Impact of Climate Variability and Land Cover Dynamics on Groundwater Potential of Upper Benue River Basin, Nigeria

[1]Joshua, Ma'aku Mark, [2]Oruonye E.D., [3]Zemba, A.A. & [4]Yusuf, M.B.

[1,2&4]Department of Geography, Taraba State University, Jalingo, Taraba state, Nigeria.
[3]Department of Geography, Modibbo Adama University, Yola, Adamawa State, Nigeria.

Abstract

The study assessed the effects of climate variability (precipitation and temperature) and landcover changes on groundwater potentials of the Upper Benue River Basin in Nigeria. The study involved the use of remotely sensed data with the application of Geographic Information System (GIS). It was based on survey design and both primary and secondary data were used. The study was anchored on the concept of hydrological cycle. The analytical hierarchy process (AHP) was employed in the analysis of groundwater potential of the study area. The results of this study revealed that climate variability (temperature and precipitation) and landuse/landcover both have strong positive effect on groundwater potential in the Upper Benue River Basin. That is, when precipitation increases, the depth to abstract groundwater reduces, however, when the precipitation decreases, the depth of ground water (GW) increases. The findings of the study reveal that by 2070, the mean depth to ground water will increase from the current level (2021) of 48.9m to 65m; which is an addition of 6.1m. Furthermore, there was a loss of 15.4 % in the vegetation cover over the period while the built-up area and rock outcrop revealed significant gains of 15.2% and 2.9% respectively. The areal coverage of various GWP levels reveals that a larger portion of the basin has low GWP with an area of 44,822.4 Km^2, while the poor GWP area was 43,315.7 Km^2, the area covered by moderate GWP was 25,863.8 Km^2 as the areas of high potential covered 11,550.9Km^2. Vegetation monitoring of the basin should be mainstreamed into existing laws establishing the UBRBA to prevent further degradation as this study established a decrease in the vegetation of the basin. Afforestation of the basin is of urgent importance to help more water infiltration into the basin and sustain the ground water recharge and potential in the future.

Keywords: Catchment area, Drainage basin, Groundwater, River Basin and Upper Benue.

Introduction

Water is an essential and necessary natural resource, and its shortage puts human society at risk and under stress. Without responsive water development, lengthy and extreme droughts, seasonal volatility in rainfall, and resource degradation, growing water scarcity is projected to worsen under population pressure (Adesina & Odekunle, 2011; Adejuwon & Adelakun, 2012).

The degree of water stress experienced is further threatened by the vagaries of climatic variability. In its Fourth Assessment Report, the Intergovernmental Panel for Climate Change (IPCC) projects that Africa will be disproportionately affected by climate change (Bates *et al*, 2008). The projected warming in Africa is 1.5 times the global average (Taylor, Koussis & Tindimugaya, 2009). The availability and sustainability of groundwater in many aquifers in Nigeria, like many principal aquifers around the world (USGS, 2009; Brekke *et al*, 2009; Alley *et al*, 2002), may be under threat in the next few decades because of depletion of the resource imposed by human and climatic stresses.

Furthermore, land use and land cover have exerted small to large scale changes on regional hydrological processes (Genxu *et al*, 2005; USGS, 2009). The current scenario regarding groundwater resources suggests a global water crisis in terms of quantity (availability) and quality. Land use change is the most important factor that is considered in global change study (Loveland *et al*, 2000; Tsarouchi *et al*, 2014; Rolando *et al*, 2017). Land use describes utilisation of land resources by humans (Pielke, 2005). The Sub-Saharan African region recorded the fastest conversion of forest land to agriculture in the past 20 years (Nkonya *et al*, 2013). Nigeria has one of the highest rates of vegetative cover losses in the world, having continuously lost about 410,100 hectares per year between 2005 and 2010 at a rate of 3.12% per annum (Ozor & Odo, 2008). The main drivers of this situation in the country have been agriculture, logging, grazing, urbanisation, road construction and mining (Ozor & Odo, 2008; MacDicken, 2015). Land use change can modify hydrological processes at temporal and spatial scales especially in the arid regions. (Foley *et al*, 2005; Nian, 2014).

The Benue basin which originated from the Mandara mountains in Cameroun is the major tributary of the Niger River (it empties its water into the Niger at Lokoja where confluence is formed). The major tributaries of the Benue River in Nigeria are Katsina-Ala, Donga, Taraba, Gongola and Pai (Nkeki, Henah, & Ojeh 2013; Evans & Sunday, 2018; Usman *et al*, 2019). Though most studies have concentrated on the geomorphological characteristics (Overare *et al*, 2015; Ezekiel *et al*, 2015; Adebola *et al*, 2018), while several other studies have focused on the flooding implication (Tanko & Agunwamba, 2008; Nwilo *et al,* 2012; Izinyon & Ajumuka, 2013; Bello & Ogedegbe, 2015), less focus has been on the ground water potential of this significant region and the implications of climate and land use and land cover dynamics at a spatio-temporal scale. This work seeks to bridge this research and methodological gap of considering the joint impact of climatic parameters and anthropogenic driven land use changes on ground water potential of the Upper Benue River Basin of Nigeria incorporating space intelligent approaches.

Statement of Research Problem

The Upper Benue River Basin lies between sub humid and semi-arid parts of Northeastern Nigeria. Between one-third and half a million people in the basin rely on unprotected and protected groundwater sources for domestic water usage. Groundwater is the major source of drinking water across much of the world and plays a vital role in maintaining the ecological value of an area including the study area. Despite the huge number of wells and boreholes drilled each year, groundwater monitoring systems for obtaining, compiling, and analysing information have failed in various sub regions in several nations (Allaire, 2009; Foster & MacDonald, 2014) leading to losses on the huge amount of money invested to drill such wells since it failed to yield the relevant information for research, policy and socio-economic development. The availability and reliability of water resources data has been a problem for many decades. Almost half of the population of the seven (7) Nigerian states in the Upper Benue River Basin lives in severe and chronic water shortage.

As at today, ground water potentials data in the UBRB still remains scarce and the information which is gathered is being done in an unsystematic manner. The reasons behind this are numerous and complex (Adelana & MacDonald, 2008), including the lack of clear institutional arrangements and responsibilities, inadequate resourcing, lack of technical expertise and the absence or disconnect with database management and retrieval systems. Although, several studies relating to the effect of climate change on surface water bodies have been undertaken but very little studies exist on the potential effects of climate variability on groundwater in the basin.

More so, understanding the impacts of land use/land cover change (LU/LC) on the hydrologic cycle is needed for optimal management of water resources. It has been observed that the global impact of LU/LC change on the hydrologic cycle may surpass that of recent climate change (Vorosmarty *et al,* 2004). Impacts of LU/LC change on atmospheric components of the hydrologic cycle (regional and global climate) are increasingly recognized (Pielke, 2005; Shi *et al*, 2013; Pitman *et al*, 2004). Impacts of LU/LC change on subsurface components of the hydrologic cycle are less well recognized and this has not been extensively studied in the basin. It is against this background that this study examined the joint influence of climate variability and LU/LC on ground water potentials of the Upper Benue River Basin in Nigeria.

Description of Study Area

The Upper Benue River Basin is located between latitude 6°29′N to 11°46′N and longitude 8°55′E to 13°30′E (Fig. 1) which traverses seven States of the Nigerian Federation (Adamawa, Gombe, Bauchi, Plateau, Yobe, Borno and Taraba State). The Basin extends 532 km from north to south and 480 km from west to east. The watershed covers an area of 155,552.8 km^2. It represents one of the eleven river basin development authorities created in 1976 to enhance the management of water and agricultural resources (Akpabio, 2008) in Nigeria. Lake Chad basin bounds the Upper Benue River Basin to the north, to the east and south by the Republic of Cameroon, and to the West by the Lower Benue and Upper Niger watershed.

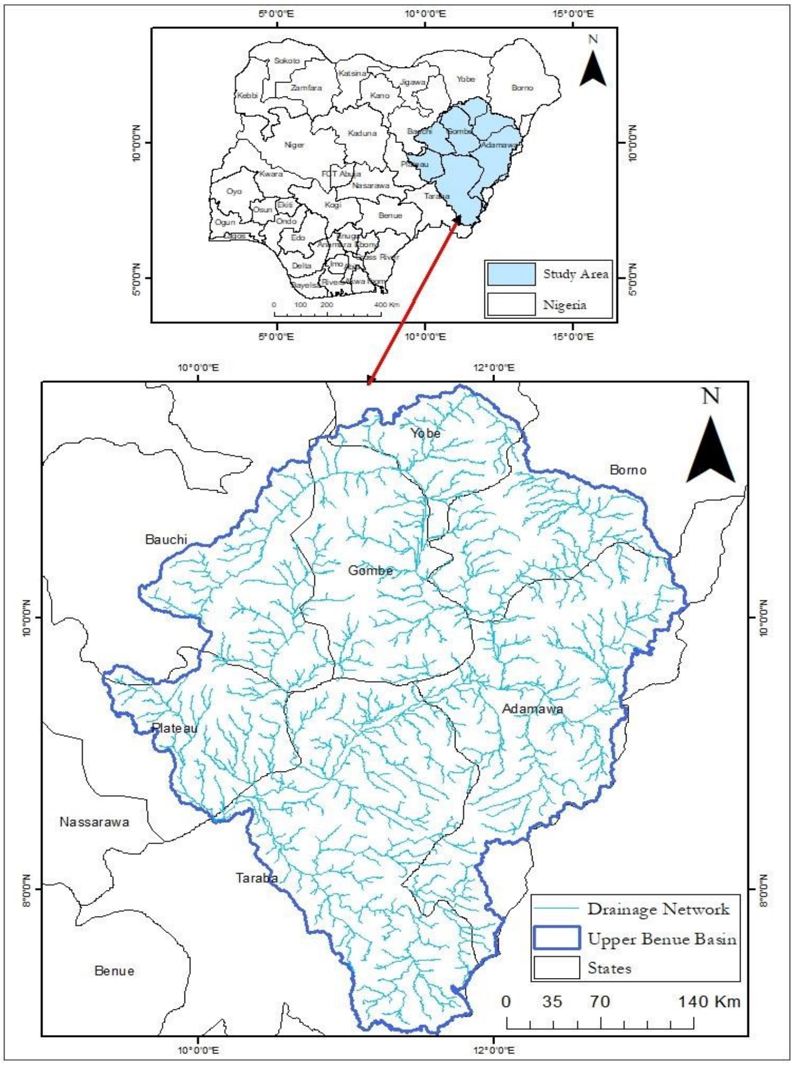

Figure 1: Map of the Study Area

The major river in the basin is the river Benue that has its origins in the Adamawa Plateau of Northern Cameroon and flows south-west to meet with River Niger in Lokoja. The river Benue is joined by its major tributaries; the Gongola River, the Mayo Kébbi, Taraba River, and River Katsina-Ala (Nkeki, Henah, & Ojeh, 2013). The watershed is a seventh stream order system characterized by a dendritic drainage pattern (Odiji *et al*, 2021). The characteristics of the basin gives its unique ground water potential and makes it able to adapt to the changes in climate.

The geology of the study area comprises of Precambrian basement rocks, Cretaceous to Recent sedimentary sequences and Tertiary volcanics (Osinowo & Abdulmumin, 2019). The Basement rocks that underlain the study area especially those that occur as exposures are of the Older Granite category which comprises granites, granodiorites and mylonites and Asu River group, Kerri kerri formation and undifferentiated sedimentary rocks (Lar, 2013). These types of rocks influence the basin's ability to recharge and its groundwater potentials.

The Upper Benue River Basin is characterized by a tropical continental climate (Odiji *et al*, 2021). The area has two distinct seasons, dry and wet season with temperature and humidity varying with the seasons. The mean annual rainfall ranges between 700 and 1200 mm and an average annual temperature range from 24 to 27 °C (Ishaku *et al*, 2015). The variability and change in the climate of the basin has both positive and negative effects on the groundwater potential of the area.

Apart from the small areas in the high plateau (Mambilla) which is marked by montane vegetation (Adebayo, 1997), the study area is predominantly marked by these agro-ecological zones; mid-latitude zone, derived savannah, northern guinea savannah, southern guinea savannah, and Sahel savannah. Vegetation plays key roles in the interactions between groundwater and surface-water systems, because of its direct and indirect influence on recharge and because of the dependence of vegetation communities on groundwater. Changes in vegetation cover and structure, particularly from low vegetation such as grassland to tall vegetation such as a forest can have a significant impact on groundwater recharge by altering components of the hydrological cycle such as interception and transpiration. Aquifers are impacted by vegetation because it directly pulls groundwater from saturated strata and blocks precipitation from the atmosphere from reaching the water table in recharge areas, which reduces the amount of rainfall that is ultimately recharged.

The area is rich in surface water resources and this supports commercial and subsistence scale farming, food production, livestock, forestry and fisheries. It is also endowed with enormous touristic potentials and presence of minerals. However, insurgence and communal clashes have taken a toll on the socioeconomic activities in some parts of the study area. The socio-economic activities, especially industries that produces bottled and sachet water, beverages and drinks as well as tourist centers in the basin have effect on groundwater abstraction level occurring in the area. In addition to serving as the main supply of drinking water for half of the world's population (Velis, Conti & Biermann, 2017), groundwater supports ecosystems by giving them access to nutrients, water, and a generally constant temperature (Klove et al, 2011). Such ecosystems associated to groundwater may be crucial to human health, food and energy production, as well as recreation (Machard de Gramont *et al*, 2011). For instance, more than 40% of the world's consumptive water used for irrigation comes from groundwater, which is utilized to irrigate almost 100 million hectares of arable land (Siebert *et al*, 2010). For these reasons, groundwater is inextricably tied to many facets of human development, such as the reduction of poverty (e.g. Moench, 2003).

Materials and Methods

The study used the field survey research design. Primary and secondary data were used. Secondary data include archival data obtained from government ministries and agencies, as well as published materials such as books and journals. Gridded climatological data (precipitation and temperature) covering the study basin from 1981 to 2021 was acquired from the Intergovernmental Panel on Climate Change (IPCC) repository (https://www.ipcc/data.org). The data on the groundwater depth (the geo-location, depth to water table and the season of the year when the data was collected) was acquired from Upper Benue River Basin Authority (UBRBA) head office in Yola, Adamawa State and State Water Agencies of Plateau, Taraba, Bauchi and Borno States.

The study involves interpolation of precipitation data in the form of point rain gauge readings from 25 rain gauge stations spread across the study area. The point rain gauge data are handled using MS EXCEL spreadsheets in order to calculate yearly precipitation and other statistical parameters. The analysis was carried out using Geographic information system (GIS) Technology.

Field survey was undertaking for identification of 51 boreholes and wells comprising 32 boreholes and 19 wells (Fig. 2) having their depth provided by the various state water agencies and the integrity of the data was tested using tape. At each location, coordinates were obtained using the Global Positioning System (GPS). Landsat images and SRTM of the study area was downloaded and downscale to cover the upper Benue Basin using the study area map.

Landsat Imageries spanning the years 1981, 2001 and 2021 was pre-processed. Supervised approach with maximum likelihood classifier was adopted for the classification and generation of LULC maps for the selected time periods to show the various LULC types across the study area. Using spatial transition modelling, the changes, gains and losses between LULC classes overtime were geo-visualized. The LULC first and last epoch was further subjected to Markov Cellular Automata model to predict the status of LULC of the catchment for year 2070.

To examine the association or absence of relationship amongst the hydrological regimes, climatic and land use/cover, multivariate correlation was used to determine the strength and direction of relationship. The band collection statistics tool provides statistics for the multivariate analysis of a set of raster bands. When using the compute covariance and correlation matrices, option is enabled, the covariance and correlation matrices are output as well as the basic statistical parameters, such as the values of minimum, maximum, mean, and standard deviation for every layer (Esri User Manual, 2010).

The covariance matrix contains values of variances and covariances. The variance is a statistical measure showing how much variance there is from the mean. To calculate these variances, the squares of the differences between each cell value and the mean value of all cells are averaged. The variances for every layer can be read along the diagonal of the covariance matrix moving from the upper left to the lower right. The variances are expressed in cell-value units squared. The remaining entries within the covariance matrix are the covariances between all pairs of input rasters. The following formula is used to determine the covariance between layers.

$$Cov_{ij} = \frac{\sum_{k=1}^{N} (Z_{ik} - \mu_i)(Z_{jk} - \mu_j)}{N - 1}$$

where:

Z - value of a cell

i, j - are layers of a stack

μ - is the mean of a layer

N - is the number of cells

k - denotes a particular cell

The covariance of two layers is the intersection of the appropriate row and column. The covariance between layers 2 and 3 is the same as the covariance between layers 3 and 2. The values of the covariance matrix are dependent on the value units, while the values of the correlation matrix are not. The correlation matrix shows the values of the correlation coefficients that depict the relationship between two datasets. In the case of a set of raster layers, the correlation matrix presents the cell values from one raster layer as they relate to the cell values of another layer. The correlation between two layers is a measure of dependency between the layers. It is the ratio of the covariance between the two layers divided by the product of their standard deviations.

Correlation ranges from +1 to -1. A positive correlation indicates a direct relationship between two layers, such as when the cell values of one-layer increase, the cell values of another layer are also likely to increase. A negative correlation means that one variable change inversely to the other. A correlation of zero means that two layers are independent of one another.

The correlation matrix is symmetrical. Its diagonal from the upper left to lower right is 1.0000 since the correlation coefficient of identical layers is +1 (ESRI user Manual, 2010). This approach has been adopted in several studies in drawing relationship between multiple spatial scales (Yao *et al*, 2018; Ghalambordezfooli & Hosseini, 2019; Moskalenko & Malytska, 2020).

Multiple regression method was utilized to predict the impacts of land use dynamics and climatic variability on ground water regimes within the study area. Multivariate-Multiple regression method was used as follows:

$$y = mx1 + mx_2 + mx_3 + b$$

- Y= the dependent variable of the regression (average piezometric height)
- M= slope of the regression
- X_1=first independent variable of the regression (predicted precipitation)
- The X_2=second independent variable of the regression (predicted temperature)
- The X_3=third independent variable of the regression (Markov CA prediction of LULC)
- B= constant

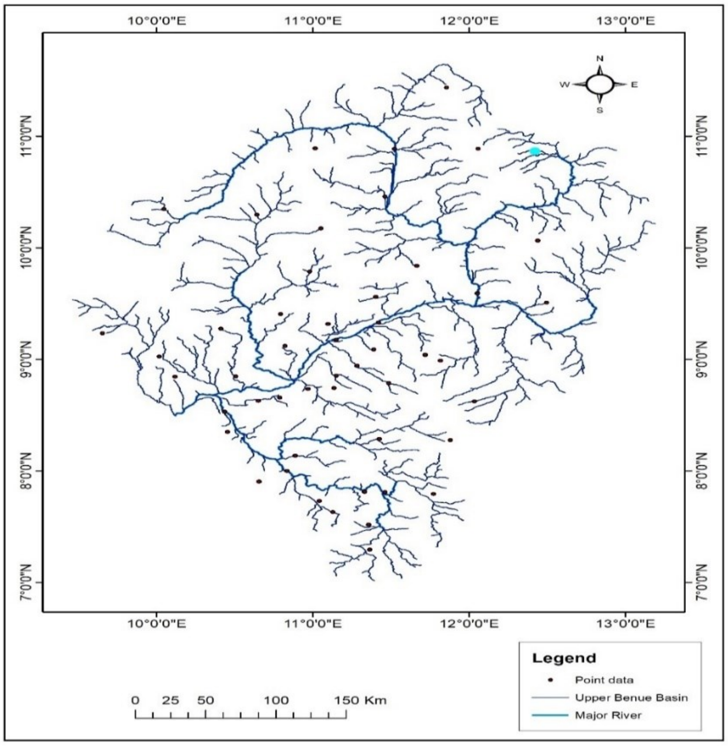

Fig. 2 Water Table data point of the study area

The results of the study are presented in the form of maps, graph, and tables where appropriate. Maps were mostly chosen because it is best suited in presenting spatial relations of hydrogeomorphic characteristics and the modeled and predicted groundwater potential zones of the upper Benue Basin.

Result of the Findings

Influence of Climate and Landcover Changes in the Upper Benue River Basin

To assess the joint and partial influence of the climatic parameters and LULC on the hydrologic regime, the variables were subjected to multiple regression analysis. Here, the ground water depth was the dependent variable while the climatic factors and LULC were explanatory variables. The result is presented in Table 1.

The results of the multiple linear regression in Table 1 indicates that there was a very strong collective significant effect between the Precipitation, Temp, LULC, and GW Depth, as $p < .001$, $R^2 = 0.96$, $R^2adj = 0.95$. R square (R^2) equals 0.956392. It means that the predictors (LULC, Precipitation, Temperature) explain 95.6% of the variance of GW. The individual predictors were examined further and indicated that Precipitation ($t = -5.957$, $p < .001$) and Temp ($t = 12.662$, $p < .001$) were significant predictors in the model, and LULC was non-significant predictor in the model with a $p<0.05$. Adjusted R square equals 0.954575. The coefficient of multiple correlation (r) equals 0.977953. It means that there is a very strong correlation between the predicted data (GW in 2070) and the observed data (GW in 2021).

Table 1. Result of the Regression Analysis

Regression Statistics	
Multiple R	0.98
R Square	0.96
Adjusted R Square	0.95
Standard Error	2.69
Observations	51

ANOVA

	Df	SS	MS	F	Significance
Regression	3	7611.80	2537.27	349.76	0.00
Residual	47	340.95	7.25		
Total	50	7952.75			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-378.22	40.449	-9.35	0.00	-459.587	-296.843	-459.587	-296.843
Rainfall	-0.028	0.005	-5.97	0.00	-0.038	-0.019	-0.038	-0.019
Temp	16.181	1.355	11.9	0.00	13.455	18.907	13.455	18.907
LULC	0.419	0.466	0.89	0.37	-0.519	1.356	-0.519	1.356

Source: Data analysis

Against this backdrop, the joint and partial influence of climatic variables is seen to influence the hydrological regime significantly, while LULC had less influence on the dependent variable (GW). Based on the foregoing, Fig. 3 and 4 are the line fit plots for temperature and precipitation.

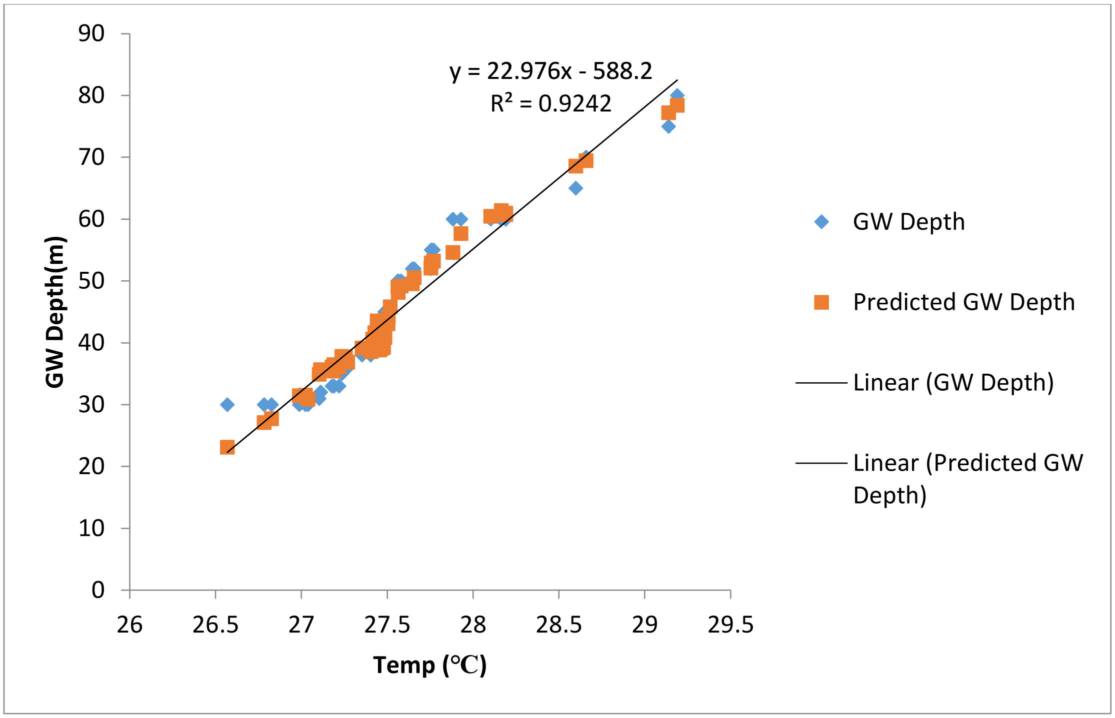

Fig 3. Temperature Line of Fit Plot

Fig. 3 shows that there is a strong positive correlation between temperature and the groundwater depth (GW) with spearman (r) value of 0.9242 which is 92% influence of temperature and GW.

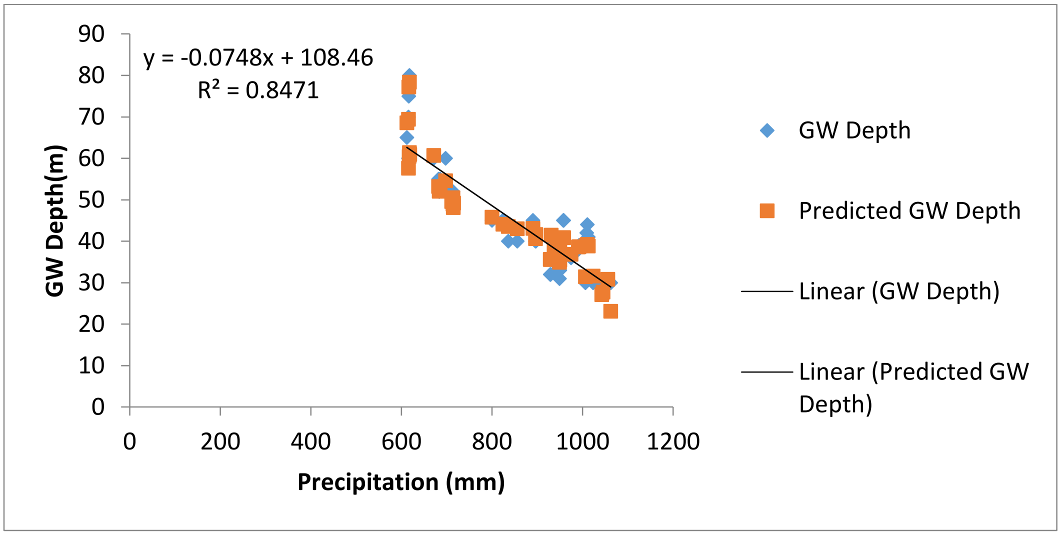

Fig 4. Precipitation Line of Fit Plot

Fig. 4 shows that there is a strong positive correlation between precipitation and the groundwater depth (GW) with spearman (r) value of 0.8471 which is 85% influence of precipitation and GW. This result shows that when precipitation increases, the depth to abstract groundwater reduces. However, when the precipitation decreases, the depth of ground water (GW) increases in the Upper Benue River Basin.

Prospects of Groundwater Potentials in the Upper Benue River Basin

In this section, the coefficients of the joint and partial relationship between climatic variable (precipitation and temperature), LULC and ground water depth as was presented in Table 1 were fitted into a multiple regression model as follows:

$$\text{GW Depth} = -378.22 - 0.028\ \text{Rainfall} + 16.181\ \text{Temperature}$$

This was subjected to raster calculation using year 2070 projected Rainfall and Temperature data from IPCC. The outcome of the raster calculation using the regression model is reflected in the prediction of the GW depth for the basin in the year 2070 (Fig. 5 and Table 2).

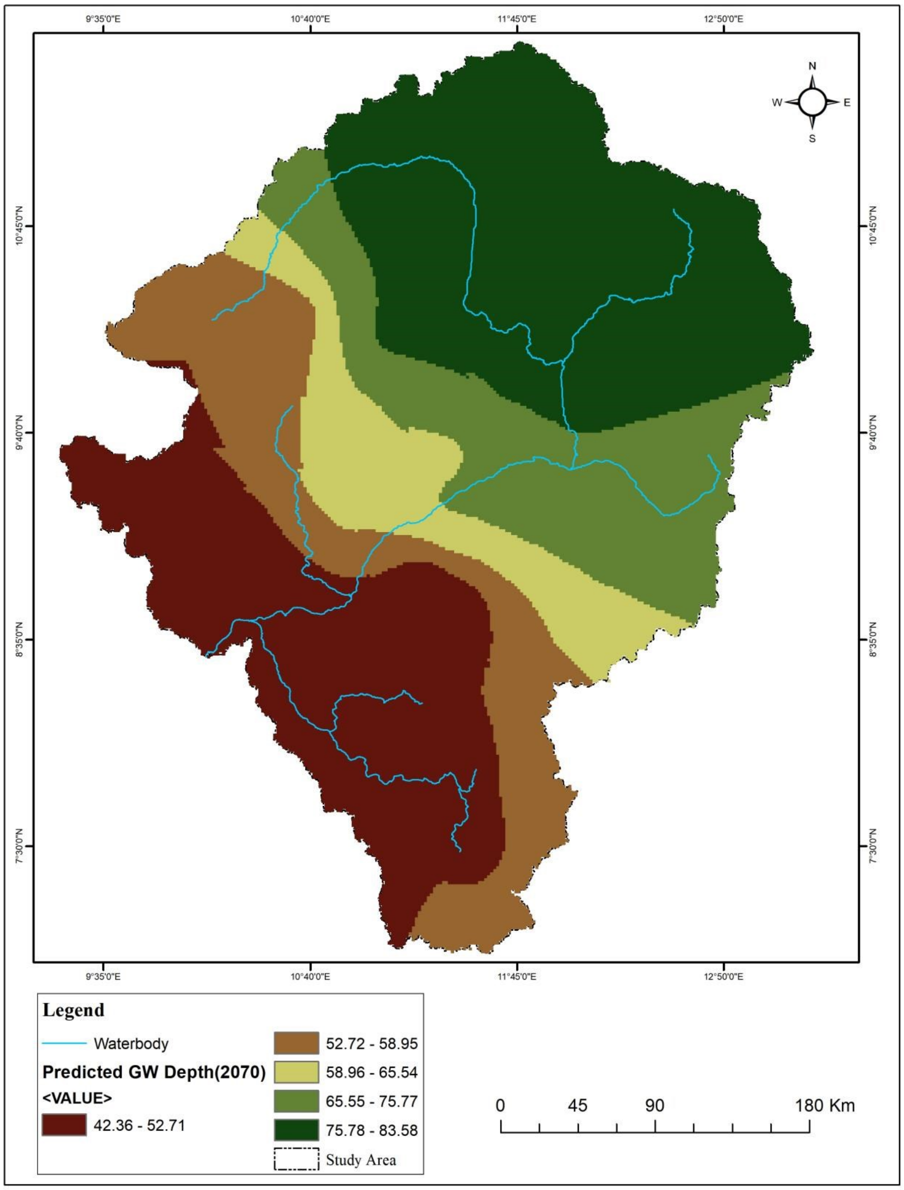

Fig. 5: Predicted GW Depth for 2070

As seen in fig. 5, for the predicted GW depth, the minimum range is 42.3m - 52.7m while the maximum range is 75.8m - 83.3m. As observed, the water table depth is lowest at the southern part of the basin, with the northern part having higher depth or lower water table heights. This implies that access to ground water resources is relatively better in the southern part of the catchment as it coincides with the pattern of climatic variables spread across the area. This result is similar to the one obtained by Ifediegwu (2021), whose result showed good groundwater potential in the southern part of Lafia district of Nasarawa State.

Table 2. Comparison between Actual and Predicted GW Depth

Statistic	2021	2070	Difference
Min GW Depth	31.3m	42.3m	11m
Mean GW Depth	48.9m	65m	6.1m
Max GW Depth	76.4m	83.3m	6.9m

Source: Data analysis

Comparing the minimum, mean and maximum values of actual and predicted ground water depth was pertinent to appreciate the long-term changes in the ground water regime. As observed in Table 2, from the 2021 data, the minimum value is predicted to increase from 31.3m to 42.3m, with an 11m difference. The mean value is also predicted to rise from 48.9m to 65m, an addition of 6.1m by 2070. The maximum values are also predicted to rise by 6.9m, as the predicted value is 83.3m, varying from the 2021 value of 76.4. This implies a relatively deeper water table which will impinge on accessibility of ground water in the future. Climate variability will affect the status of ground water significantly in the next 50 years and negatively impact availability and access. Ojeh and Semaka (2021) observed that there is an existing challenge of access to household water in the Upper Benue River Basin. This will adversely affect all socio-economic activities such as water production, beverage production etc. which depend largely on water availability as access for production.

Conclusion

This examined the impacts of climate variability and landuse / landcover dynamics on groundwater resources of the Upper Benue Basin Nigeria. The multivariate correlation was used to determine the strength and direction of relationship between climate variability and landuse / landcover dynamics on groundwater. Multiple regression method was utilized to predict the impacts of land use land cover dynamics and climatic variability on ground water regimes within the study area. The results of this study revealed that climate variability (temperature and precipitation) and landuse/ landcover both have strong positive impacts on groundwater potential in the Upper Benue River Basin. It is therefore ascertained that by 2070, the depth to ground water will increase by addition of 6.1m from the current status.

Recommendations

Based on the findings of the study, the following recommendations are made;

i. There is the need for integration of existing weather station data which will solve the challenge of using gridded satellite data instead of in-situ observation which would have given a better and robust result of the basin.
ii. Vegetation monitoring of the study basin should be mainstreamed into existing laws establishing the UBRBA to prevent further degradation the basin. Afforestation of the basin is of urgent importance to help more water infiltration into the basin and sustain the ground water recharge potential in the future.
iii. Since the projected trend shows that the northern part of the basin is most likely to be adversely affected in the future, there is need for policy to protect the land and conserve vegetation, reduce forest degradation in this zone of the basin. However, the southern part of the basin which is basically more of the GW potential region of the basin should equally be protected from excessive anthropogenic activities.

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