential incidences of salinity hazards and proffer timely interventions. These solutions may be in forms of design and installation of surface or subsurface drainage systems, adopting conjunctive use of surface and groundwater supplies for all-year-round agricultural productivity.

Studies into groundwater fluctuation in Nigeria have focused on the humid tropical regolith of south western Nigeria [17], the chad basin of north-eastern Nigeria [18] and the inland valley at Gidan Kwano of Niger State, Nigeria [19]. These studies employed simple geological and hydrological techniques to assess the trend of water table fluctuations over extended periods of time in different regions of the country. To the best of our knowledge, no study of groundwater level fluctuation has been carried out or reported in literature for the fadama lands around the Niger-Benue confluence area in North-Central Nigeria. However, [20] reported that the fluctuation of the water table in fadama lands around the Sokota basin of North-West Nigeria is about 2–3 m throughout the year, with peaks in September (end of raining season) and lowest values recorded in the month of June.

In Nigeria, adequate and accurate, climatic, hydrologic, hydrogeologic, and other associated environmental data for irrigation and drainage are scarcely available, especially for the Lokoja area which hosts the confluence of Rivers Niger and Benue within the Lower-Niger-River Basin Development area. This has been an impediment to the efficient design of irrigation and drainage projects aimed at crop improvement in most small-scale farms.

This work seeks to provide preliminary information about the trend of the groundwater table fluctuation (mean depth per time) as it occurs in the irrigated Sarkin-Noma fadama farm, and to understand the possible factors responsible for the trend. In an initial study, samples of the groundwater from tube wells used for irrigation were collected and analyzed to ascertain their quality status. It was found that the samples had very low salinity values (Electrical conductivity of 250 to 385S/m) and low Sodium Adsorption Ratio (SAR, 1.05 to 1.55) indicating probable problem of water infiltration into the soils [21] and possible salt build-up overtime, depending on the level of flooding/waterlogging. As a follow-up, the need for determining the trend of the groundwater fluctuation is expedient in order to ascertain the existence and levels of flooding/waterlogging in the area. This study spanned February to September, covering some portion of both dry and rainy seasons respectively. Obviously, the duration of observation in this study falls short of recommended periods for data collection in hydrological studies [22], however, it extends previous investigations by these authors and adds some experimental data points to the body of existing knowledge about the hydrological characteristics of the fadama lands used for agricultural development in Kogi State. Further, this studies opens up research and development paths for future investigations and policy experts to explore relative to the sarkin-noma fadama farm and other locations that share similar climatic characteristics.

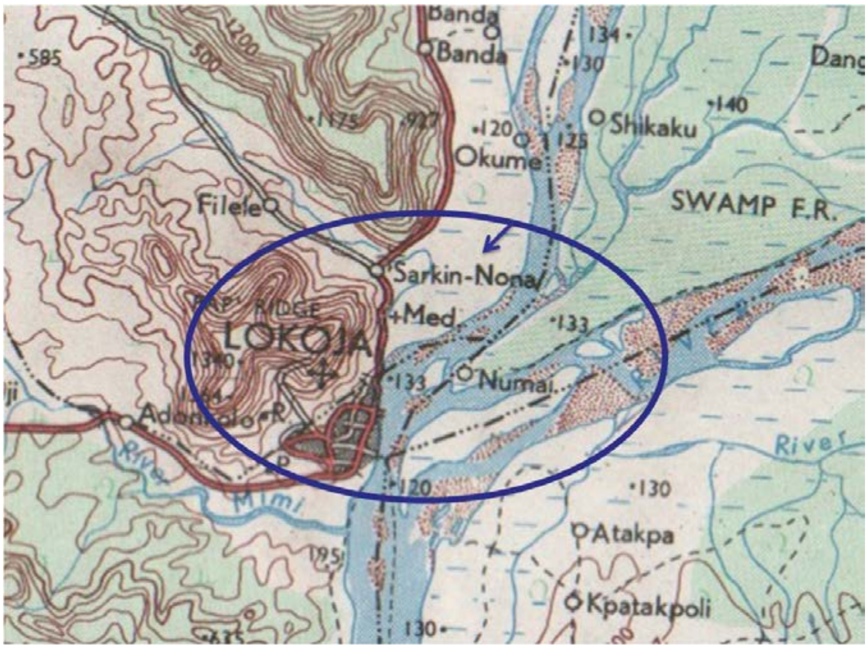

Figure 1. Topographical map showing the study area; Topo sheet no. 37 (Source: 23)

3. Materials and Methods

3.1. Study Area

Sarkin-Noma Fadama farm is situated within the cusp of the confluence of the Rivers Niger and Benue, in Lokoja, north-central geo-political zone of the Federal Republic of Nigeria. Kogi Agricultural Development Project (KGADP) is the government parastatal which directly manages fadama farms covering cumulative area of over 70 ha, with the Sarkin-Noma farm as one of the major site where all year round farming took off earlier and smoothly. The farm lies between longitude 6° 42' and 6° 48' North, and latitude 7° 47' and 7° 52' East. It is bounded by the Niger-Benue confluence to the south, River Niger to the east and Sarkin-Noma farm settlement (populated by population of nomads and agriculturists) to the west, in the North-Western area of Lokoja (Figure 1).

Lokoja falls within the 'tropical climate zone' in the guinea savannah grassland characterized with vegetation like shrubs and scattered orchard bush; this area has two major seasons yearly: rainy (April to October) and dry seasons (November to March). Mean annual rainfall in dry and rainy seasons range from 0 mm to 42 mm and 105 mm and 1560 mm respectively, with peak rainfalls occurring around July to September annually. Mean annual temperature ranges from 26°C to 35°C in July/August to February/March respectively, with RH of 50 – 63% [24,25].

All-year-round farming is practiced in this fadama farm. Vegetables and leguminous crops such as egg plants, pepper, tomatoes, spinach, and cassava as well as rice, sugar-cane, maize and guinea-corn are grown in both dry and rainy seasons respectively.

4. Experimental Procedures

4.1. Construction and Layout of Piezometers

Five (5) piezometers were installed at different stations within the study field; their spatial location, drilling and installations were done according to the guidelines for monitoring water levels and flows at wetland sites [26] and as adapted/modified by [27] for local studies in Gidan-Kwano valley in Nigeria. A grid pattern was adopted for spatial location of the piezometers on the farm (Figure 2). Table 1 shows the location and depth of wells in the experimental field.

A 50 mm diameter soil auger capable of drilling 70 mm diameter hole was used to manually drill the piezometers. Variation in depth occurred due to the level of substrata under the ground; however, all the piezometers were greater than 2.50 m in depth, satisfactorily beyond the water table surface of the field. PVC pipes of 50 mm diameter were used and the extra 10 mm clearance between the pipe and the wall of the drilled hole was backfilled. The portion of this pipes that come in contact with water below the water table surface were first 'screened', i.e., perforated with several holes, sufficient enough to prevent envelope materials from entering into the well and also sizable enough to allow lateral discharge of water into the piezometer. 5 mm size drill bit was used for the random perforations. The bottom end of the pipe was plugged (sealed) to avoid uptake of soil materials and to serve as bottom datum for efficient measurement of the depth of water table.

The perforated part of the pipe was further screened with fine net materials to filter soil particles from discharging into the well to prevent clogging. The pipes were then lowered into the auger holes with the perforated end below the ground surface and the top allowed to protrude at least 30 cm above the ground surface to prevent inflow or runoff of surface water. Gravelly envelope materials of average diameter of 10 mm were used to backfill the clearance up to the perforated end at the bottom of each piezometer. The remaining length was filled with clay materials to prevent inflow of surface water and to enhance stability. The open end of each piezometer was covered with polythene material to prevent evaporation and/or entry of unwanted materials, while the entire area in the experimental field around each piezometer was 'cordoned' to prevent extraneous human interferences.

4.2. Determination of Groundwater Table Depth per Time

The height of the pipe above the ground surface (h) was noted. Readings in the well were made by measuring the distance from the top of the pipe to the water surface. Measurements of water table depths were made using steel tape dusted with a chalk. This is inserted into the piezometer until it touches the plugged bottom. Each depth of groundwater Table (D) (eqn. 1) was evaluated by subtracting the length of the pipe above the ground surface (h) from the distance from the top of pipe to the water surface (H) as read off from the dusted steel tape (Figure 3).

$$D = H - h \tag{1}$$

Weekly readings were taken from February to June while daily readings were taken for a precise study between July and September (period of peak rainfall).

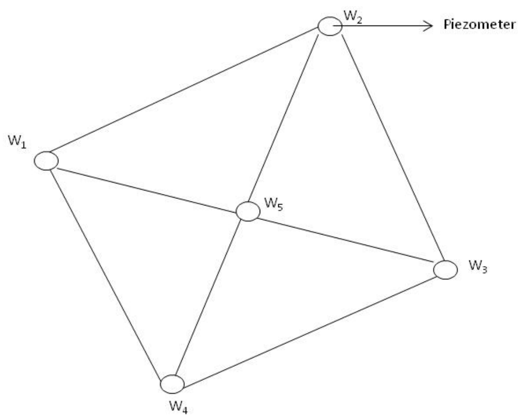

Figure 2. Spatial distribution of Piezometers across the field for the investigation

Table 1. Depth of wells in the experimental field

Observation well	Depth of Well (m)
W_1	2.70
W_2	2.65
W_3	3.05
W_4	2.90
W_5	3.20

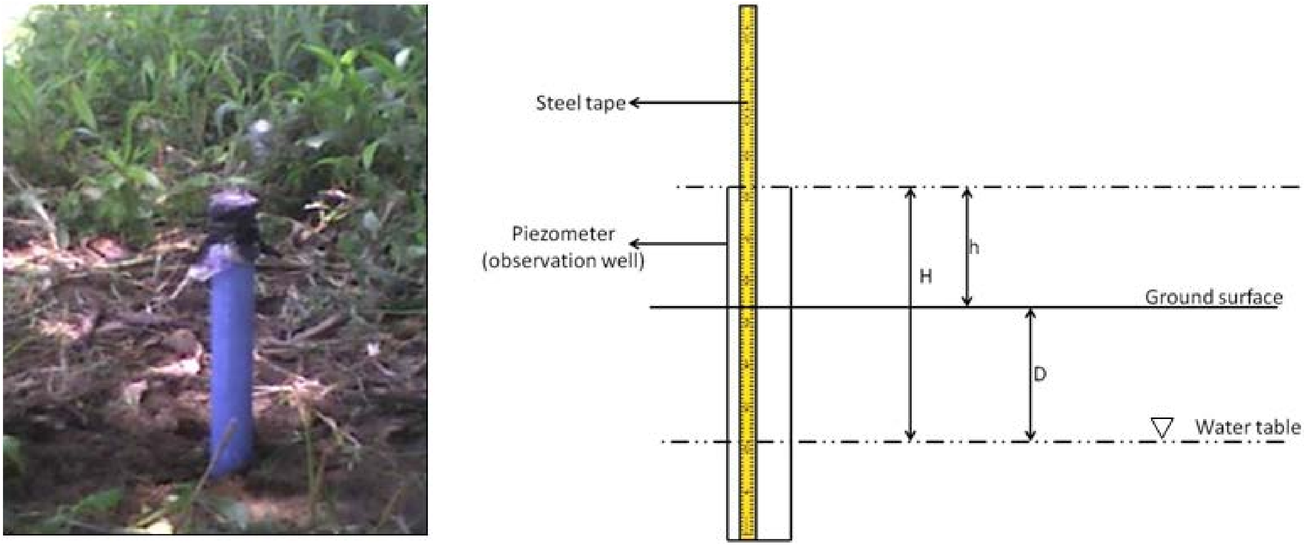

Figure 3. Pictorial and schematic layout of typical piezometer in the field

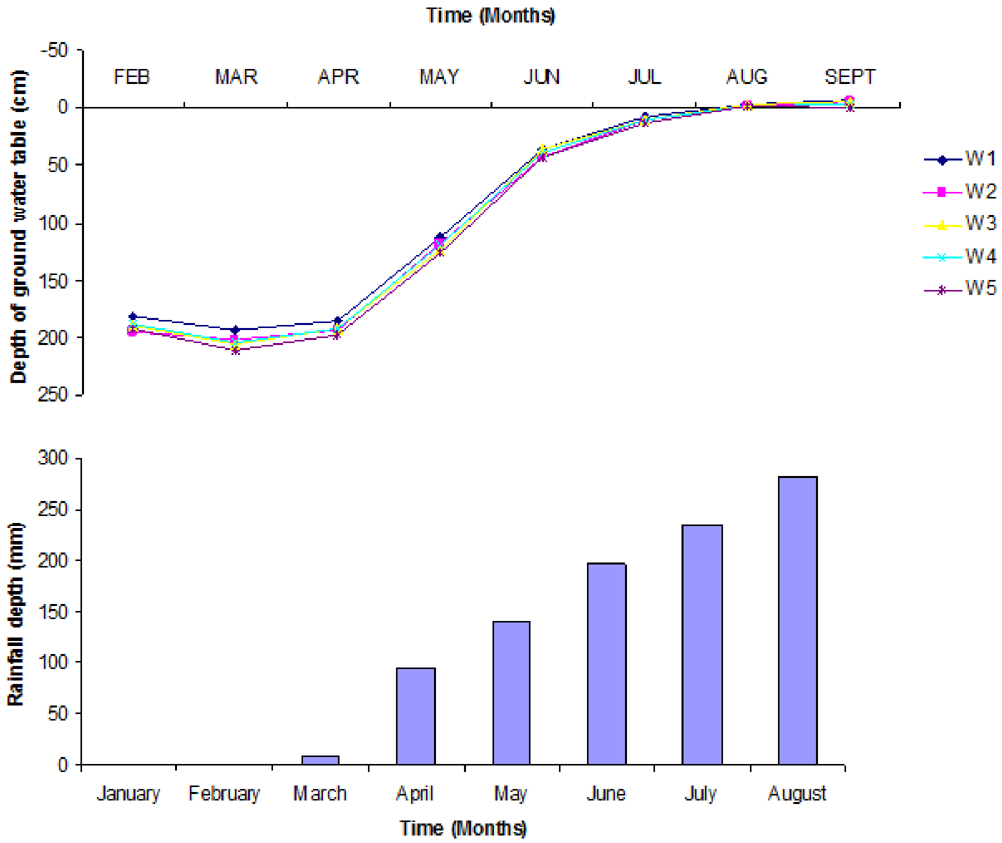

Figure 4. Rainfall depth and trend of ground water table from February to September

5. Results and Discussions

Results from critical examination of fluctuation in groundwater table monitored at five (5) piezometric locations within the experimental field are as shown in appendices 1 and 2. Mean monthly rainfall data was also collected from the Nigerian Meteorological Agency (NIMET) throughout the study period.

The results show that the depth of water table fluctuates between 1.81 m and 1.95 m below ground level (bgl) in February to a range between 1.94 m and 2.11 m bgl in March, and hovered around mean depth of 1.92 ± 0.04 m in April. Between May and August, the depth of water table witnessed a sharp rise from 1.20 ± 0.05 m bgl to an alarming negative value of 0.022 ± 0.0083 m above ground level (agl). The negative value implies that water table surface had risen above the ground surface. This trend continued in September, with the weekly measurements indicating a negative water table rise to a mean depth of 0.044 ± 0.003 m agl.

These results of the water table fluctuation trend observed show that the land is prone to and was experiencing waterlogging throughout the period of this study [according to 28; 29]. Although there was no official record of flooding events reported for the rivers Niger and Benue during the period under review, the waterlogging may be attributed to the recharge of the groundwater resulting from rainfall events and consequent increase in infiltration and lateral flows. This is because, when these observations were juxtaposed with the rainfall record in the study area within the months of study (Figure 4), it clearly revealed that as rainfall depth increases, the water table rose steadily and decreased steadily too after the recharge period elapsed. The trends in all the observation wells were similar.

The expression relating the depth of groundwater table with time for the various observation wells and the regression coefficient of best fit, R^2 for all the well locations were obtained and are as shown in Table 2.

Expressions relating depth of groundwater as a function of time for each well location was determined using quadratic and cubic functions for curve estimation; this choice was informed based on the visual appreciation of the depth of groundwater table versus time plot. A third order hyperbolic function was considered rather than a second order quadratic function simply because of the rationality of the third order approximation in terms of best fit curve and general results, more so, as seen in the significant R^2 values obtained for the cubic function. The hyperbolic function is given as:

$$Y = a + b_1 X + b_2 X^2 + b_3 X^3 \tag{4.1}$$

Where:
a = constant of regression
b_1, b_2 and b_3 are parameters of the equation of fit
Y = depth of groundwater table
X = time in days.

Table 2. Depth of groundwater table expression and the corresponding R^2 values

Well	Equation of best fit	Regression coefficient of fit (R^2)
W_1	$Y = 109.5 + 109.47x - 38.47x^2 - 2.89x^3$	0.982
W_2	$Y = 126.97 + 104.06x - 37.69x^2 + 2.84x^3$	0.985
W_3	$Y = 112.84 + 117.08x - 40.89x^2 + 3.06x^3$	0.982
W_4	$Y = 111.16 + 116.56x - 40.7x^2 + 3.06x^3$	0.984
W_5	$Y = 110.8 + 122.54x - 42.17x^2 + 3.15x^3$	0.985

6. Conclusion and Recommendations

The findings of this study are as follows:

1. That the depth of water table from ground surface dropped from about 1.89 m in February to 2.03 m in March and then began to rise gradually in April to a mean depth of 1.92 m. Between May and August, the depth of water table witnessed a sharp rise from 1.20 m to an alarming -0.022 m. In September, the weekly depth measured indicated that the depth of water table rose to a mean depth of -0.044 m. The general trend is directly correlated to rainfall recharge and obeys a third order polynomial.
2. This trend shows that Sarkin-Noma Fadama farm land is critically waterlogged during the entire period of this study. There have never been any prior studies of this nature at this site.

Based on the findings from this field study and the water quality results for this site as reported in our initial study [21], it can be inferred that the crop production on this fadama lands may witness imminent decline as the combined effect of waterlogging and potential salinity bear negative influence on crop production [28,29]. A quick suggestion in terms of intervention/recommendation maybe to install active drainage structure/facilities between the months of February and September in conjunction with the construction of more tubewells for irrigation purpose in months of less rainfall. However, before such recommendations may be adopted, it is essential to perform other ancillary hydrological investigations like the determination of infiltration, hydraulic conductivity and evapotranspiration for this site, as well as extended periods of hydrological monitoring and data acquisition. These along with hydrogeological studies will better buttress the phenomenon of waterlogging on this site and reveal the actual cause of the rise in ground water depth; thereafter, better informed corrective measures for mitigating the hazard of waterlogging can be implemented to avoid imminent food crisis.

This study employed a very simple technique for monitoring groundwater fluctuation considering the study area, however, this technique is prone to error from subjectivity of the observer to adverse effects of harsh weather impeding access to observation well especially during periods of intense rainfall. Future studies may consider using self-recording apparatus and other sophisticated equipment capable of logging observations over extended periods of time.

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Statement of Competing Interests

The authors declare no conflicting interests.

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Appendix 1. Mean weekly depth of water table from February to part of September

MONTH	FEBRUARY				MARCH				APRIL				MAY			
WEEK/ WELL	1	2	3	3	1	2	3	4	1	2	3	4	1	2	3	4
W_1	180.41	180.50	180.80	183.23	189.46	192.27	195.00	198.12	200.55	199.79	173.41	169.04	129.00	120.40	112.19	90.00
W_2	192.35	192.44	193.00	195.04	197.22	200.05	204.02	207.44	208.00	207.06	198.35	161.23	134.33	122.10	116.00	100.00
W_3	188.76	188.82	189.72	191.90	199.13	204.33	208.54	212.35	214.35	211.00	180.09	165.80	138.19	127.94	120.49	107.89
W_4	186.83	186.80	187.11	190.00	198.00	202.65	206.25	210.59	215.10	208.93	179.35	163.18	133.58	124.38	119.36	101.50
W_5	191.12	191.00	191.84	193.59	200.00	210.04	216.98	218.25	220.05	217.42	184.64	167.77	131.67	129.12	130.23	113.90
MONTH	JUNE				JULY				AUGUST				SEPTEMBER			
WEEK/ WELL	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
W_1	40.94	44.26	36.32	23.63	20.08	11.60	3.38	-5.00	1.10	-3.10	-4.39	-6.15	-7.08	-	-	-
W_2	50.27	51.60	39.27	28.45	22.25	13.33	6.35	2.05	0.00	-1.42	-2.15	-5.27	-5.33	-	-	-
W_3	34.33	40.57	37.81	29.00	20.00	16.45	4.84	0.94	-1.00	-1.96	-2.00	-6.21	-5.98	-	-	-
W_4	43.75	43.00	39.86	26.62	21.46	17.39	3.97	-2.00	1.08	-2.05	-2.67	-4.37	-3.01	-	-	-
W_5	49.81	50.10	42.69	29.98	24.91	19.66	8.42	1.58	0.80	-1.09	-2.03	-1.69	-0.79	-	-	-

Appendix 2. Mean Monthly Depth of Water Table

	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
W1	181.24	193.71	185.7	112.9	36.29	7.52	-3.14	-7.08
W2	195.04	202.18	193.66	118.1	42.4	11	-2.21	-5.33
W3	189.8	206.09	192.81	123.63	35.43	10.56	-2.8	-5.98
W4	187.69	204.37	191.64	119.71	38.31	10.21	-2	-3.01
W5	191.89	211.32	197.47	126.23	43.15	13.64	-1	-0.79
Mean	189.13	203.53	192.26	120.11	39.11	10.59	-2.23	-4.44
Standard Deviation	5.18	6.45	4.27	5.15	3.51	2.18	0.83	*2.52

*This value was not used in the report since values for only 1 week were observed for the month of September.