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**GIS-Based Evaluation of the Spatio-Temporal Impacts of Rainfall and
 Temperature Variability on Vegetation Cover in Bauchi State, Nigeria**

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ABSTRACT

Vegetation cover is an important natural resource for sustainable development, these resources have been affected by both environmental and human factors. The present study evaluates the impacts of temperature and rainfall variability on vegetation cover in Bauchi State, Nigeria. Normalized Difference Vegetation Index (NDVI), mean monthly temperature, total monthly rainfall for 2001, 2011 and 2021 were used and analysed in ArcMap 10.8 environment in this study. The results indicated a consistent relationship between temperature and rainfall with vegetation cover whereby an increase in 1 unit of temperature may lead to the in-vegetation density by about 0.05 unit of vegetation throughout the study period. The result also revealed that a rise of rainfall by 1 unit may consequently resulted to an increase in the density of vegetation by 0.0002, 0.001 and 0.0003 in 2001, 2011 and 2021 respectively. Result further indicated the residual with a negative Moran's I index throughout the study period this therefore showed a random pattern. It was also revealed from the findings that during 2001, Bauchi State observed more vegetation cover in many areas due to climatic factors than what will be recorded in future. This is more specifically in Ningi, Toro, Ganjuwa and Dass Local Government Areas (LGAs). This clearly indicated that temperature and rainfall variability are important factors that determine the nature of vegetation cover in the area. Hence, due to the importance of vegetation cover in the provision of food, shelter, wildlife habitat, and provision of fuel. This study recommended the integration of geospatial technologies (especially GIS) to assess the contribution of climatic factors to vegetation distribution.

Keywords: GIS-based, Vegetation, Variability, Temperature, Rainfall, Bauchi.

1.0 INTRODUCTION

Climate is the average weather conditions in a particular location or region at a particular time of the year of at least 30 to 40 years. This includes the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are temperature and precipitation. World biomes are controlled by climate. The climate of a region will determine what plants will grow there, and what animals will inhabit it. In fact, climate affects the structure of an environment, the individual species, and alters the functions and structure of their ecosystem (Maqbool et al., 2021).

Climate change through increase in temperature, and variability in rainfall events and other climatic elements may affect soil porosity and pore-size distribution and consequently alter vegetation root development and can ultimately affected the

general health pattern of the vegetation (Mondal, 2021). Therefore, as a whole vegetation development in any place has been influence by climate and soil because any changes in the climate and soil porosity causes direct effect on the soil water holding capacity and emission of CO₂ and CH₄ from soil (Tóth et al., 2018). Availability of vegetative cover in an area has an important role to play on the earth surface because it is linked via several feedback mechanisms to hydrological and climatological processes.

As a whole, spatial and temporal variability of vegetation is principally determined by two interwoven factors: anthropogenic and environmental. It has been established by Sigwa Consult Nigeria Limited (2001) during a work on Environmental Impact Assessment of the imminent explosion of Lake Nyos in Cameroon and its consequences on the Benue valley that, the highest rates of vegetation modification in Bauchi State

occur mostly on forest lands for subsistence and heavy dependence on shifting agriculture.

Studies in various part of the world such as that of Jucker et al. (2018); Hofhansl et al. (2020) found that vegetation distribution, diversity and productivity are determined by environmental gradients in climate, even though the effects were also determine by other edaphic and human factors. Hence, the relative effects of the climatic factors are scale-dependent. According to Mensah et al. (2023) at regional and global scales, climatic factors are revealed to be the most important drivers due to the fact that, the survival of the species and growth are mainly related to their tolerance range for larger-scale gradients in mean annual precipitation Furthermore, Aponte et al. (2020) also reported that, the influence of environmental factors such as temperature and rainfall to the distribution of vegetation and tree species diversity have become more prominent globally. This is mainly due to the fact that, vegetation is highly sensitive to the behaviour of the prevailing temperature and rainfall of any area as these elements are necessary for the development and growth of plants.

Globally, increased rainfall and temperature variability and climate change have been and will continue to adversely modify the natural resource and the environment. Climate exerts a strong influence on relevant socio-economic sector and people's livelihood in sub-humid and semi-arid zones of Northern Nigeria where the dry condition has been on the increase. These changes are occurring at unprecedented rate thereby drastically reducing bio-productivity of the physical environment. The nature of vegetation resource in Nigeria and Bauchi State in particular reflect a very close relationship between vegetation and climate. The similarity in the west-to-east zonation of both climate and vegetation in the country is very clear.

The South to the North progressive decline in total rainfall and length of wet season also links with the vegetation belts.

The study area (Bauchi State) with an estimated population of 4,676,465 million people and annual growth rate of 3.0% (National Population Commission, 2006), is not exceptional. The nature of vegetation resources in the State is changing both spatially and temporarily. Although many researchers were of the view that, an intensive cultivation of land resulted to high loss of soil fertility, which in return brings about changes in the quality and quantity of the vegetation (Bauchi State Economic Empowerment and Development Strategy, BASEED, 2005). However, linkages between climatic elements and vegetation cover in the State is very essential due to the fact that climatic factors more especially rainfall and temperature were highly fluctuating in the area which may consequently affected vegetation cover. Despite the fact rainfall and temperature are important factors in determination of pattern of vegetation cover, researchers such as Mua'azu et al., (2018).and Usman et al. (2019) were mainly concerned on one of these variables. Furthermore, even though Saleh (2019) tries to link climatic variable with vegetation density in Bauchi State, but the researcher major problem lies with the appropriate method employed to attain the objective. Based on this, the present study made use of Geographic Information System (GIS) technology to assess impact of temperature and rainfall variability on the vegetation cover in Bauchi State, Nigeria.

2.0 MATERIALS AND METHODS

2.1 Study Area

Bauchi is bounded by latitudes 9° 30' - 12° 30' N and longitudes 8° 50' - 11° 0' E which marks the points of longest and widest stretches of the state (Figure 1).

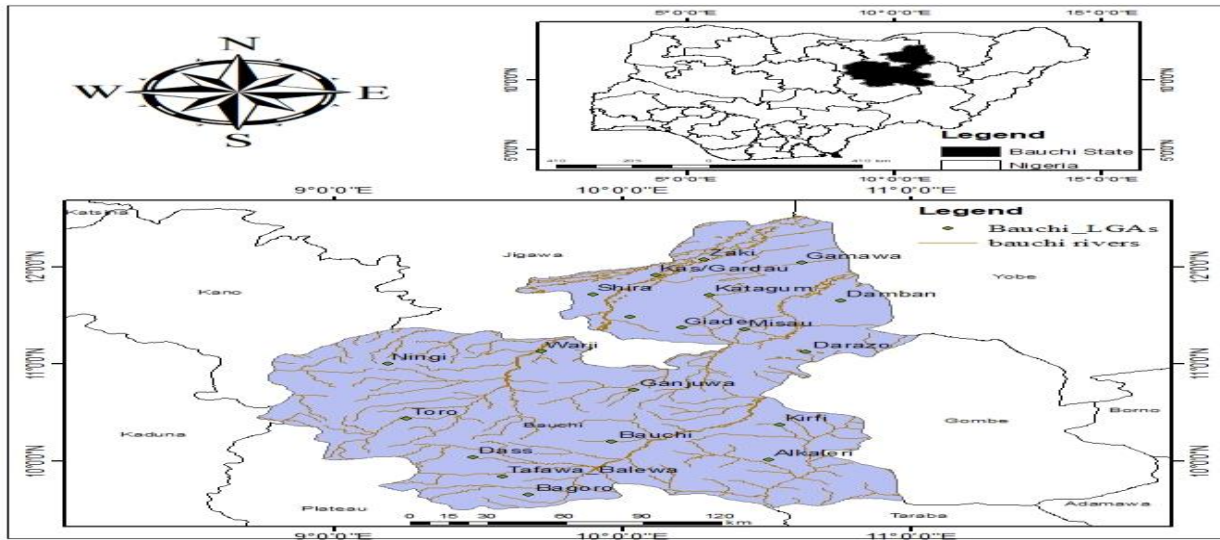


Figure 1: Map of the Study Area
Source: Adapted from Administrative Map of Nigeria

The State occupies a total land area of 49,119 km² representing about 5.3 % of Nigeria's total land mass (BASEED, 2005). In 2011 the State has an estimated population of 5,515,303 people (Adamu et al., 2020), with economic active population constituting 41.2%. Bauchi State is one of the states in the northern part of Nigeria characterized by two distinctive vegetation zones: the Sudan Savannah in the North and the Guinea Savannah in the South. Generally, the vegetation gets richer and richer towards the south but less uniform and grasses are shorter than what grows even further south, that is, in the forest zone of the middle belt. The vegetation pattern is conditioned by climatic factors. For instance, the rainfall in the area ranges between 700 mm per annum in the extreme north and 1300 mm per annum in the south. There is a progressive dryness towards the North, culminating in desert condition in the far North (Bauchi State Government, BASG, 2012). During the rainy season, the whole southern zone is green and covered with tall grasses that grow and reach maturity rapidly and thus become fibrous and tough. In the dry season they tend to die and disappear and one can see for kilometers. The mean daily maximum temperature ranges from 27° C to 29° C between July and August and 37.6° C in March and April. The mean daily minimum ranges from 22.0° C in December and January to about 24.7° C in April and May (Saleh, 2019). This therefore, indicated the influence of rainfall and temperature variability to the nature of vegetation

in the area. However, the rate at which this occurred is not always known.

Besides rainfall and other climatic factors that affected vegetation of the state, Bauchi state is drained by river system such as River Gongola which originates from the Jos Plateau area and Jama'are Rivers, Gubi and Tilde-Fulani dams, and Maladumba Lake as well that further provide the necessary conditions to the development of vegetation cover. On the other hand, the southwestern part of the state is mountainous as a result of the continuation of the Jos Plateau, while the northern part is generally sandy. The east and north-east of the State belong to the Benue and Gongola Cretaceous rift system and consist of folded marine and continental sequences. Yahuza et al. (2018) describe Bauchi State to have been characterized by highly undulating terrain with hills and ridges occupying the northern portion at maximum height of 478 m and minimum height of 386 m above Sea level. The state also made up of shallow soil such as sandy, clay, and loamy soil in iron pan, underlined by crystalline rocks, hills, mountains, which consists of rock elements on slope of hills and mountains all of which are factors that affect vegetation in the area.

2.2 Data Collection

The study made use of Système Probatoire d'Observation de la Terre (SPOT -NDVI) data for 2001, 2011 and 2021 at 1 km resolution,

downloaded from Vlaamse Instelling voor Technologisch Onderzoek (VITO) archive. Mean monthly temperature and monthly rainfall data for the study were also downloaded from Climatic Research Unit. The unit is under the University of East Anglia (CRUv3.4, 0.5° resolution). Political map of Bauchi State was obtained from Bauchi State Ministry of Land and Physical Planning.

2.3 Data Analysis

To perform data analysis the study employed Ordinary Least Squares (OLS) method and spatial autocorrelation were applied on the data set in ArcMap 10.8 environment as used by Abdullahi (2023). Before running the model, the researchers assumed that, residuals are homoscedastic, independently and identically distributed normally around a mean of zero. Also, when Variance Inflation Factor (VIF) values are > 7.5 in the analysis it indicated a redundancy among explanatory variables, however when it was less than or equal to 7.5 there is no redundancy.

The result of the OLS analyses was presented in form of tables and maps, while interpretations and discussions were done based on the following statistical parameters:

- i. An asterisk next to a number in a table indicates a statistically significant p-value ($p < 0.05$).
- ii. R-Squared [R^2 and Akaike's Information Criterion (AICc)] were used to measure the model fit/performance (When the value of R^2 is high and/or that of AIC is low, it indicate model higher performance).
- iii. When Jarque-Bera Statistic test is statistically significant model predictions are biased (the residuals are not normally distributed).
- iv. When Koenker (BP) Statistic test is statistically significant, the relationships modeled are not consistent. In other words, there is variation in the influence of explanatory variables to the occurrence of dependent variable.
- v. Coefficient of intercept was used to explain the strength and type of relationship between each explanatory variable and the dependent variable.

Spatial autocorrelation was used to evaluate the spatial independency of the residuals using Moran's I index sub menu of analyzing patterns. The tool was used to assess whether temperature and rainfall resulted to random spatial pattern of the vegetation. When moran's I index is positive implies there are similar values, while when it is negative nearby locations are having dissimilar values. In the same vein, the result of p value that ranged between -1 and +1 was also used for the interpretation in such a way that, if the value is not significantly different from zero, autocorrelation is not present in the residuals otherwise autocorrelation is present.

3.0 RESULTS AND DISCUSSION

3.1 Results on the Relationship between the Variables

Results of the regression analysis between NDVI and climatic factors (rainfall and temperature) using OLS model in this study were shown in Table 1. The results generally showed that, all predictors returned Variance Inflation Factor (VIF) values of 1.03 (2001), 1.04 (2011) and 1.16 (2021) which are less than 7.5 and therefore, indicated that none of the explanatory variables is redundant. Hence, the data has been successfully run using the model. Results from Koenker statistics indicate non-significant p values throughout the study period with 0.52, 0.75 and 0.93 during the year 2001, 2011 and 2021 respectively. This implies that, the linkages between rainfall and temperature with the distribution of vegetation in the study area were consistent and therefore, temperature and rainfall in the study area reliably influence the distribution of vegetation. This more over means that temperature and rainfall are important factors to the determination of the nature of vegetation cover across geographical region of Bauchi State, Nigeria.

The strength and direction of the influence based on the coefficient of intercept using the model as indicated in the Table 1 showed that temperature has been negatively related with the distribution of vegetation Bauchi State throughout. In other word, result revealed that an increase in 1 unit of temperature may lead to the decreases in vegetation density by about 0.05 unit of vegetation This is

related with the situation that, when temperature rises there will be increase in evapo-transpiration

which will consequently resulted to the drying up and dying of vegetation.

Table 1: OLS Relationship between Vegetation, Rainfall and Temperature

Parameters	2001	2011	2021
Variance Inflation Factor (VIF)	1.034419	1.044964	1.160622
Koenker	0.524468	0.751798	0.934299
Jarque–Bera	0.000000*	0.000000*	0.000000*
Multiple R-Squared [d]:	0.024645	0.184462	0.031929
Rainfall coefficient of intercept	0.000155	0.001100	0.000269
Temperature coefficient of intercept	-0.049115	-0.053167	-0.045068
Spatial autocorrelation (Moran's I)	-0.029412	-0.145942	-0.049474
Spatial autocorrelation (P values)	0.368667	0.219687	0.828226

* Significant at 0.01

This result supports the finding of Kumaresan et al. (2018) that rising of temperature resulted to the decrease in the amount of soil water due to increase in the rate of evaporation. This according to the researchers brings about reduction in the amount of water required by the vegetation, hence shading of leaves and dying of its body. The finding also corresponds to that of Pessi et al. (2020) and Khalis et al. (2021) in the Oued Lahdar Watershed. Northeastern Morocco who reported negative correlation coefficients between vegetation and temperature in their study. This result is also conformed with that of Joshua et al. (2023) who reported the relationship between temperature variability and vegetation cover to have been negative Upper Benue River Basin of Nigeria. Findings also support Lawrence et al. (2020) who revealed increase in evapotranspiration and water stress to plants as a result of high temperature and strong solar radiation.

In addition, the finding revealed positive relationship between rainfall and vegetation distribution Bauchi State within the period of the research. The result indicated that when amount of rainfall rises by 1 unit it may lead to increase in the density of vegetation by 0.0002, 0.001 and 0.0003 in 2001, 2011 and 2021 respectively. This linkage further shows that, availability of water is one of the major factors that determine the density of vegetation. Hence, rainfall is considered as factor toward that determined soil moisture content which affects the life of vegetation. It also helps in reducing negative impact of temperature on the rate of transpiration. Hence, higher rainfall implies

more vegetation cover and lower rainfall less vegetation cover. This testifies to the findings by Ayanlade et al. (2021) and Zerkani et al (2022). Both studies opined positive relationship between vegetation and rainfall in their findings. The results also supported the study carried out by Al-Kindi et al. (2023) in Dhofar, Southern Oman which showed that precipitation is the major climatic factor that support the development of vegetation.

Table 1 also showed that, Jarque–Bera statistic returned a significant p value of 0.000 throughout the study period which indicated that there is bias in the distribution of residuals during the study period. To examine the pattern of the residuals, spatial autocorrelation was used. The Table 1 indicated that the residual has a negative Moran's I index throughout the study period this therefore showed a random pattern. On the other hand, the result shows a non-significant p-value at 0.4, 0.2 and 0.8 in 2001, 2011 and 2021 respectively. Based on this value of p, the null hypothesis cannot be rejected hence the random pattern of vegetation cover are as a result of climatic factors.

3.2 Results on the Pattern of the Distribution of the Residues

Figure 2, 3 and 4 presents how the residues were distributed in the study area. Figure 2 for instance shows that during 2001 Bauchi State observed more vegetation cover in many areas due to climatic factors than what will be recorded in future. This is more especially in Ningi, Toro, Ganjuwa and Dass LGAs and this may be

associated with the higher rainfall received in these areas.

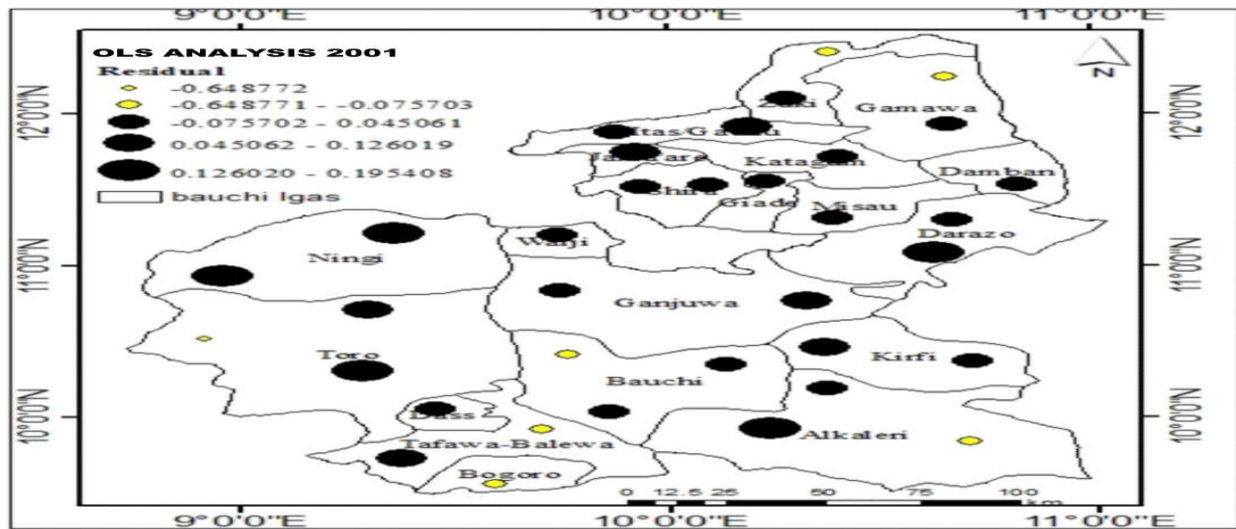


Figure 2: OLS Residual 2001

However, the result in Figure 3 showed that, in 2011 influence of climatic factors to the density of vegetation will be less than what will be in future, this is because areas with negative residual have been more than those with positive residual. For instance, Bauchi, Warji and Giade were expected to experience more vegetation cover due to climatic factors than what has been observed. Similar result to that of 2011 were also found in the analysis of

2021 data which shows that more vegetation resource will be found due to climatic factors in Bauchi State than what is observed currently. This result may be associated with higher rainfall received in the area and other factors in place. However, due to factors such as deforestation and construction activities the nature of vegetation cover may not be positively related with rainfall pattern.

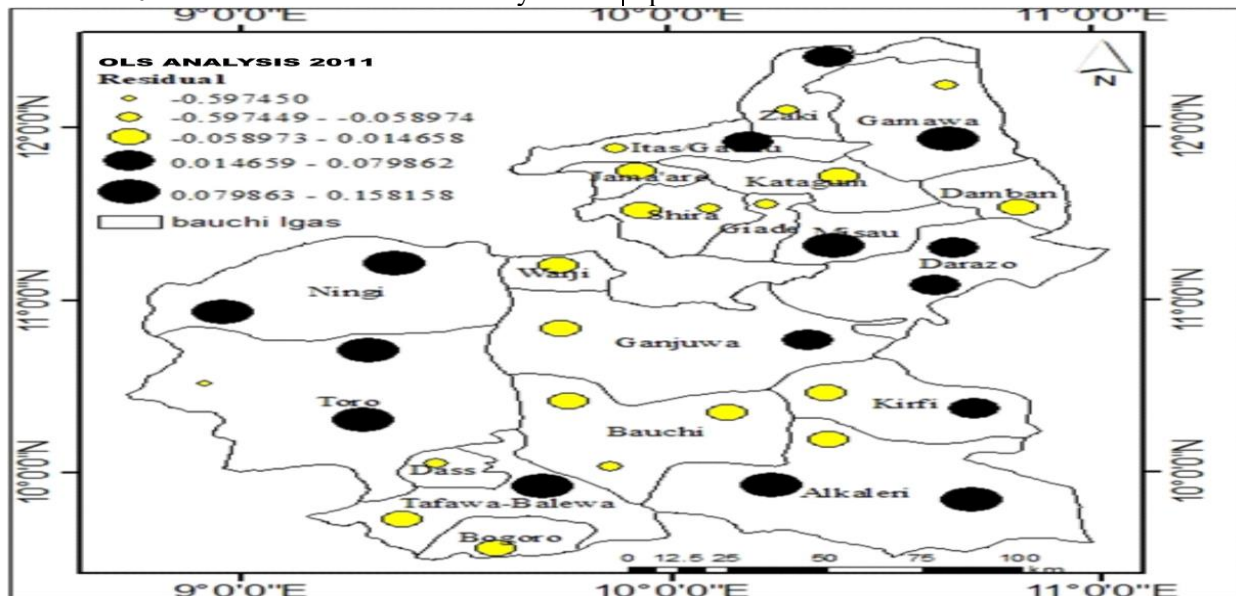


Figure 3: OLS Residual 2011

In addition, finding of this study is in line with that of Joshua et al. (2023) in the Upper Benue River Basin of Nigeria who stated that variability of

climatic elements notably temperature and rainfall have strong effect on groundwater potential. That is, when rainfall increases, the depth to abstract

groundwater reduces, however, when the rainfall decreases, the depth of ground water increases. This, therefore affected the spatial and temporal pattern of vegetation resources. Findings from this research also support that of Abera et al. (2023)

who reported that rainfall variability was linked to risks such as late onset, early cessation, short and prolonged dry periods, and drought, which generally affected the sustainability of vegetation resources across geographical area.

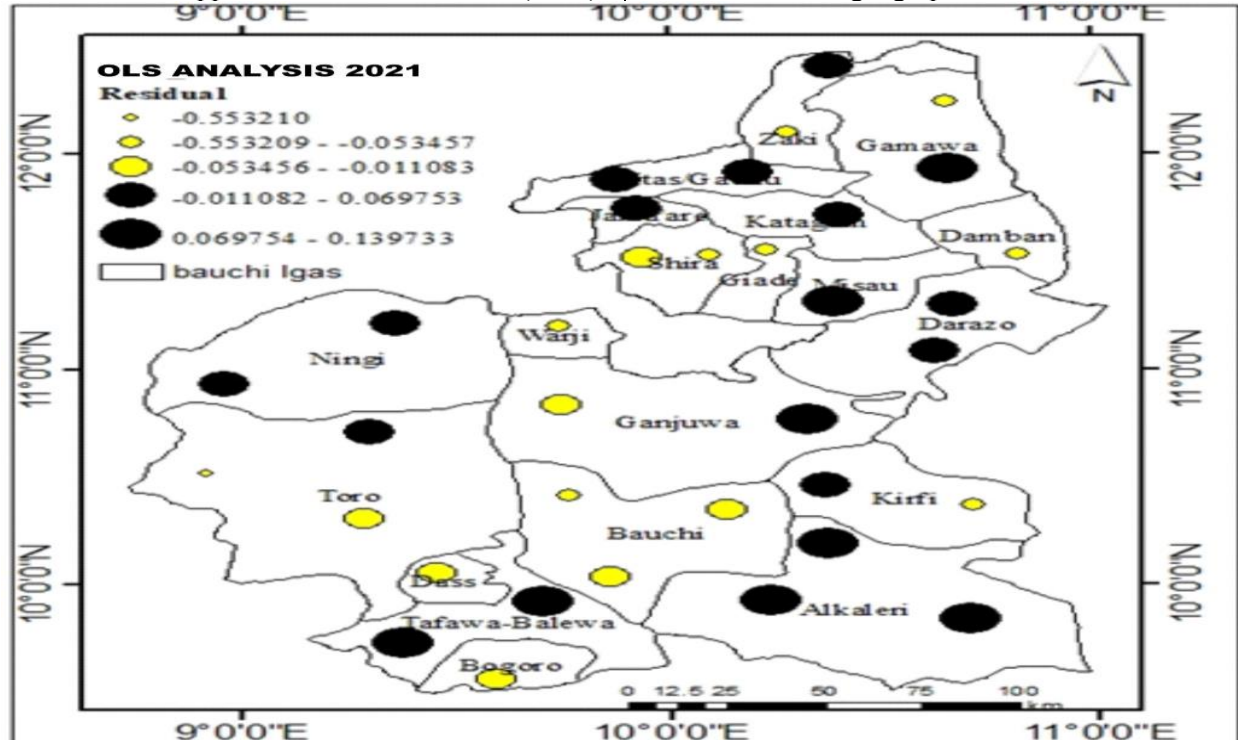


Figure 4: OLS Residual 2021

4.0 CONCLUSION

This study shows, the capabilities of GIS technology in sustainable vegetation resource monitoring and evaluation. Hence, despite the diversity of methods that could be use in vegetation resource studies. A significant conclusion can be drawn about the role of geospatial techniques in climate and vegetation resource management. It clearly shows that vegetation resources in Bauchi State were linked with temperature and rainfall variability. It is also concluded that when the amount of rainfall increases there is a correspondence increase in vegetation cover while an increase in temperature brings about decrease in the density of vegetation resource. Based on the findings of this study, the researchers recommended that researchers should integrate geospatial technologies to assess the contribution of climatic factors to vegetation resource pattern in their respective study areas.

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