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Rainfall-Groundwater Table Fluctuations Impact on Root Zone Soil Water Simulated in Upflow for Crop Production Planning in Obio Akpa Watershed, Nigeria

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Abstract— The non-predictability of rainfall-groundwater table relationships in the ungauged Obio Akpa watershed has rubbished remedial measures against seasonal crop losses. This study utilizes ten years (2011-2020) of climate data from the study area to predict the seasonal rainfall-groundwater table variations and simulate the effects on crop root zones using the Upflow model. Twelve wells monitored monthly characterized the seasonal behavior of the Groundwater Table (GT). Gravimetric direct measurements of soil water contents were the inputs to the UPFLOW model used to simulate the seasonal responses of GT to rainfall. Correlation-regression analysis was used to obtain a prediction equation of GT responses to rainfall. Results showed that in the month of April, the mean rainfall of 230mm induced GT rise of 1.35m (35%) from 3.85m in March to 2.50m in April. The effect on the soil water properties included a corresponding increase of 1.8 vol.% (10.7%) in field capacity at equilibrium with the water table in the preceding month. Mean soil water condition remained optimal at 15.9 vol.% with the GT at 1.5m below the root zone. In September and October when 1859mm and 2129mm of the mean annual rainfall was received, the water table increased by 72% and 74% respectively, and field capacity in equilibrium with the GT increased to 34.9 vol.%, causing GT inundation of the root zone (RZ) and deficit aeration in 74% of the RZ, respectively. In November, with reduced rainfall and decreased input to groundwater, only 16% of the RZ was in deficit aeration. UPFLOW simulations of the annual soil water regime showed the months of September, October, and November as high GT months suitable for planting and harvesting of only shallow-rooted, short-maturity crops. This knowledge will guide effective water resources and crop management in the watershed.

Keywords— *Groundwater, rainfall-groundwater table fluctuations, root zone waterlogging, UPFLOW, Obio Akpa Watershed.*

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1.0 Introduction

Traditional crop cultivation in the Obio Akpa watershed is limited by seasonal changes and weather fluctuations, which restrict farmers to specific planting and harvesting periods. The gap in knowledge of rainfall and groundwater dynamics in the ungauged watershed prevents year-round crop production that could optimize the utilization of land and water resources and enhance adjustments to weather factors to avoid imbalances that could negatively impact crop growth. For over 20 years, the stretch of land bordering the Akwa Ibom State University and the Obio Akpa River along the Abak – Ikot Okoro road has been under agricultural production by beneficiaries of the 2002 European Union Assisted Small Scale Irrigation (SSI) assistance to farmers in the Obio Akpa river watershed [1]. The major problem affecting the scheme in recent years is the inability of farmers to predict rainfall-groundwater table relationships across the seasons to enable them to schedule their farming activities and avoid occasional destruction of crops due to inundation of the watershed by rising groundwater table (GT) during the rainy season.

GT rise, which results in waterlogging in the crop root zone, is triggered by numerous factors comprising climate that affect the amount of water entering the soil, excess runoff amounts moving through or over the soil surface, and evapotranspiration by plants, and use of water by other organisms [2]. GT rise is linked to the increase in the frequency of extreme rainfall events and multiple wet days [2] received within an environment. Rainfall variability gives important information on the water balance dynamics for water resources management and agricultural planning, flood frequency analysis, hydrological modeling, and assessing and understanding climate change impacts [3].

Climate change has been implicated in varying rainfall characteristics and distribution both seasonally and annually [4]; and the impacts of the portion that may drain through the soil profile into aquifers to recharge the groundwater [5], [6], [7]). These impacts, however, vary locally depending on the type of aquifers, their locations, and overriding processes in the groundwater recharge [8], [9].

In lowland areas, groundwater recharged by rainfall during and after the rains causes significant water table to rise and flooding [10]; [11]; [12] in vulnerability due to exposure, perturbations, and inability to cope, recover or adapt to high intensities of rainfall. These watersheds have the greatest amount of anthropogenic disturbances and have the highest potential for impacts on the riparian and wetland resources due to high percentages of anthropogenic activities. The coupled influence of climate change and anthropogenic pressures, including agriculture, continue to significantly impact these watersheds because both circumstances amplify hydrologic events, including floods [13]. The effects of water table rise to the crop root zone (CRZ) are widely reported in the literature [14], [12], [15].

In Nigeria, a high probability of flooding due to increasing precipitation intensity was predicted by [16], with particular reference to the inundation of coastal lands. Within Southern Nigeria, the Niger Delta is the most vulnerable ecological zone to flooding due to unsustainable climate impacting anthropogenic activities and practices [17] with consequential impacts on groundwater table dynamics [18].

Several years of Nigeria Hydrological Services Agency's Annual Flood Outlook reports [19], [20], [21] have consistently placed Akwa Ibom State within the High Probability Flood Risk Areas. These predictions, which portend the vulnerability of her watersheds to inundation and disruption of livelihood activities, including crop production cycles, raise concern about appropriate water management in the watershed.

The Obio Akpa watershed is a massive low-lying rural agricultural land in the coastal plain and river flood lands of Akwa Ibom State [22]. The relationship between the water table, soil profile, and root zone depicted in Figure 1 shows that the closer the water table is to the soil surface, the more the saturation of the soil profile with water and the more the root zone aeration becomes deficient [23]. Depending on the crop rooting depth and the proximity of the water table to the root zone, the waterlogging can be regarded as the light for a GT depth of 3m

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for a substantial part of the year, moderate for less than 1.5 m, and severe for a water table at 0 – 30 cm depth in the soil profile [24]

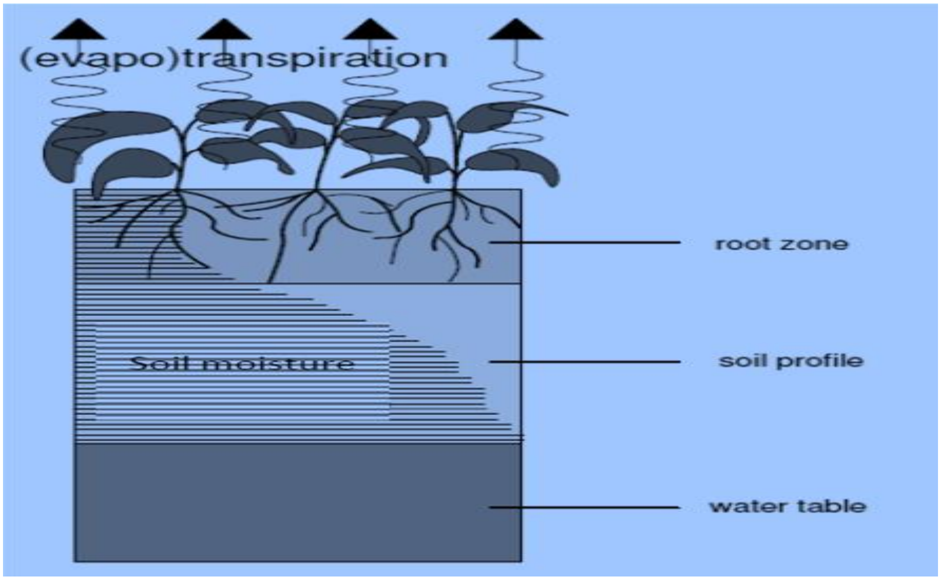

Fig. 1: Relationship of water table, soil profile and root zone (Modified from Raes, 2009)

The condition of the root zone determines the management approach for adaptation to root zone flooding. The degree of water logging is derived from the calculated moisture profile. If the soil water content is above the anaerobiosis point at a particular area in the root zone, the soil is assumed to be waterlogged in that area. If the soil water content is above the anaerobiosis point over the root zone, the root zone is fully waterlogged and the transpiration rate becomes zero. UPFLOW model [25] correctly predicts the soil and water conditions at each depth of the water table and also displays the soil water content that can be expected in the topsoil when the water content in the specified soil profile is in equilibrium with the water table.

Proper observation, analysis, delineation, and correlation of rainfall to GT in waterlogged areas are obligatory to appropriately manage watershed water and land resources and to set basin management objectives [26]. Thus, seasonal and spatial fluctuations of GT and rainfall should be studied jointly to understand the fluctuating behavior of watershed systems [26], [27]

Suitable management of water resources could bring enormous benefits to agricultural outputs and increase food security for poor farmers and the nation. Among the management-adaptation options identified by [28], altering the timing and the location of farmers' cropping activities to cope with the projected climatic hazards was identified as a measure to cope with projected climatic hazards to limit negative impacts and increase positive impacts.

At the Obio Akpa watershed, the behavior of the GT and its fluctuation with seasons has not yet been studied in detail, and the heightening of farm ridges [29] has failed to provide the needed all-round protection against high GT. This situation in the watershed requires immediate facts about the probable GT behavior in the watershed through the dry and wet seasons so that suitable and timely counteractive measures can be adopted. The present study, consequently, purposes to offer clear information concerning the behaviour of GT of the watershed across the prevailing two seasons of the study area. Therefore, the GT and rainfall will be recorded methodically by means of some observation wells and rain gauges installed in the watershed. Then, the seasonal fluctuations of the GT will be analyzed. The effects of the fluctuations on CRZ soil water will be analyzed using the UPFLOW model. Finally, recommendations on proper planning and necessary safeguards will be made. The structure and results of this research can be applied in practice to other regions with similar characteristics.

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2.0 Materials and Methods

2.1 The Study Area

Fig. 2: Map of study area showing water table monitoring points in the watershed.

The study was conducted at the European Union Assisted SSI scheme in the Obio Akpa River watershed, which covers an approximate area of six hectares. Obio Akpa lies between latitude 4°7'N and 5°49'E and longitude 7°40'E and 7°49'E in the southwestern part of the state within the humid tropical zone. The mean annual rainfall is between 2500mm and 3600 mm, and the rainy season begins in March and lasts till October or early November. The clearest rainfall months are July and September, with an average wet day of 26.6. The dry season lasts 4.2 months from November to March. The temperature is high all year round with a monthly mean of about 26°C, relative humidity in the range of 60% - 90%, and potential evaporation is about 4.6mm/day. The drainage systems of the Cross and Kwa Iboe rivers influence the watershed's hydrology. [22] placed the area in Etebe soil series of Akwa Ibom State soil series and land capability class C (deep, fine sandy loam over clay loam, weak structure, well-drained, porous, moderate moisture capacity, very acid, very low nutrient status, and high aluminum content) moderately suitable for traditional crops (yam, cassava, vegetables etc.) with moderate soil restrictions in rainy areas. As the main agricultural enterprise with multiple land-use systems, the watershed is subjected to high anthropogenic disturbances for arable crop farming.

2.2 Installation and monitoring of observation wells and soil

The watershed is closely monitored by three meteorological stations operated by the Cross River Basin Development Authority (CRBDA), Abak station, located about two kilometers on the southern fringes of the study area, National Institute for Oil Palm Research (NIFOR) located about one kilometer from the study area and the Akwa Ibom State University Meteorological Station located within the watershed. Both NIFOR and AKSU are drained on their eastern boundaries by the Obio Akpa river, the main channel for the watershed.

Daily rainfall data of Obio Akpa for ten years (2011-2020) was obtained from the Akwa Ibom State University weather station. From the daily rainfall data, mean monthly and annual rainfall was determined for each year.

To avoid conflict in water use, each farmer develops his/her plot-specific shallow well. These wells were adopted for GT monitoring to save the cost of installation of PVC piezometers. The GT was monitored within the European Union Assisted SSI scheme using these existing farmer irrigation shallow wells. A total of 12 wells selected randomly from fifty active farm units' size of 35 m x 35 m each were monitored in 2023 to characterize the seasonal behavior of GT of the watershed. The settings (latitude, longitude, and elevations) of each well

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location (Table 1) were registered using a handheld GPS (Garmin GPSMAP67i) obtained from the Department of Civil Engineering of the University.

Table 1: Coordinates of sampled wells

Piezometer /Field No	Mean water table depth	Coordinates		
		Latitude (^{O}N)	Longitude (^{O}E)	Altitude (m)
1	2.5	4.9645	7.7598	38
2	2.05	4.9500	7.7599	33
3	1.9	4.9399	7.7538	31
4	1.6	4.9550	7.8233	26
5	1.424	4.9212	7.7620	22
6	0.664	4.9247	7.7716	15
7	0.639	4.9458	7.8124	15
8	1.182	4.9257	7.7933	19
9	2.82	4.9552	7.8126	40
10	4.113	4.9164	7.8223	55
11	4.6	4.9706	7.7537	57
12	3.85	4.9551	7.8122	52

The sampled wells ranged in depth from 3 m to 5 m. Four wells each were selected from the scheme's lower, middle and higher elevations. The depth to GT at the experimental site was accessed through the sampled wells by use of an improvised well dipper [30] made by attaching an up-turned reducing coupler and an eyebolt to the end of a calibrated line or measuring tape. When the weighted end is lowered to contact the water surface in the well, it 'pops', allowing the distance to the water level to be determined by reading off the graduated thread tape. The visibility of the water line was improved by using chalk on the lower part of the tape to confirm that the popper device is in contact with water. The data from which the well's water level was measured was the top of the well installation. Crop water requirement (evapotranspiration) was considered to be solely responsible for well drawdown. The water table depth was monitored monthly for twenty-four months (January 2022-December 2023). The field records for the groundwater levels at various distances were averaged over the period of the study. Gravimetric direct measurements of soil water content were carried out according to [31]

2.3 Data Analysis and Mapping

The monthly readings of the piezometer installations were analysed in an excel spreadsheet for monthly and annual values. The seasonal responses of GT to rainfall excess were analysed based on the Accumulated Monthly Residual Rainfall (AMRR) [32]

$$AMRR_t = \sum_{t=1}^{t} \left(M_{i,j} - \bar{M}_j \right) \qquad 1$$

Where,

$M_{i,j}$ – rainfall (in mm) in month, *i* (a sequential index of time since the start of data set), which corresponds to the *j*th month of the year, $\bar{M}_j$ Mean monthly rainfall for the *j*th month of the year, and *t* – month since the start of the data set.

Correlation-regression analyses were then used to predict how much a change in rainfall was associated with a change in the water table. This resulted in a regression equation (model) describing the line on a graph of the variables and a coefficient of determination describing the correlation percentage between rainfall and groundwater table. The equation can then be used to predict the value of groundwater table changes based on the given value(s) of rainfall variations.

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2.4 UPFLOW simulations of CRZ soil water conditions

The main menu and the root water uptake and soil Profile sub-menu of UPFLOW simulation model are shown in Figures 3 and 4, respectively.

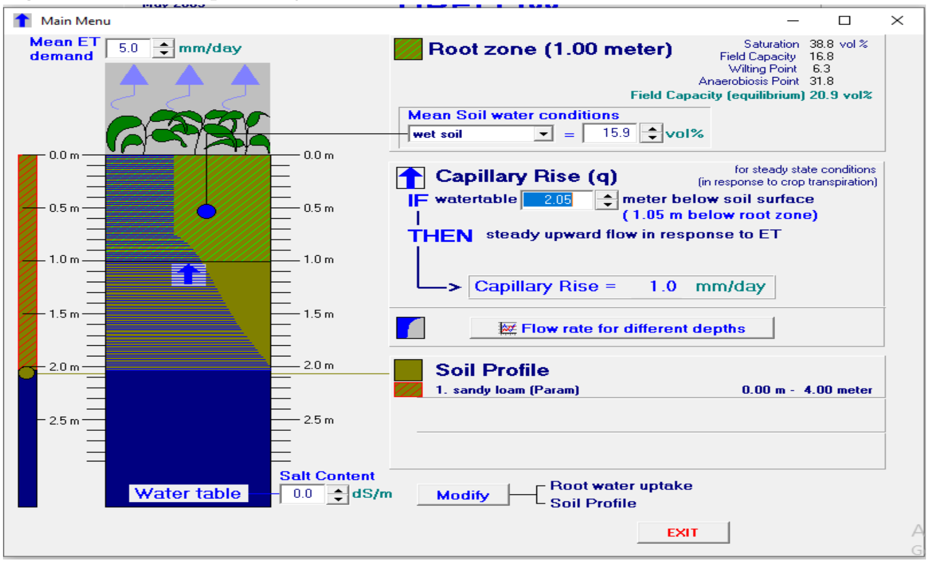

Fig 3: Main menu of UPFLOW simulation software.

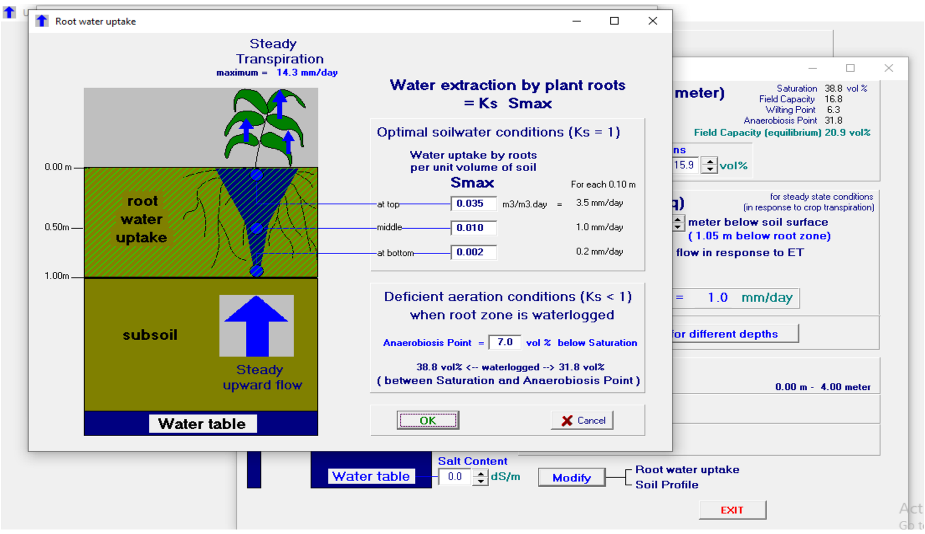

Fig. 4: Root water uptake and soil Profile sub-menu in UPFLOW.

By stating the mean soil water conditions (wet or dry) of the soil , GT and CRZ depths in the main menu of UPFLOW and specifying the soil profile (soil type, thickness) in the root water uptake and soil profile sub-menu, UPFLOW displays the optimal soil water conditions (water uptake by roots per unit volume of soil/day), deficient aeration conditions (depending on the waterlogging condition), hydraulic properties (saturation, field capacity, wilting point, anaerobiosis point and field capacity in equilibrium with the water table) and the amount of salt transported to the root zone if the groundwater contains salt. Above all, UPFLOW graphically displays the soil water profile in the CRZ.

The gravimetric method determined the soil's mean soil water conditions (moisture content). Soil samples from each grid square of the respective plots were collected at a depth of 0.5m in air-tight polythene bags and taken to the laboratory for analysis on a bi-monthly basis. This was done every second and last week of each month between January 2022 and December 2023.

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3.0 Results and Discussion

3.1 Seasonal variation in rainfall

The mean monthly rainfall distribution in Akwa Ibom State is shown in Figure 5

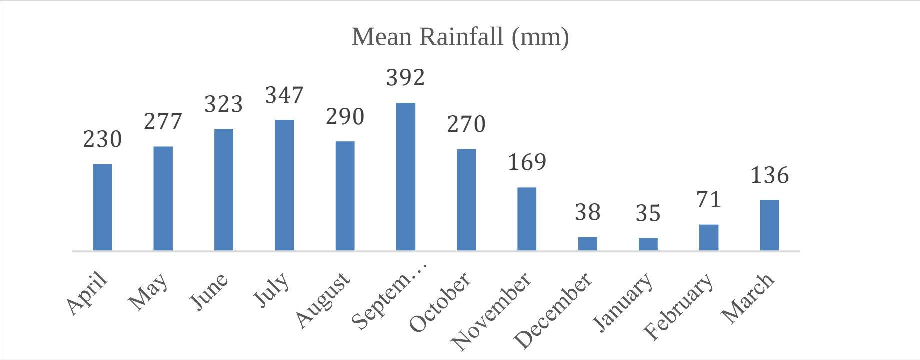

Fig. 5: Mean monthly rainfall distribution in the study area

In the month of April, a mean rainfall amount of 230 mm was received in the study area. The amount of rainfall increased and peaked in September when 392 mm (15.2%) was received. The effect of the August break was felt with the rainfall amount reducing from 347 mm in July to 290 mm in August. Thereafter, there is a drastic and rapid drop in the quantity and frequency of rain till December and January. In February, the wet cycle commenced again with an increase of over 50% in rainfall. There is no time (month) of the year that the study area does not receive rainfall on the average. The only variation is the quantity.

Rainfall in Akwa Ibom is dependent on the location of the Inter Tropical Zone of Convergent (ITZC). In January, when the Front (ITZC) was nearly 8O N of the Equator, Akwa Ibom experienced frontal rainfall [22]. This is when the Warm Dry Tropical Continental Air mass, usually referred to as the North Easterly Winds, flows into most of the country. Due to the reduced quantity and distribution of rainfall during this period, it is often referred to as the Dry Season. In the study, January received only 35 mm (1.4%) rainfall.

The period around January is predominated by Warm Dry, Tropical Air mass. However, convectional rainfall still occurs in this area. In July, the ITZC moved to around 21O N, which is farther north of Akwa Ibom, resulting in the influx of warm wet tropical air mass, commonly called the Southwest Trade Winds. This moist air mass produces a lot of rainfall. This is usually referred to as the rainy season, a period of about eight months, between March and October. It is worth noting that there is a gradual, steady increase in rainfall from January until the peak in the months of July and September, when about 85-90% of the total annual rainfall is received during this period of the rainy season.

3.2 Variation of Annual rainfall

The variability of rainfall in the study area based on historical data collected from 2011 to 2020 is shown in Figure 6. Variability of rainfall has been recognized as a good parameter for assessing the reliability of rainfall over any area within specific time.

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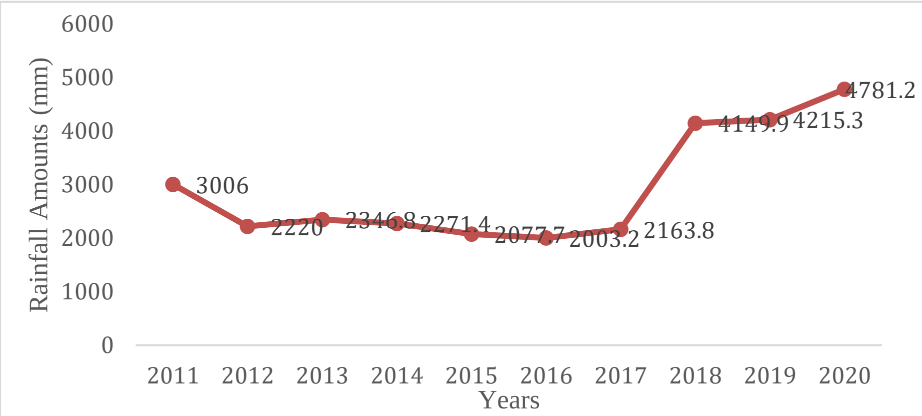

Fig. 6: Decadal variation of mean annual rainfall in the study area

Rainfall variation refers to the change that occurs in rainfall amount received in any location. In other words, the differences that occur in time over the total amount of rainfall in a given environment. Figure 6 indicates that rainfall amounts minimally decreased from 2011 to 2017 except 2013, but drastically increased from 2017 to 2020. In agreement with the findings of [16] the effects of the global warming phenomenon on the terrestrial water balance include (i) higher rainfall intensities i.e, heavier rainfalls, and (ii) higher frequency of great floods with increasing trends in runoff in humid areas. Moreover, [33], asserts that in the coastal Niger Delta region of Nigeria, meteorological accounts show an increasing rainfall trend, and statistically significant positive trends were recognized for Uyo (Akwa Ibom State capital), and the extent of the trend and variation rate contributed by climate change at 24-hour duration was 21.6 mm/decade for Uyo. This study outcome confirms the claim of climatic change in trends and variability of rainfall increases in the Niger Delta region of Nigeria as observed by [34], [35]. Therefore, these effects have fully manifested in the study area.

3.3 Seasonal Variation of GT Depth The mean piezometer monthly GT responses throughout the study are shown in Figure 4.

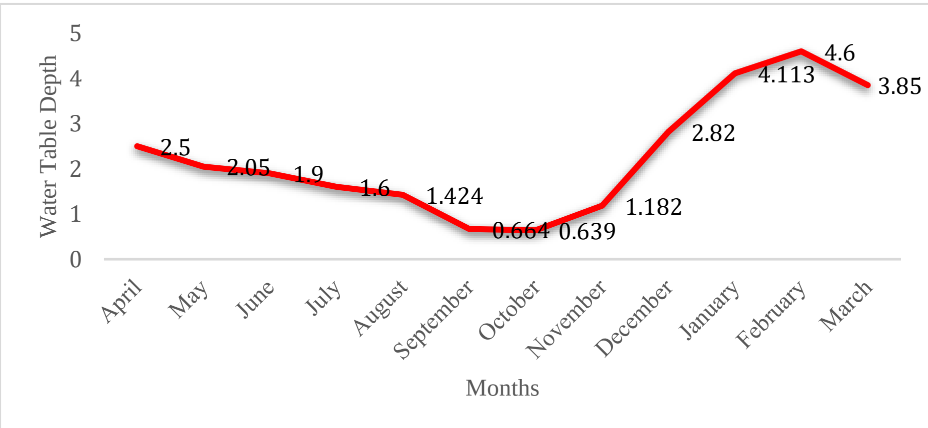

Fig. 7: Seasonal variation of mean GT depth

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Figure 7 portrays the mean fluctuation of the shallow GT throughout the monitoring period. The actual GT monitoring started in April 2022 immediately after the commencement of the planting season (April) and lasted till December 2022. The GT reduces in depth from 2.5m in April to 2.05m in May 1.9m in June, 1.6m in July, and the lowest being 0.639 m in October and thereafter starts to increase from November; the dry season in the area begins.

From the figure, it is possible to visualize the status and fluctuation of GT values before the planting season (November-February). The explanations for the behaviour of the GT during this period are typically centered on the effects of rainfall (amount and distribution pattern) (Fig. 5), runoff, and base flow effects. The poor drainage system exacerbates this and gently rolling topography common in the study area. From November to February, the GT rate reduced considerably. November is the onset of the dry season in the study area, which is characterized by little rainfall. Hence, direct rainfall and runoff do not affect the watershed area, and the GT continues to decrease. The likely source feeding the GT during this time is base flow. Due to this fact, a major drop in GT level is observed throughout this period. The GT depth continuous increase in rate is mostly due to the effect of the dry season. The GT ranges from 1.16 m to 4.60 m (Fig. 7), with an average value of 3.17 m below the ground. GT depth in this season is comparatively deeper when matched with the rainy season due to unfavorable climatic conditions, peak rate of crop evapotranspiration, and scanty rainfall (Fig. 5). Consequently, the farms struggle to get adequate water for crops by relying on irrigation wells during this season. The effects of direct rainfall and the resulting runoff on GT depth fluctuation are also insignificant during this season.

During the rainy season (March to October), the GT ranged from 3.85m to 0.639m with mean value of 1.54m depth (Fig. 7). The decrease in GT depth started in March and climaxed in October with GT depth of 0.639 m. March marks the commencement of the rainy/planting season in the study area in response to increased rainfall input. This implies significant inputs to groundwater storage, the response of which is evident in the rise of the GT depth in Fig. 7. In September and October, the GT depth is almost at the surface. This period is characterized by severe waterlogging conditions in the area with GT as low as 6 cm below the ground surface. This indicates that the reaction of the GT depth to rainfall is significant.

3.4 Rainfall-Groundwater Table Relationship in the Study Area

The association between the mean monthly rainfall amount and the mean monthly GT depth from the ground surface for the watershed is shown in Figure 8 for the period 2013 to 2022.

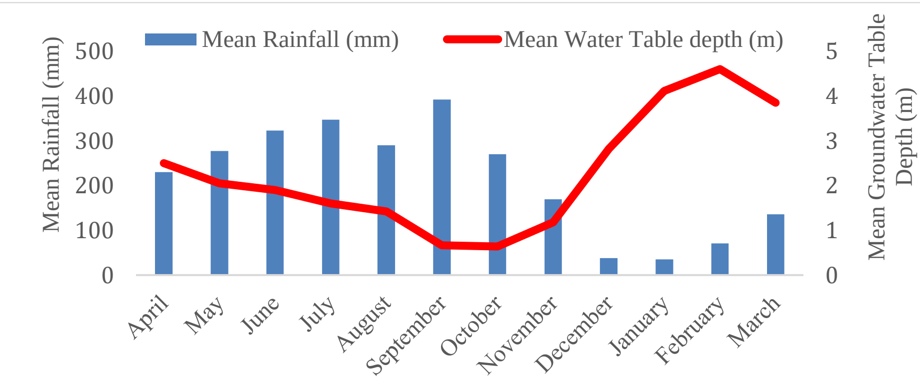

Fig. 8: Mean monthly Rainfall – Groundwater table relationships

The bar chart plots represent the mean monthly rainfall values in mm, while the line graph plots the mean GT depth. The plots evidently help to visualize the interactions between the two variables. Clearly, the GT depth is shallower during the rainy season than during the dry season. The variability of the GT progresses with rainfall as the season advances and external inputs to groundwater (runoff, infiltration, base flow) increase in rate and volume.

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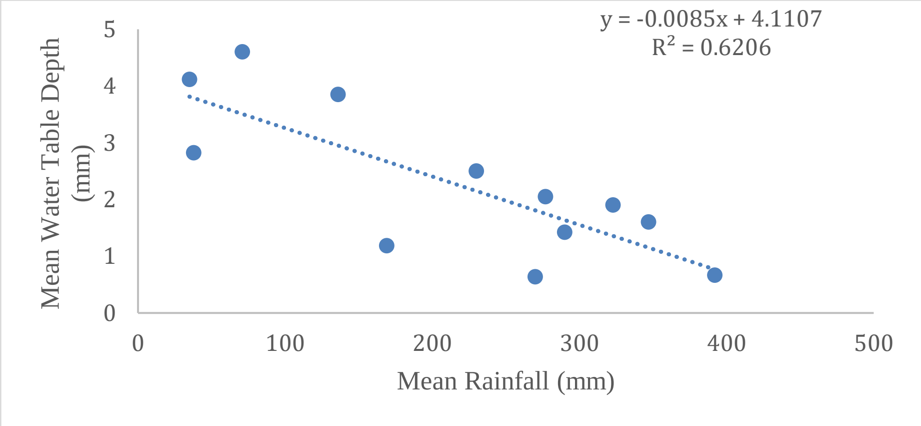

Fig. 9: Correlation of GT with mean rainfall

While the water table depth from the ground surface decreases to October and increases to February, rainfall is on the opposite with decrease from September to January and increases. Overlaid on Figure 9, the regression curve is the prediction equation for the mathematical relationship between rainfall and GT in the watershed as: Y=-0.0085X + 4.1107

Where

X = Rainfall (mm)

The general tendency here is that rainfall is inversely proportional to GT depth measured from the ground surface. The coefficient of retardance (R^2) 0.6206 indicates that about 62% of the variation in GT depth is explained or accounted for by variation in rainfall. This value of R^2 is desirable for forecasting purposes because the higher the value of R^2, the smaller the value of the standard error of estimate.

Table 2 shows UPFLOW prediction of the annual cycle of RZ soil water conditions in the watershed based on the mean annual rainfall, GT depth, and RZ depth of one meter.

Table 2: Rainfall-GT fluctuations effects on Crop Root Zone soil water.

Months	Mean rainfall (mm)	Mean Water Table depth (m)	Root zone (1 m)		
			Field capacity at equilibrium Vol %	Deficient aeration conditions	Mean soil water condition Vol %
April	230	2.5	18.6	Optimal	Optimal 15.9 Vol %; Water table (WT) at 1.5 m below root zone
May	277	2.05	20.9	Optimal	1.05 below root zone
June	323	1.9	21.5	Optimal	0.9 m below root zone
July	347	1.6		Optimal	0.6 m below root zone
August	290	1.424	25.0	Optimal	0.42 below root zone
September	392	0.664	34.9	Optimal	WT in root zone Mean soil water condition at 34.9 Vol %
October	270	0.639	34.9	Deficient aeration in 74% of root zone	WT in root zone. Mean soil water condition at 34.9 Vol
November	169	1.182	27.2	Deficient aeration in	WT at 0.18 m below root zone

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				76% of root zone	
December	38	2.82	17.5	Deficient aeration in 16% of root zone	WT at 1.82 m below root zone
January	35	4.113	16.8		WT at 3.1 m below root zone
February	71	4.6	16.8		WT at 3.6 below root zone
March	136	3.85	16.8		WT at 2.85 m below root zone

In April, the sixth month into the rainy season in the study area, the mean rainfall of 230 mm induced GT to rise of 1.35 m (35%) from 3.85 in March to 2.50 m in April. The effect on the soil water properties included a corresponding increase of 1.8 vol.% (10.7%) in the value of field capacity at equilibrium with the water table in the preceding month. However, the mean soil water condition remained optimal at 15.9 vol. %, with the GT at 1.5 m below the root zone. As the amount of rainfall received in the watershed increased, GT depth from the surface and below the RZ with the water table decreased, and the value of the field capacity at equilibrium with the water table correspondingly increased assuredly due to poor drainage in the RZ.

Up to August when 1467 mm (57%) of the annual mean rainfall was received, 0.42 m of the GT remained below the RZ, and the field capacity increased to 25 vol.% in equilibrium with the GT. Mean soil water condition was still optimal, and anaerobiosis remained at only 31.8vol% of the RZ.

Equally, in September and October, when 1859 mm and 2129 mm of the mean annual rainfall was received, the water table increased by 72% and 74%, and field capacity in equilibrium with the GT increased to 34.9 vol.% respectively. Here, the GT inundated the RZ, and there was a deficit aeration in 74% of the RZ.

During this deficit aeration period, the degree of saturation S will increase. For dry soil, S will be 0% and for fully waterlogged soil, S will be 100%. In a fully waterlogged state, the entire volume of void is filled with water. This surplus water in the soil limits the easy transmission and circulation of oxygen between the environment and the soil system. The ensuing waterlogging and anaerobiosis can eventually result in the build-up of harmful metabolites such as lactic acid, ethanol, and aldehydes, in combination with rises in volatile oxygen types, particularly hydrogen peroxide, hence ultimately resulting in damage to plant cells and plant senescence [36]. Also, ensuing changes in the waterlogged soil's biological properties significantly influence the activities of soil micro-organisms and plant roots and slow down the growth of plants poorly adapted to waterlogged environments. Reduction of shoot and leaf growth and yellowing of mature leaves indicate early senescence. Extended waterlogging can result to the death of whole plants in types that cannot adapt [36].

For yam, [37] reported that waterlogging resulted in a steady deterioration and damage of yam plants, speeded the senescence of the yam plant and reduced tuber yield by 32.4% and 43.2% after 48 and 72h of waterlogging respectively and; yield when waterlogged at the early stage was 47.6% less than waterlogging at a later stage. [38] recommended well drained sandy loam soils as ideal for cassava and yam as opposed to heavy and swampy soils which cause rot of the tubers in prolonged conditions.

However, in November, when the rainfall amount decreased the input to groundwater, there was a reduction in GT so that only 16% of the RZ was in deficit aeration. Subsequently, the water table decreased in November, and RZ aeration and field capacity increased. GT rise can increase and stabilize yields [39], cause anaerobiosis of the CRZ [25], and negatively impact agricultural activities like sowing, harvesting, and transportation.

Implications for Watershed Agriculture

UPFLOW simulations of the annual soil water regime showed that September, October, and November are high GT months with a higher negative effect on coastal crops than other months. The heightening of farmland ridges can yield reasonable benefits over time but has never completely addressed the GT issue or alleviated the impacts entirely. The resilience of farmers can be enhanced by varying the planting date of crops to increase

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agricultural output and adaptation of the farming season. [40], recommended that one of the best approaches farmers could adopt to cope with climate change and increase agricultural production, particularly in developing countries, is to vary their planting dates. The amount and value of crop production can be improved greatly by a small appropriate change in the planting dates [41]. However, it was warned that while one can increase farm productivity and lessen the risk of hazard impact on crops, crops can become vulnerable to harmful environmental conditions.

In Obio Akpa watershed, the peak of hazards for floods is likely to occur between September and November, directly influencing the agricultural rain-fed season and production. The timing of crop production in the watershed can be altered slightly to reduce or prevent the climate impact at peak-risk periods and to ensure that farmers production periods are more resilient during peak-risk periods by either early or late planting of crops. Table 3 presents the adaptation plan for the watershed for key crops traditional to the area.

Table 3: Crop production timing plan for GT adaptation in the Obio Akpa watershed

CROPS	ROOT DEPTH (CM)	MATURITY (DAYS)	MONTHS AND WATER TABLE DEPTHS (CM)											
			JAN .4.1	FEB .4.6	MAR 3.85	APR 2.5	MAY 2.05	JUN 1.9	JUL 1.6	AUG 1.42	SEPT 0.66	OCT. 0.64	NOV. 1.18	DEC. 2.82
Carrots	45	60-80	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Corn (sweet)	60	60-100	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Cucumbers	45	35-45	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Eggplant	45	60-90	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pumpkins	60	30-240	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Tomatoes	60	70-100	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Melons	60	78-90	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Onion (green)	30	80-90	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sweet Peppers	45	90-110	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sweet Potatoes	45	90-120	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spinach	15	38-55	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Okra	45	50-60	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cassava	100	9-12 months	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Yam	100	5-7 months (14 weeks)	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓

Source: Modified from USDA NRCS Irrigation guide and FAO (1998) for Obio Akpa watershed.

From Table 1, planting and harvesting of shallow-rooted, short-maturity crops (15-60 cm) can be scheduled within the year as early or late planting and harvesting, provided the critical months (marked with X in the table) are avoided.

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For the deep-rooted long-duration crops, late planting in the watershed gives more assurance of safe harvest than the early season planting, which will mature during the critical months. Hence, for cassava, intensive crop cultivation during the late planting season ensures crop safety and investment if adopted and sustained in the watershed. Late planting or planting after the normal planting season or when the planting season is delayed until the severe hazards have passed is considered to be the planting of crops after the rainy season. [42] and [43] believes that late planting might lessen the crops' valuable growth period and hence yield whilst it can also delay or reduce crops' initiation and maturity. However, [41] states that in the late planting of crops, the stress of drought during the early growth stages could be avoided because more water is available nonetheless, the crops could be exposed to higher temperatures while maturing, and the risk of scarcity of rain in the final stages of crop growth, except if late planting is combined with short-cycle varieties and with good cropping techniques and supplementary irrigation.

For yam, early planting in January assures farmers that the crop can be harvested within the maturity period of the crop before the incidence of high GT. According to [41], this can considerably increase dry-matter build-up and crop yields compared to normal planting times.

4.0 Conclusions and Recommendations

Based on the findings from this field study and the GT results for this watershed, it can be concluded that the crop production in this watershed may witness impending decline due to the influence of high GT and seasonal rainfall that negatively impact crop production.

Shallow GT in the Obio Akpa watershed has amplified the negative impact of high rainfall on farming activities. The GT at the Obio Akpa watershed is shallow during the months of September to November for the dominant economic crops produced in the watershed. It is subject to a rise during the peak of the rainy season and a gradual drop in the dry season due to water uptake by plants, decreased rainfall, and increased ET and possible groundwater discharge to streams and wetlands.

Major findings are that: In September and October, when 1859mm and 2129mm of the mean annual rainfall was received, the water table increased by 72% and 74% respectively, and field capacity in equilibrium with the GT increased to 34.9 vol.%, causing GT inundation of the root zone (RZ) and deficit aeration in 74% of the RZ respectively. This indicates that waterlogging is the major reason for crop losses in the watershed during this period. There have been no previous similar studies or at this watershed.

The linear response of the GT in the study area shows that rainfall is the major source of recharge of the water table. Therefore, the crop losses accompanying the GT fluctuations can be minimized by avoiding the coincidence of the crop production cycle with the months of September, October, and November.

Although other yet to be identified causes for the rise in GT of the study area are possible, the current study clearly indicates that the recharge from direct rainfall and runoff in the watershed are the main causes responsible for the rise and fluctuation of GT. The confirmation is that the GT is shallower during the rainy season than in the dry season, and the GT is rapidly responsive to high rainfall in the course of the study and the consequential substantial rise of the GT.

Detailed studies of the entire watershed for other possible causes of GT rise and the implementation of a viable water management and drainage strategy, such as deep drainage and slope modifications for free flow of runoff to discharge points, are recommended. UPFLOW simulation of soil water conditions in the watershed shows that adjustment in the timing of crop cultivation will guarantee flexibility of farming activities and reduce economic losses to farmers. Although vulnerable areas will continue to be exposed to natural hazards, the effect of these hazards on agriculture can be minimized with the application of proper agricultural strategies. It is suggested that depending on the crop root depth and maturity period, small-scale farmers should practice selective early planting and late planting to increase their resilience to high GT at peak periods.

This study adopted simple, inexpensive methods and assumed uniform soil and favorable hydrological conditions to achieve the results on which the recommendations presented in this report are based. To ensure well informed decisions for alleviating the danger of high GT and evade impending food crunch, the required caution for adoption of the recommendations are the performance of other secondary hydrogeological and hydrological monitoring

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and data procurement activities based on studies such as infiltration studies, evapotranspiration, and soil hydraulic conductivity for this watershed to explain the occurrence of waterlogging and expose the real basis of the GT rise in the watershed. To improve the accuracy of the data for future study of this problem, the use of self-recording gadgets and other sensitive equipment capable of logging real-time observations over long periods is recommended.

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