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GROUNDWATER RESPONSE TO WEATHER VARIABILITY IN A POOR AQUIFER UNIT: AN EXAMPLE FROM TROPICAL BASEMENT COMPLEX ROCK OF NIGERIA

ABSTRACT. More than 50 % of Nigeria is underlain by basement complex rock which is a poor aquifer unit and evidences abound that the climate of Nigeria is changing. The posing question is how this poor aquifer will respond to the vagaries of climate variability and change. However, understanding the response of groundwater to climate variability and change in Nigeria will be hampered by dearth of data, because the nature of change in groundwater is not monitored. On this basis, the study tried to understand how groundwater responds to weather variability in a poor aquifer unit of Ilara-mokin and its environs in the tropical area of Nigeria. Rainfall and temperature data for forty years (1973–2012) were collected from NIMET and groundwater level were monitored in the area for two years (2012–2014).The general trends in rainfall and temperature received in the last forty years were examined using regression analysis and moving average. The dry and wet episodes were also examined using Standard Rainfall Anomalies Index (SAI). Also, the percentage changes in the rainfall and temperature received were determined using reduction pattern analysis. The response of groundwater to weather variability was however established using Pearson Moment Correlation and multiple regression analysis. The results of the analyses revealed an average of six years dry episode every decade in the last 40 years. The temperature of the study area is increasing in the last 20 years. Groundwater responded negatively to temperature but positively to rainfall in the area. Rainfall and temperature accounted for 67 % of variability in monthly groundwater level. This study is a good starting point in understanding groundwater response to climate in poor aquifer units of Nigeria despite the dearth of data.

KEY WORDS: groundwater, climate, weather, variability, management, poor aquifer, trend.

INTRODUCTION

Groundwater is an important natural resource which serves as a primary source of water for domestic, agriculture and industry in many countries of the world. According to Taylor et al. [2009], the current assessments of the effects of historical and projected climate variability and change on water resources commonly omit groundwater. However, there should be a great concern for this omission in the continent of Africa, where current usage and future adaptation to response of climate change and rapid population growth, place considerable reliance upon groundwater to meet domestic, agricultural and industrial demands [Taylor et al., 2009]. The effects of climate on surface water resources is directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, however, the relationship between the changing climate variables and groundwater is more complicated and poorly understood [Jyrkama and Sykes, 2010; Singh and Kumar, 2010].

The relationship between climatic variables and groundwater is considered to be more complicated than surface water [Holman, 2006; IPCC, 2007] cited in Green et al. [2011]. This is because groundwater residence time can range from days to tens of thousands of years, which may delay and diffuse the effect of climate change on groundwater and may not be detected immediately [Chen et al., 2004] cited in Green et al., [2011]. This was why Sekhar et al., [1994] and Nyagwambo [2006] stressed that climate variability, being a relatively short term compared to climate change will have greater impact on crystalline basement aquifer systems. This study was based on their submissions to understand the relationship between groundwater and monthly weather variability in Ilara-mokin and its environs.

The implications of a changing climate on water resources of the world and Africa in particular especially on groundwater resources cannot be overemphasized. This was why UNESCO International Hydrological Programme (IHP) and its Groundwater Resources Assessment under the Pressure of Humanity and Climate change (GRAPHIC), in its attempt to raise the global attention on the interaction of climate and groundwater, supported the compilation of a book edited by Triedel et al. [2012] titled "Climate Change Effects on Groundwater – A Global Synthesis of Findings and Recommendations". They made a compilation of about 20 case studies on climate and groundwater resources from more than 30 different countries. The studies in the book addressed groundwater resources in different hydrological settings ranging from mountainous to coastal aquifer systems, including unconfined, semi-confined and confined aquifers to unconsolidated to fractured-rock material and different climatic settings/scenarios. However, the studies of groundwater under the influence of climate have not received enough consideration in developing countries especially Africa and Nigeria in particular. Very few studies have been carried out in this part of the world solely because of the dynamic nature of groundwater resources and the dearth of hydrological data and expertise.

More than 50 % of Nigeria is underlain by basement complex rock which is a poor aquifer unit. Basement rock aquifers are very poor aquifer because of their very low level of porosity and permeability which resulted into poor groundwater yield and recharge in areas located on this type of aquifer. Although, there are places on a basement complex rock with very thick overburden produced by weathering which have sizeable amount of extractable groundwater. Sekhar et al., [1994] and Nyagwambo [2006] reported that in a basement complex rock aquifer, groundwater is characterized by the presence of shallow water table and recharge is primarily from rainfall. The presence of shallow water table and recharge primarily from rainfall is an indication that groundwater in a basement complex aquifer will respond more to the vagaries of climate variability than the long term climate change.

However, this study is trying to understand how groundwater respond to monthly weather variability in a shallow overburden aquifer, an example from Ilara-mokin and its environs which is underlain by basement complex rock in tropical area of Nigeria. This reason why the study is based on groundwater response to monthly weather variability was because the available groundwater data is not enough to determine the influence of climate variability on groundwater in the area. The population of this area depends mainly on groundwater resources for their domestic needs and is faced with the challenges of inadequate water supply as the population is increasing [Oladapo et al., 2009].Two major studies have been carried out in this area to understand structural configuration of the basement rocks, groundwater potential [Oladapo et al., 2009] and groundwater yield and flow pattern [Ashaolu and Adebayo, 2014] to have an insights if the available groundwater will keep up with the increasing population. None of these studies in their quest to understand the groundwater resources of this area have tried to see the influence of climate or weather variables on groundwater of the area in this era of pronounced climate variability and change. Therefore there is a need to understand how groundwater in this area responds to monthly weather variability for sustainable groundwater supply.

STUDY AREA AND DATA

Study area description

Ilara-mokin and its environs (Ipogun, Ikota, Ero and Ibule) are in Ifedore LGA of Ondo state, south-western Nigeria. The town and its surrounding villages are located between latitude 07°21'16"and 07°22'20"N and longitude 005°05'58" and 005°07'12" E (Fig. 1). The climate of Ilara-mokin and its'environ can be described as the Lowland Tropical Rain Forest type, with marked wet (April to October) and dry (November to March) seasons. The dry season is marked with little or no rainfall. The total annual rainfall in this area is about 1800 millimeters. The mean monthly temperature is between 27 °C to 30 °C. The geology of Ilara-mokin and its environs is Precambrian Basement Complex rocks and which is mainly of the medium grained gneisses. These are strongly foliated rocks frequently occurring as outcrops. According to Oladapo et al. [2009] the lithological units include variably migmatized biotite-hornblende-gneiss with intercalated amphibolite. They further stressed that the greater part of the study area is underlain by marginally thick overburden which constitute a shallow aquifer units. Its estimated population is about 45,000 people and most of the local residents practiced fish and poultry farming.

Data Sources

The secondary data for this study are rainfall and temperature data which were obtained from the Nigeria Meteorological Agency (NIMET). The data spanned from 1973–2012 (40 years), it is believed that these length of years will be enough to ascertained variability in the climatic data set obtained. This is because World Meteorological Organization in 1956 suggested thirty to thirty five years as the minimum period for averaging climatic variables before variability can be detected [WMO, 2009, 2007]. The groundwater level data were obtained directly from field observation that spanned for two (2012–2014). It is important to note that there are no observation wells in the study area which is a peculiar characteristic of most of the developing countries of the tropics. Forty wells with peculiar characteristics (hand-dug,

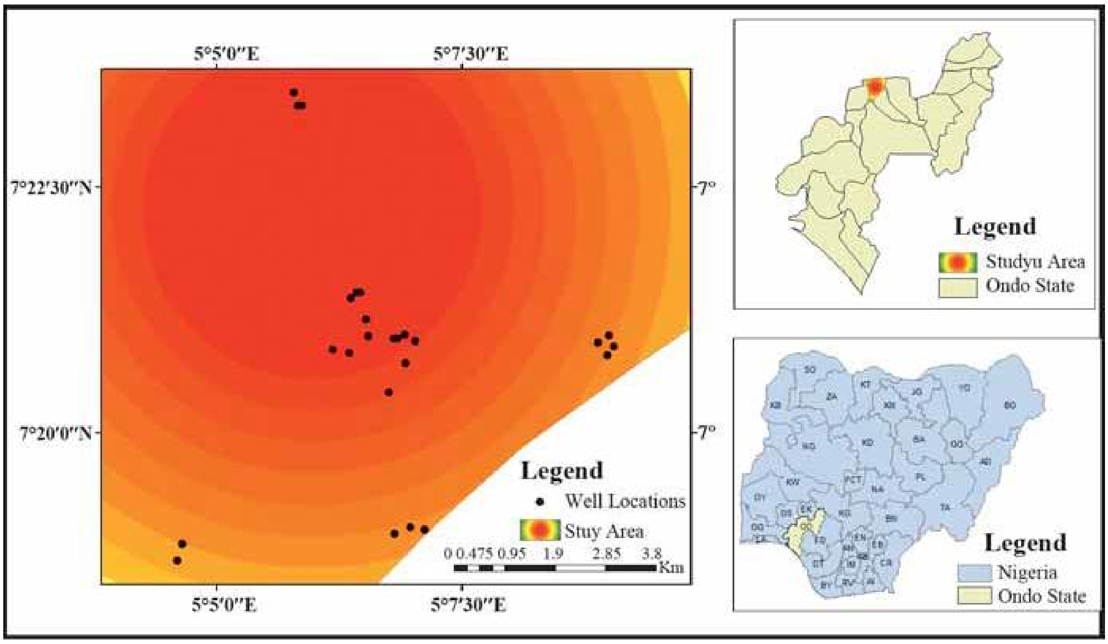

Fig. 1. Map showing Nigeria, Ondo state, the study area and locations of monitored wells.

installed with circular ring, fetching period is between 7am and 6pm daily) were however selected in the whole of the study area which were monitored consecutively for two years.

METHODS

This section discussed the method employed for the well monitoring and the methods of data analysis.

Well Monitoring

A total of 40 wells were monitored consecutively for two years (2012–2014) in the study area. A total of 24 wells were selected in Ilara-mokin and 4 wells each from the four surrounding villages (Ipogun, Ikota, Ero and Ibule). The surface elevation, latitude and longitude of each well location were taken using Global Positioning System (Garmin GPS Channel 76 model). Well estimator was used to measure the depth to water early in the morning around 6:00am on an average of three times per week for two years. Most especially after individual rainfall incidence in the previous day, this is to determine how the well responds to rainfall occurrence. This was based on the observation of Sekhar et al. [1994] and Nyagwambo [2006] that recharge in a basement complex aquifer is solely from rainfall. Although the wells were also monitored during the dry season when there are little or no rainfall in the study area. Groundwater level of the research area was computed by deducting depth to water from the surface elevation. This is written as shown in equation 1:

$$S_{wl} = E - D_{wt}, \qquad (1)$$

where S_{wl} = Static water level; E = Surface elevation; D_{wt} = Depth to water table

Methods of data analysis

The trend, anomalies and percentage changes in the climate condition of the area were first established. Then the relationship between the two major climatic drivers (rainfall and temperature) and groundwater level were examined to determine the response of groundwater to these climatic variables on monthly basis.

Trend analysis

The Kolmogorov–Smirnov test was carried out on the climatic variables to determine that they were normally distributed. Two methods (simple regression analysis and moving average) were adopted in determining the trend in the climatic variables used. Scatter plot was carried out on the data set and the assumption of linearity was fulfilled. This is to validate the result of the trend analysis using regression. The formula is as written in equation 2:

$$Y = aX + b, \qquad (2)$$

where X is the time (year), a is the slope coefficient and b is the least square estimates of the intercept. a and b were obtained from equations 3 and 4 respectively.

$$a = \frac{n\sum(xy) = \sum x \sum y}{n\sum(x^2) - (\sum x)^2}; \qquad (3)$$

$$b = \frac{\sum y - b\sum x}{n}. \qquad (4)$$

Standard Rainfall Anomalies Index (SAI)

This is used to determine the departure of rainfall from the normal climatic condition established for the forty years period under consideration. According to Olaniran [2002], any departure above or below the established normal climatic condition are referred to as anomalies. According to him, a persistent departure from the normal condition constitutes a climatic fluctuation. SAI is used in this study to determine the number of dry and wet episodes experienced in the study area during the period under consideration. The equation is as shown in equation 5:

$$SAI = \frac{x_1 - \overline{x}}{SD}, \quad SAI = \frac{x_1 - \overline{x}}{SD}, \qquad (5)$$

where x_1 is the annual rainfall total; x is the mean rainfall for the period of study and SD is the standard deviation from the mean rainfall for the period of study.

Reduction pattern analysis

This method is used to determine the percentage changes in the climatic variables on a decadal scale. Reduction analysis has been used by researchers to determine the fluctuation and percentage change in hydro-climatic variables [Salami et al., 2010; Makanjuola et al., 2010; Ifabiyi and Ashaolu, 2013]. To get the percentage changes in the climatic variables, the record years of climatic variables were divided into groups of 10 years interval. The average (annual) variable (X_i) for the 10 years was calculated. The corresponding deviations from the average (X_m) for the groups and the corresponding percentage changes are obtained. The percentage changes in the climatic variables were obtained from equation 6:

$$\frac{X_i - X_m}{X_m} \cdot 100\ \%. \quad (6)$$

Pearson Moment Correlation

This method was employed to determine the response of groundwater to the monthly weather variables. This was carried out on monthly basis because of the limited number of years of record for the groundwater level. Also, monthly analysis is considered to be the best since the focus is on management and sustainability of groundwater in a shallow aquifer of a basement complex rock which is a poor aquifer unit [Ashaolu and Adebayo, 2014] and where recharge is solely from rainfall [Sekhar et al., 1994; Nyagwambo, 2006]. The relationship was established from equation 7:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}, \quad (7)$$

where r is the Product Moment Correlation, y is the groundwater level and x is the weather variables.

Multiple Regression Analysis

This analysis was carried out to further ascertain the response of groundwater to weather variability and determine the percentage of variability in groundwater level that can be attributed to weather variability. The analysis was first carried out by ordinary multiple regression and later subjected to stepwise multiple regression analysis. This result was derived from equation 8.

$$y = a + b_1x_1 + b_2x_2 + e, \quad (8)$$

where y is groundwater level, a is the intercept on y-axis, b_1–b_n is partial regression coefficient of the independent variables, x_1 = rainfall and x_2 is air temperature.

RESULTS

Before the groundwater response to weather variability was determined, the general trend, anomalies and percentage changes in climatic variables in the study area was first determined. Hence, the relationship between groundwater and weather (rainfall and temperature) variability was established.

Trend analysis

Two methods were adopted in determining the trend in the climatic variables. These are simple regression analysis and moving average. The trend in the climatic variables in relation to time was first determined by regression analysis. The result of the regression analysis is displayed in Table 1. The p-value for the rainfall slope is 0.69 which is greater than 0.05, thus, there is no statistically significant relationship between rainfall and year at 95 % confidence level. The R-squared statistic shows that the model, as fitted, explains 0.40 % of the variability in rainfall. The correlation coefficient of 0.06 reveals a very weak relationship between the rainfall and time (year). The p-value for the air temperature slope is 0.01 which is less than 0.05, thus, there is a statistically significant relationship between

Table 1. Climatic trend derived from regression analysis

Variables	Regression equation	P-value	Statistically Significant	Sample correlation	R^2
Rainfall	Y = 1586.98 + 1.79X	0.69	No	0.06	0.40 %
Air Temperature	Y = 30.38 + 0.021X	0.01	Yes	0.40	16.10 %

air temperature and year at 95 % confidence level. The R-squared statistic reveals that the model, as fitted, explains 16.10 % of the variability in air temperature. The correlation coefficient of 0.40 indicates a mild relationship between air temperature and time (year).

Figure 2 shows the annual rainfall and five year moving average curve for Ilara-mokin and its' environ, from 1973–2012. The five year moving average curve shows an increasing trend from 1987 to 1998 but revealed a declining trend from 1999 to

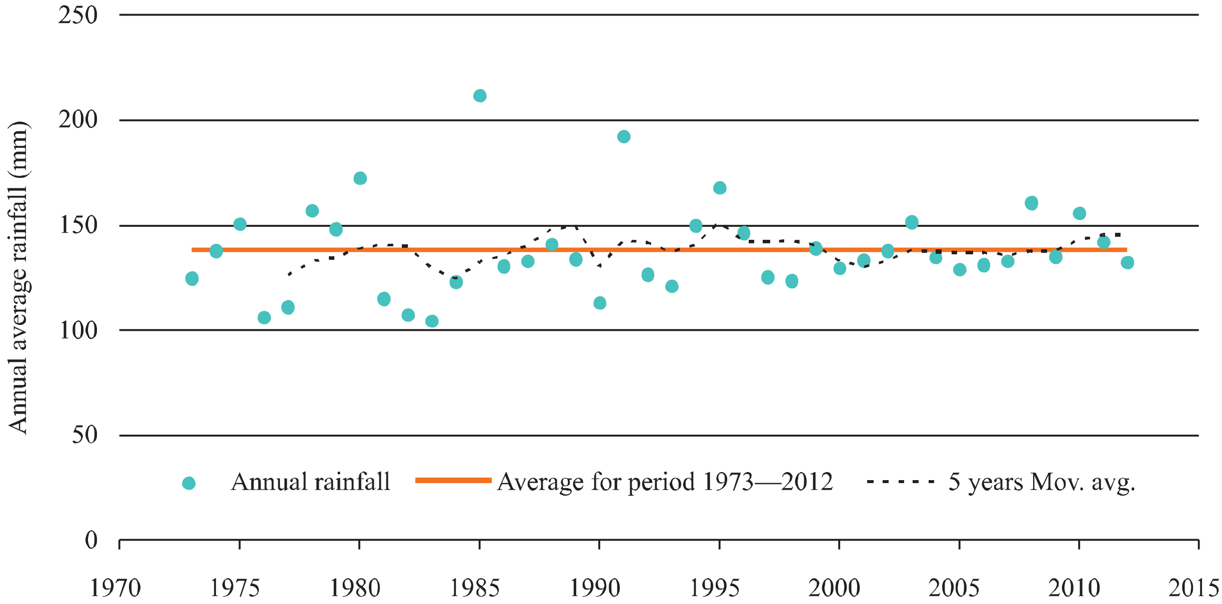

Fig. 2. Annual rainfall at Ilara-mokin and its' environs for period 1973–2012.

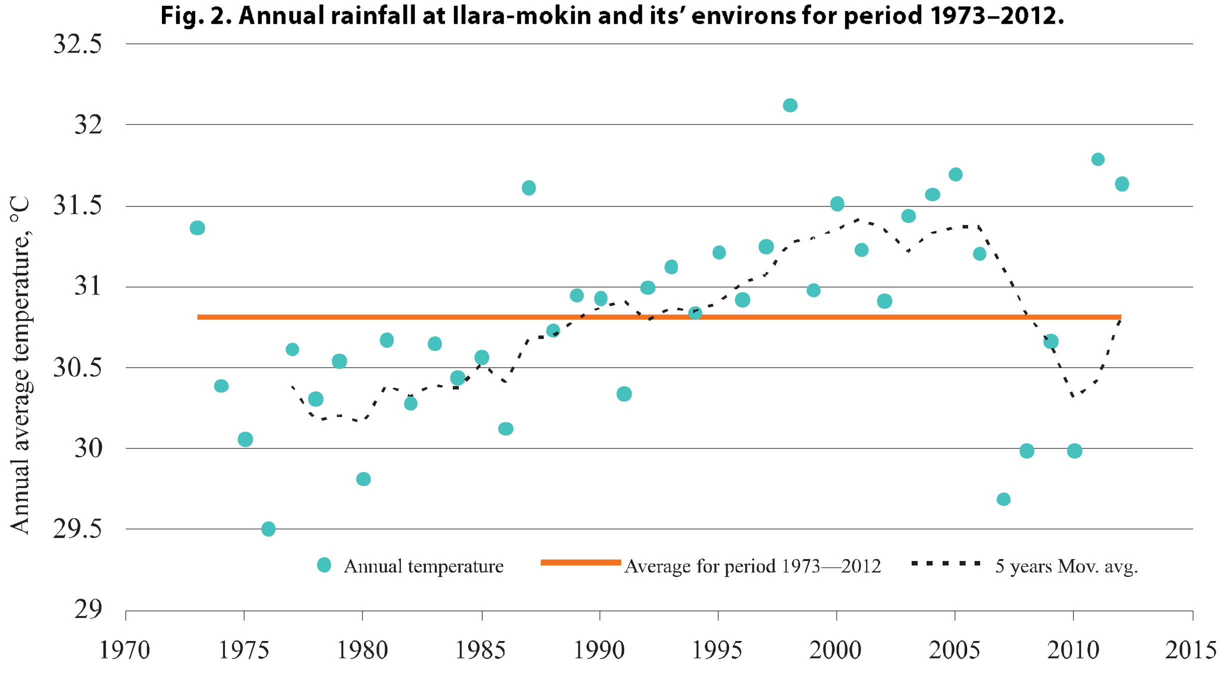

Fig. 3. Annual temperature at Ilara-mokin and its environs for period 1973–2012.

2009, however the curve start increasing again from 2010. Figure 3 shows the annual temperature and five year moving average curve for Ilara-mokin and its environ from 1973–2012. The five year moving average curve shows an increasing trend from 1988 to 2008 but dropped for four years and peaked again in 2012.

Rainfall anomalies, percentage changes in rainfall and temperature

Rainfall anomalies are the departure above or below the long term established normal (rainfall) climatic condition [Olaniran, 2002]. According to him, a persistent departure from the normal condition constitutes a climatic fluctuation. SAI is used to establish the dry and wet episodes in the study area under the period of consideration and the results are presented in Table 2. The forty years under consideration were divided into four periods of ten years (decade) and the number of dry and wet episodes (years) within these ten years period were identified. Table 2 shows an average of six dry episodes in every ten years in the last four decades in the study area.

The record years of rainfall and temperature are divided into groups of 10 years intervals for decadal analysis. This was used to get the percentage change in rainfall and temperature over time in Ilara-mokin and its' environ. The results of percentage changes in rainfall for the forty years period are presented in Table 3. From the rainfall record of 1973–2012 in Ilara-mokin and its' environ, the average rainfall was 138.12 mm. From 1973–1982 rainfall decreased slightly to 133.18 mm, showing a percentage change of –3.58 %. From 1983–1992, rainfall increased to 141.11 mm, showing a positive change and a percentage increase of 2.16 %. From 1993–2002, rainfall decreased to 137.52 mm, showing a negative change with a percentage difference of –0.43 %. Rainfall rose again to 140.66 mm from 2003–2012 with a positive change of 1.84 %.

The results of percentage changes in air temperature for the forty years period are presented in Table 4. From the air temperature record of 1973–2012 in Ilara-mokin and its' environ, the average air temperature was 30.82 °C. From 1973–1982 and 1983–1992, air temperature decreased slightly to 30.66°Cand 30.74 °C respectively. These show a negative

Table 2. Dry and Wet Episodes in the Study Area in the last Four Decades (1973–2012)

Periods	Dry years	Wet years
1973–1982	1973 (*–0.60*), 1974 (*–0.00*), 1976 (*–1.45*), 1977 (*–1.21*), 1981 (*–1.04*), 1982 (*–1.38*)	1975 (*0.57*), 1978 (*0.85*), 1979 (*0.45*), 1980 (*1.56*)
1983–1992	1983 (*–1.51*), 1984 (*–0.67*), 1986 (*–0.34*), 1987 (*–0.22*), 1989 (*–0.18*), 1990 (*–1.13*), 1992 (*–0.52*)	1985 (3.35), 1988 (*0.14*), 1991 (*2.47*)
1993–2002	1993 (*–0.77*), 1997 (*–0.57*), 1998 (*–0.65*), 2000 (*–0.38*), 2001 (*–0.21*), 2002 (*–0.01*)	1994 (*0.53*), 1995 (*1.35*), 1996 (*0.38*), 1999(*0.05*)
2003–2012	2004 (*–0.15*), 2005 (*–0.40*), 2006 (*–0.31*), 2007 (*–0.22*), 2009 (*–0.13*), 2012 (*–0.25*)	2003 (*0.61*), 2008 (*1.03*), 2010 (*0.81*), 2011 (*0.18*)

**Standard Rainfall Anomalies Index are italics in parentheses.

Table 3. Percentage Changes in Rainfall over Ilara-mokin and its Environs 1973–2012

Period	Decadal Averages (mm)	Average for the period of study (mm)	Deviation from long term average	% Change
1973–1982	133.18	138.12	–4.94	–3.58
1983–1992	141.11	138.12	2.99	2.16
1993–2002	137.52	138.12	–0.6	–0.43
2003–2012	140.66	138.12	2.54	1.84

Table 4. Percentage Changes in Temperature over Ilara-mokin and its Environ 1973–2012

Period	Decadal Averages (°C)	Average for the period of study (°C)	Deviation from long term average	% Change
1973–1982	30.36	30.82	–0.46	–1.49
1983–1992	30.74	30.82	–0.08	–0.26
1993–2002	31.21	30.82	0.39	1.27
2003–2012	30.97	30.82	0.15	0.49

change and a percentage reduction of –1.49 % and –0.26 %. However, from 1993–2002 and 2003–2012, air temperature at Ilara-mokin and its' environ increased to 31.21 °C and 30.97 °C, with a percentage difference of 1.27 % and 0.49 % respectively.

Groundwater response to weather (rainfall and temperature) variability

To determine how groundwater responds to weather variability, the relationship between groundwater, rainfall and air temperature were determined using multiple correlation analysis. Also, the response of groundwater to climatic variable was estimated with multiple regression analysis. The results of the multiple correlations were presented in Table 5. The result revealed a very strong negative relationship between air temperature and rainfall (r = –.807**) at 99 % confidence level. Also, there existed a very strong negative relationship between air temperature and groundwater (r = –.716**) at 99 % confidence level. While a very strong positive relationship was revealed between rainfall and groundwater (r = .815**) at 99 % confidence level. Figures 4 and 5 show the graphical representation of the relationship

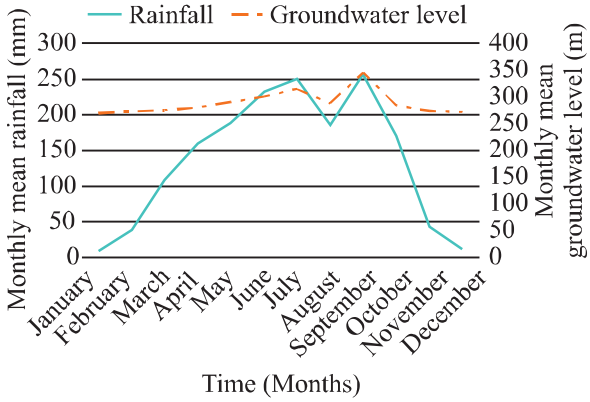

Fig. 4. Relationship between rainfall and groundwater level.

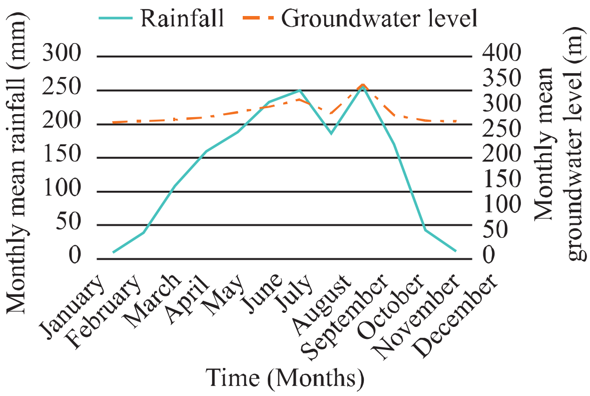

Fig. 5. Relationship between air temperature and groundwater level.

between rainfall and groundwater, air temperature and groundwater respectively.

Table 5. Relationship between Rainfall, Air temperature and Groundwater level

Variables	Rainfall	Air temperature
Rainfall		
Air temperature	–.807**	
Groundwater level	.815**	–.716**

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6 shows the results of the multiple regression analysis between groundwater (dependent), rainfall and temperature (independents). The model using enter method has an R^2 of .673, standard error of 14.01 and p-value of 0.006 which indicates that the model is statistically significant at 95 % confidence level. Also, the stepwise method has an R^2 of .663, standard error of 13.38 and p-value of 0.001 which indicates

Table 6. Groundwater response to climatic variables

Methods	R	R^2	Adjusted R^2	Std. Error of the estimate	Sig.
Enter	.821	.673	.601	14.01	0.006
Stepwise	.815	.664	.630	13.38	0.001

that the model is statistically significant at 95 % confidence level.

The estimated models from the regression analysis using enter and stepwise methods are presented in equations 9 and 10 respectively.

$$GroundwaterLevel = \\ = 316.88 + 0.163_{ra\inf all} - 1.632_{temperature}; \quad (9)$$

$$GroundwaterLevel = \\ = 262.160 + 0.195_{ra\inf all}. \quad (10)$$

DISCUSSION

Rainfall and air temperature revealed a positive trend in the area. Rainfall has a positive trend line and an R^2 value of 0.004, which indicates that there is a very weak relationship between rainfall and year. Also, from the regression equation Y = 1586.98 + 1.79X, it is observed that there is a positive correlation between time (year) and rainfall for Ilara-mokin and its environs. This indicates that there will be increment of 1.79 mm in rainfall relative to time but this trend is not statistically significant because p-value is 0.69. This may be attributed to high rate of year to year variability in the amount of rainfall received in the area. Further, the five year moving average curve shows an increasing trend from 1987 to 1998 but revealed a declining trend from 1999 to 2009, however the curve start increasing again from 2010. This indicates there is variability in rainfall from decade to decade in the area. It is however, not clear if this may represent the part of a longer climatic cycle or climate change in the area.

On the other hand, air temperature has an R^2 value of 0.1610, indicating a weak relationship between air temperature and time. The regression equation of air temperature Y = 30.38 + 0.021X shows that there is a positive correlation between temperature and time (year), meaning that air temperature of Ilara-mokin and its environs will increase in relation to time, but at a very low rate. Though air temperature will increase at a very slow rate, the increment is however statistically significant with p-value of 0.01. Also, the five year moving average curve shows an increasing trend from 1988 to 2008 (20 years) but dropped for four years and peaked again in 2012. This cycle clearly indicate that the air temperature of this area is gradually increasing which may be tagged to the general increase in the world surface temperature as reported by IPCC [2007].

Olaniran [2002] described rainfall anomalies has the departure above or below the long term established normal (rainfall) climatic condition of an area. According to him, a persistent departure from the normal condition constitutes a climatic fluctuation. The forty years under consideration were divided into four periods of ten years (decade) and the number of dry and wet episodes (years) within these ten years period were identified using Standardized Rainfall Anomalies Index (SAI). The results of SAI in Table 2 show an average of six dry episodes in every ten years in the last four decades in the area. This shows that this area is always experiencing dry spell for nothing less than six years in every decade. Since recharge in a basement complex aquifer is solely from rainfall, this will seriously affect recharge and groundwater in this area. The people in this environment will always experience water stress during this dry spells since they depend mainly on shallow groundwater.

From the rainfall record of 1973–2012 in Ilara-mokin and its' environ, the average rainfall was

138 mm. The result of percentage changes in rainfall for the forty years period in Table 3, shows that from 1973–1982 rainfall decreased slightly to 133.18 mm, showing a percentage change of –3.58 %. From 1983–1992, rainfall increased to 141.11mm, showing a positive change and a percentage increase of 2.16 %. From 1993–2002, rainfall decreased to 137.52 mm, showing a negative change with a percentage difference of –0.43 %. Rainfall rose again to 140.66 mm from 2003–2012 with a positive change of 1.84 %. Sandstorm [1995] reported that a 15 % reduction in rainfall results to 40–50 % reduction in recharge, which means that small changes in rainfall can lead large change in recharge and groundwater response. These result also indicated that the rainfall received in this area is fluctuating from decade to decade and there is every possibility that this scenarios will continue into the future, greatly affecting groundwater resources of this area.

From the air temperature record of 1973–2012 in Ilara-mokin and its' environ, the average air temperature was 30.82 °C. The result of percentage changes in air temperature for the forty years period presented in Table 4 shows that from 1973–1982 and 1983–1992, air temperature decreased slightly to 30.66°Cand 30.74 °C respectively. These show a negative change and percentage reduction of –1.49 % and –0.26 % respectively. However, from 1993–2002 and 2003–2012, air temperature at Ilara-mokin and its'environ increased to 31.21 °C and 30.97 °C, with a percentage difference of 1.27 % and 0.49 % respectively. This is an indication that the temperature of this area is increasing in the last 20 years and also confirmed the results of the trend analysis which is statistically significance. The increasing temperature observed may also be as a result of increase in urbanization at the state capital (Akure) where the weather station is located and which is very close to the research area, population growth and the associated changes in land use type also in the area. A study by Olanrewaju [2009] attributed the steady rise in air temperature of Ilorin city to the population growth rate of Ilorin.

The results of the multiple correlation in Table 5 revealed a very strong negative relationship between air temperature and rainfall (r = –.807**) at 99 % confidence level. This is an indication that any month when there is high temperature, there will be low rainfall and vice versa. It can be concluded that monthly rainfall and monthly air temperature are inversely related in this area. Also, there existed a very strong negative relationship between air temperature and groundwater (r = –.716**) at 99 % confidence level. Chen et al. [2002] also reported a negative correlation between annual average groundwater level and annual air temperature in the carbonate rock aquifer of the southern Manitoba, Canada. This negative relationship shows that there is an inverse relationship between monthly air temperature and groundwater. When the air temperature is high in any particular month, there is reduction in groundwater level which can be attributed to the rate of evaporation, because groundwater occurrence in this area is shallow. However, a very strong positive relationship was revealed between monthly rainfall and monthly groundwater level (*r* = .815**) at 99 % confidence level. Chen et al. [2002] in their research discovered a positive correlation between annual average groundwater level and annual precipitation. This strong positive relationship shows that groundwater level increases and decreases at the same frequency with the amount of rainfall occurrence. This is expected since the study area is underlain by basement complex rock where recharge is solely from rainfall. This is in agreement with Sekhar et al. [1994] and Nyagwambo [2006] that recharge in a basement complex aquifer is solely from rainfall. This therefore shows that groundwater level is subjected to the degree of rainfall variability in this area, which the results of the rainfall anomalies, percentage change in rainfall of this area have clearly shown.

The results of the multiple regression analysis in Table 6 has an R^2 of .673 which is an indication that rainfall and air temperature accounted for 67.3 % of variability in monthly groundwater level in Ilara-mokin and its environs. The model in equation 9 revealed that for every 1 % increase in rainfall in any month, there is 0.163 % increase in monthly groundwater level, and for every 1 % increase in temperature in any month, there is –1.63 % decrease in monthly groundwater level. This is an indication that groundwater respond positively to rainfall occurrence but negatively to air temperature incidence. This also supported the result of the multiple correlations. While the stepwise multiple regression has an R^2 of .664 which is an indication that monthly rainfall in the study area accounted for 66.4 % of variability in the monthly groundwater level in the area. The model in equation 10 revealed that for every 1 % increase in monthly rainfall there is 0.195 % increase in monthly groundwater level. This is also in agreement with Sekhar et al. [1994] and Nyagwambo [2006] that recharge in a basement complex aquifer is solely from rainfall. However, the remaining 33.6 % variability in groundwater level can be attributed to the type of overburden on which the monitored well are located. Chen et al. [2002] though carried out their research on a shallow carbonate aquifer, their results also revealed variability in groundwater response to rainfall, which they attributed to differences in recharge characteristics and the permeability of overlying sediments. The study area is generally underlain by thin weathered basement rocks which has produced thin and marginally thick overburden [Oladapo et al., 2009] but areas with thick and sandy overburden which are high groundwater potential zones [Bala and Ike, 2001] are absent from the study area [Oladapo et al., 2009]. This is an indication that the groundwater is highly exposed to the vagaries of climate especially rainfall because of the shallow overburden aquifer in the study area.

CONCLUSION

Having established the climatic scenarios of this area looking at the trend, anomalies and changes in climate, especially rainfall and air temperature. It is clear that while air temperature is on the increase, though at a very slow rate, the rainfall received in this area is highly varied from year to year and on decadal basis. The relationship between groundwater and air temperature is negative, while there existed a positive relationship between groundwater and rainfall. This is an indication that increasing monthly temperature will greatly affect the groundwater of this area and the change (positive or negative) in rainfall received will also have significant effect on groundwater resources of the area. This may be the reason for water supply shortages reported by previous study in this area. Hence, there will be enormous challenges facing the inhabitant of this area as they depend mainly on shallow groundwater which respond to the vagaries of climate (rainfall and temperature). Though the study focused on the response of groundwater to rainfall and temperature as if they were the only two variables that affect recharge in a shallow aquifer based on the suggestions of Sekhlar et al [1994] and Nyagwambo [2006]. It is however a good starting point in understanding how groundwater will respond to climate variability in a shallow aquifer of a tropical basement rock to enhance adaptation and management of the groundwater resources of the area. ■

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