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A Preliminary Assessment of the Effects of Climate Variability on Agulu Lake, Anambra State, Nigeria

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Abstract

The paper assessed the effect of variability of climatic elements on Agulu lake, Anambra State, Nigeria. Data for the work were acquired from Landsat website (landsat.org) for 35 years. Monthly records of the elements were collected from the synoptic meteorological station at Amawbia in Awka urban area. The penman model was used in the estimation of open water vapour from the lake. The analysis was performed using the output of the classified satellite imagery which was digitized for the entire year and the area of the lake was calculated for all the years of study. Statistical analysis of satellite imagery was further employed to analyse trends and relationships. Result shows that the trend is positive and significant at 95% confidence level. Fluctuations in the value of temperature and other variables were removed by 5-year moving average. The Agulu lake surface area was found to have contracted from 0.6177 km^2 in 1978 to 0.3583 km^2 in 2013. Recommendations on how to ameliorate the problem were made.

Keywords

Climate, Lake, Variability, Mapper, Evaporation

1. Introduction

Lakes are major repositories of biodiversity and provide multiple ecosystem services [1]. They are vital resources for aquatic wildlife and human needs and any alteration of their environmental quality and water renewal rates has wide-ranging ecological and societal implications [2]. Lakes are widely recognized as key indicators of environmental change. They show remarkable variability with time in their morphometry, physical, chemical and biological characteristics [3]. Such variations are mainly induced by climatic changes and anthropogenic activities in their catchment area. Lakes are strongly influenced by long and short term regional and global climate change. Their water level varies depending on the ratio of precipitation to evaporation, groundwater input, rate of water abstraction and other factors. Therefore, as sensitive indicators of change, they are capable of integrating the effects of human activities in their catchment and the added perturbations from climate warming [4].

A critical and perhaps the dominant global environmental problem in the last three decades is global warming resulting in global climate change [5]. Climate change refers to any change in climate overtime whether due to natural variability or as a result of human activity [6]. The global climate has remarkably changed from a climate system dominated by natural influences to one dominated by anthropogenic activities [7]. Global mean surface temperature has increased by an approximately 0.6˚C over the 20th century [8] and current global circulation models predict an increase in air temperature of several degrees by the end of the 21st century combined with large changes in the regional distribution and intensity of rainfall [2]. This realization has led to questions about the relative effects of shifts in climate conditions on natural ecosystems. Two primary hydro-meteorological variables affecting the lake ecosystem are precipitation and air temperature [4]. Changes in air temperature and precipitation have direct effects on the physical, chemical and biological features of lakes. Studies have shown that climate change can affect water temperature, surface water elevation and alter the structures of lakes [9] [10] [11], enhance eutrophication by affecting the external and internal nutrient loading, evaporation rates and further decrease the supply of dissolved oxygen causing increase in biological oxygen demand [12]. Accompanying these abiotic changes would be a general shift in the biotic characterization of lakes.

In addition, lakes and rivers are important links in the hydrological cycle of the earth and studies have noted that such changes in climate as predicted are capable of altering the hydrological and other physical features of lakes [4]. Hydrological systems are potentially very sensitive to climate change [13] and can influence many aspects of lake and stream ecosystems such as hydrological flows into and out of lakes, net basin water supply and water levels of lakes. Over long-term periods, lakes have changed repeatedly in their volume and extent because of climatic variability [14]. For example, the Lake Chad has been reported to have recorded a precipitous decrease both in surface area, water volume and depth [15] [16]. In this regard, [17] further stressed that an accurate assessment of the water resources of any area requires knowledge not only of the magnitude of rainfall and its spatial and temporal distribution but also the nature and magnitude of water losses by evaporation. This change in precipitation and temperature that accompany climate change has the potential to cause shifts in the connectivity of lakes with biological implications (e.g. for migratory fish species), changes in lake volume, surface area and depth, and other related limnological properties. For example, in the Experimental Lake Area in NW Ontario, [18] observed that white suckers (*Catostomus commersonii*) move from Experimental lake 239 to Experimental lake 240 during spring spawning due to increased flow whereas, in some years, flow between the lakes are zero thereby impairing migration. This could lead to loss of some endemic organisms from lakes as with the case of Lake Akşehir in Turkey where three species of fishes were lost [19].

This, however, necessitated the need for studies to examine how changes in lake size as a result of shifts in water balance due to climatic change are capable of making the lacustrine ecosystem vulnerable to climate change, while these changes are likely to affect the species composition [20]. Of aquatic macrophyte communities in the littoral zone of lakes [21] [22] concluded that with decreasing lake surface area, the ratio of littoral to pelagic habitat increases. Studies have shown that variations in surface area of lakes either due to abstraction of water by humans or climate change is accountable for variations in the abundance of fisheries [23], diversity and richness of fish fauna in lakes [24] [25] and that species richness and food chain length both increased with lake size [26] [27]. Climate effects have been compounded by the increasing need to irrigate farmlands, for municipal water supply, industrial uses, power generation etc. In all scenarios, the capacity of African countries to cope with the potential effects of change in climatic variables on the freshwater ecosystem is expected to be significantly challenged and potentially overwhelmed by the magnitude of such impacts. The aim of this paper is therefore to assess the effect of variations in climatic elements of temperature, rainfall, sunshine duration, relative humidity and wind speed over 35 years on the lake and recommend measures to ameliorate it.

2. Materials and Methods

2.1. Area of Study

Agulu Lake is a natural inland water lake characterized by sacred and cultural landmark of attraction which is gradually being devastated by natural and human factors of flooding, soil/gully erosion as well as landslides due to poorly consolidated geological formations, weathering and pollution [28]. It is the largest lacustrine ecosystem in Anambra state. Agulu lake is located within latitudes 6˚07' and 6˚09'N and longitudes 7˚01' and 7˚03'E (**Figure 1**). The lake has a mean depth of 5.2 m and maximum water depth of 11.2 m. The lake has a catchment area of 32 km^2 while its surface area has varied over time. The annual rainfall of the study area ranges from 1383 mm to 2090 mm while the mean annual rainfall is about 1851.9 mm. The mean maximum and minimum temperatures are 32.1˚C and 23.5˚C. Rainfall constitutes the main source of precipitation to the lake. The Nanka sands (the main aquifer of Agulu lake hydrological system) measures 5000 m × 100 m × 30 m [29], giving an aquifer potential of 1.5×10^7 m^3 [30]. [29] showed that the average annual groundwater discharge from bordering aquifers into the lake is 7.4×10^7 m^3/yr., an input into the lake. The lake is

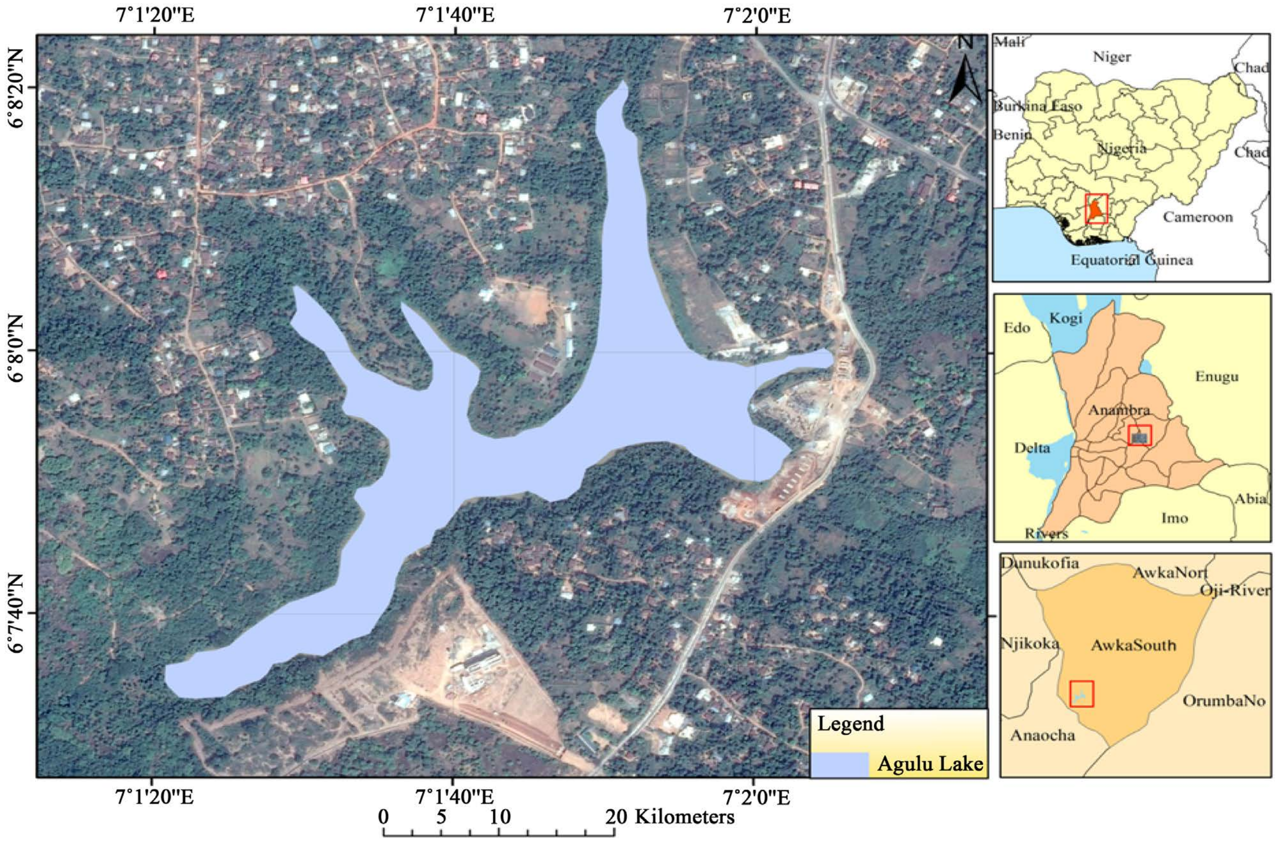

Figure 1. Map showing Agulu Lake in Anambra State-Nigeria.

the source of Idemili River which drains different communities in Anambra state before emptying into the River Niger.

2.2. Data Collection and Analysis

2.2.1. Satellite Data Acquisition

The Landsat data were acquired from the Landsat.org which comprised of the Multi Spectral Scanner (MSS), thematic mapper (TM), Enhance Thematic Mapper plus (ETM+) image and the Operational land Imager (OLI). The images were acquired to cover 36 years period. The satellite data have 30m spatial resolutions and the TM, ETM and ETM+ images have spectral range of 0.45 - 2.35 μm with bands 1, 2, 3, 4, 5, 6, 7 and 8 while the Operational Land Imager (OLI) extends to band 12. For extracting water surface feature, data from the available bands 2, 3 and 4 of the Landsat imagery of the study area were used due to its higher ability to discriminate water and land area.

2.2.2. Climate Data

Monthly records of air temperature, relative humidity, sunshine duration, wind speed and rainfall were collected from the meteorological archive of the Nigerian meteorological station closest to the lake and estimates of open water evaporation from the lake were made using the mean monthly meteorological data available for 36 years. The penman model was used in this regard.

The temporal variations in the data set for precipitation, temperature and the estimated open water evaporation are investigated using time series analysis while a trend analytical technique was carried out to test the significance of the trend in temperature, open water evaporation and precipitation characteristics over the study area by calculating the linear regression and correlation coefficients of the data sets over time. ANOVA table was used to determine the significance of the regression equation between dependent and independent variables while the assessment indices used in this work such as RMSE, PBIAS, NSE and SE indicate that the model represents the observed data quite well.

3. Result and Discussion

3.1. Result

Annual mean temperature data for a period of 36 years between 1978 and 2013 shown in **Figure 2** indicates that the trend is positive and significant given that, at 95% (0.05) confidence level, the calculated value of $t = 1.88$ was found to be less than the critical value of $t = 1.70$.

The fluctuations in the value of temperature in the study area such that, in order to easily determine the general trend of these values, we employed a 5 year moving average to smoothen these fluctuations (**Figure 3**). The general direction of the time series for the 36 year period was determined.

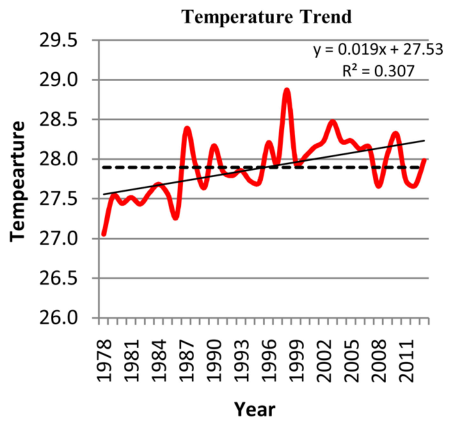

Figure 2. Trend plot of temperature variations between 1978 and 2013.

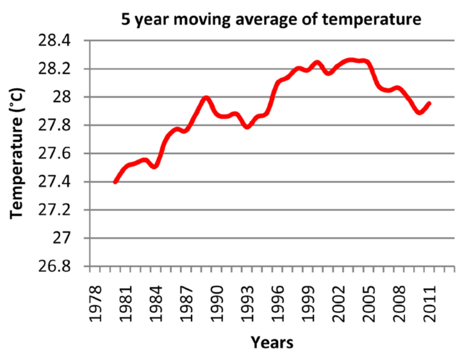

Figure 3. Moving average plot of temperature of the study area.

Dividing the study period in to three decades, it appears that, in support of the result shown above, temperature is truly increasing. From 1978 to 1987, an increasing trend in temperature was observed such that by 1987, it has exceeded the mean temperature for the decade (27.5˚C) and that of the 36-year period under study. Thus, between 1978 and 1987, temperature increased by 1.3˚C. From 1988 to 1997, there was less fluctuations in temperature value while the mean temperature for this period is 27.9˚C. In 1998, an all-time high temperature (28.9˚C) for the 36-year period was recorded for the study area and also, highest temperature values throughout the period were maintained from 1998 to 2007. The mean temperature for this third decade is 28.24˚C. The overall mean temperature as shown in the trend plot above is 27.9˚C. However, temperature is generally on the increase in the study area and this appears to be in agreement with the study by [31] where it was reiterated that temperature trend in Nigeria has shown increasing pattern; that since 1970s, there has been a sharp rise in air temperature which continued until 2005. Prior to 1970s, temperature increase was more gradual and this was also emphasized in [32]. Although the temperature increase within the study period is statistically significant, the upward trend especially since the 1970s is a worrisome evidence of regional warming [33]. In addition, monthly mean for temperature was calculated for the period of study and the pattern of variation presented in **Figure 4**.

The result shows that there is marked change in the magnitude and seasonal temperature pattern. The temperature pattern shows that temperature, during the months of January-May, October-December, has increased. The months of June, July, August and September have no marked change in temperature.

Evaporation values for the lake were estimated at monthly time step using Penman equation from1978 to 2013. The monthly values of each year were summed for the 36-year period to generate the annual time series data for lake evaporation. Annual fluctuations of the estimated open water evaporation are shown in **Figure 5**.

We applied a 5-year moving average to produce a more smoothened sequence of the data as shown in **Figure 6**. The general direction of the trend is positive as it is shown to be increasing though the strength of this is low. The significance of

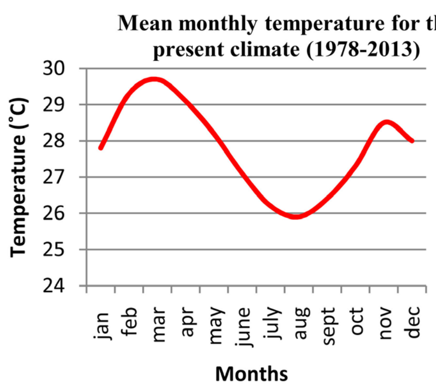

Figure 4. Present monthly temperature pattern over Agulu Lake (1978-2013).

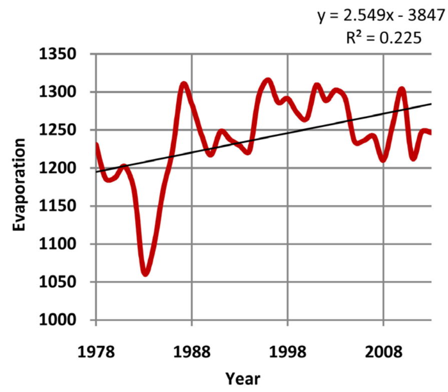

Figure 5. Trend plot of open water evaporation from 1978 to 2013.

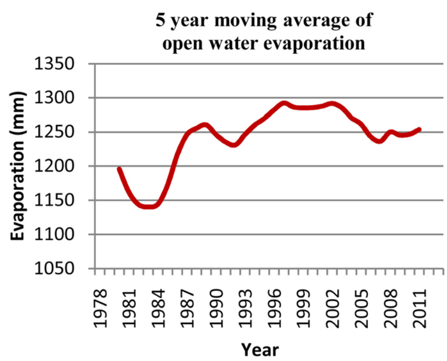

Figure 6. Showing 5 year moving average of lake evaporation 1978-2013.

this trend was tested using "*t*" test and was found not to be statistically significant at 0.05 confidence level. The observed increase in evaporation coupled with the observed change in temperature pattern as depicted in **Figure 2** and **Figure 5** is shown later to affect the size of Agulu Lake.

We performed a correlation analysis to examine the relationship between variations observed in the evaporation data and temperature. The result of the analysis (**Table 1**) shows that 37% of the variations in evaporation rate observed in **Figure 5** are accounted for by temperature or energy.

Furthermore, monthly mean for evaporation was calculated for the period of study and a graphical interpretation of the variation is shown in **Figure 6**. The result shows an increase in evaporation for the months of January-May and October-December and a decrease in evaporation during the months of June, July, August and September from 1978-2013. The similitude observed between evaporation and temperature patterns reiterate the result of the correlation between the two variables and re-emphasize the extent of influence the temperature factor has on evaporation over the lake.

The precipitation data were summed anually to generate annual time series of rainfall from 1978-2013. The trend plot of rainfall achieved is shown in **Figure 7**, indicating that the movement of the time series is sporadic.

The high irregular nature of the plot demanded the application of a smoothening function which is the moving average. The plot of a 5-year moving

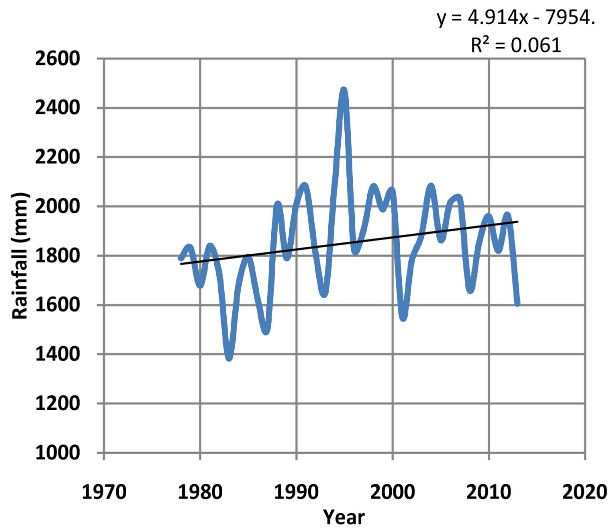

Figure 7. Trend analysis plot of rainfall of the area 1978-2013.

Table 1. PPMC coefficient between Temperature and evaporation for the period 1978 to 2013 ($p = 0.05$).

	Evap.	Temp.	CD	N
Evaporation	1.00	0.61	37%	36

average of rainfall is shown in **Figure 8**. The least square method was used to determine the trend in the tme series of rainfall shown below. While the trend is not statistically significant with a coefficient of 0.062 at 0.05 level of confidence , it is evident that the rainfall is rising at an annual rate shown by the slope of the regression coefficient (b = 4.9142). The trend plot of rainfall shows that at the start of the climatic period (1978-2013), rainfall decline was recorded for the first decade (1978-1987) after which increasing rainfall has been noticed for the lake area with intermittent decrease in some years. However, the former was found to be more pronounced after 1988 till date than the latter. A similar increasing trend in rainfall was recorded, but for the southern part of Nigeria, by [33] but a decreasing trend in the northern part. The mean annual rainfall for the 36year period is 1851.9mm. A graph of rainfall anomaly (**Figure 9**) was also shown to give a clearer picture on rainfall condition in the study area. The rainfall anomalies relative to 1978-2013 normal bear evidence to a more recent increase in the rainfall trend, which was more from the late 1980s. Between 1978-1987, rainfall was below the 1978-2013 normal while from 1988-2013, the years with rainfall values above normal are more; 19 out of the 36 years were below normal but only 16 years (44%) out of the 36 years were above the normal.

Lake Surface Area

Agulu lake surface area data were extracted from Landsat imageries from 1978 to 2013 at interval of 5years. Data were obtained for 1978, 1983, 1988, 1993, 1998, 2003, 2008 and 2013.

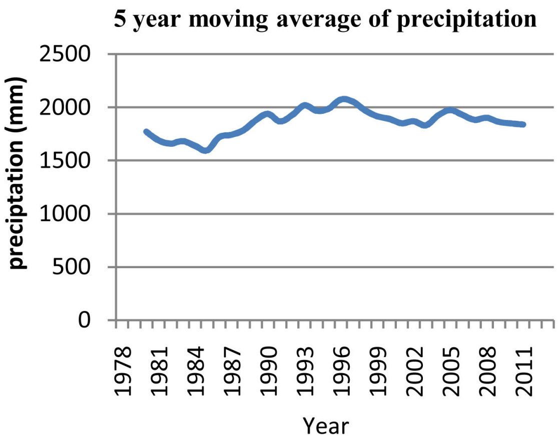

Figure 8. Moving average plot for rainfall of the area 1978-2013.

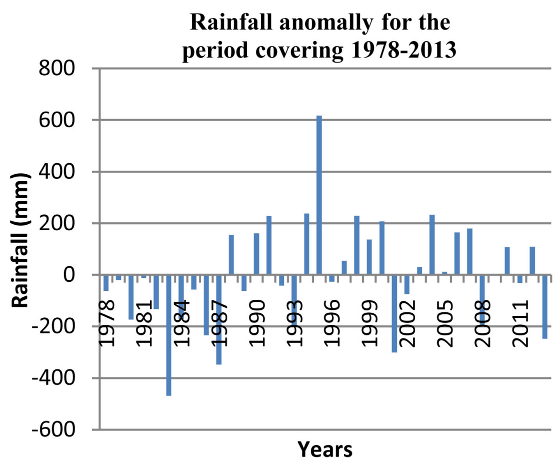

Figure 9. Rainfall anomaly in the Lake area using 1978-2013 normal.

By means of linear interpolation, we estimated for missing data on lake surface area for the years for which they are not available. The trend plot of the values is shown in **Figure 10**. The general direction of the trend is negative showing a decline over the years. The rate of this decline is shown by the slope of the regression, b = −0.0074 while the trend is statistically significant with a correlation coefficient, r, of 0.87 at 95% level of confidence.

The statistical results showed that the surface area of the lake was about 0.6177 km^2 in 1978, 0.3746 km^2 in 2008 and 0.3583 km^2 in 2013 (**Figures 11-13**). The result further showed that the lake surface area changed by 0.0289 km^2 between 1978 and 1983, 0.1065 km^2 between 1983 and 1988, 0.0584 km^2 between 1988 and 1993, 0.0012 km^2 betwen 1993 and 1998, 0.0084 km^2 between 1998 and 2003, 0.0397 km^2 between 2003 and 2008, and 0.0163 km^2 betweeen 2008 and 2013. The most intense change occurred between 1983 and 1988 during which the lake lost about 0.1065 km^2, approximately 17%, of its surface area. On a general note, between 1978 and 2013, the lake lost 42% of its surface area. However, the change in surface area of the lake for the years 1978 to 2013 is shown in **Figure 14**.

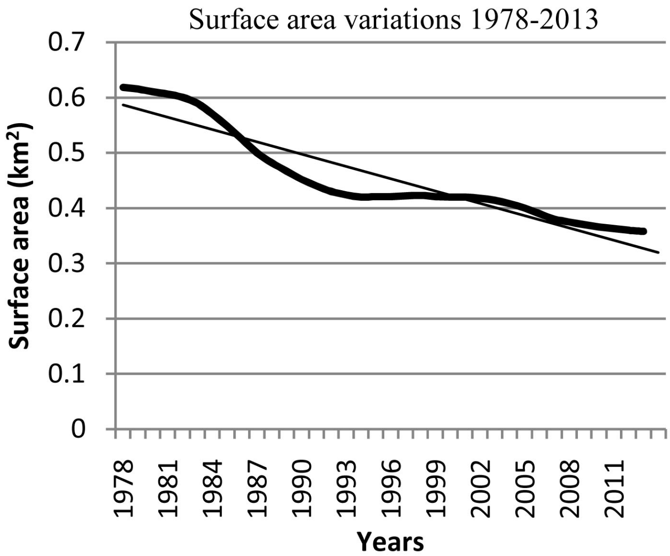

Figure 10. Trend analysis plot of the surface area of the study area 1978-2013.

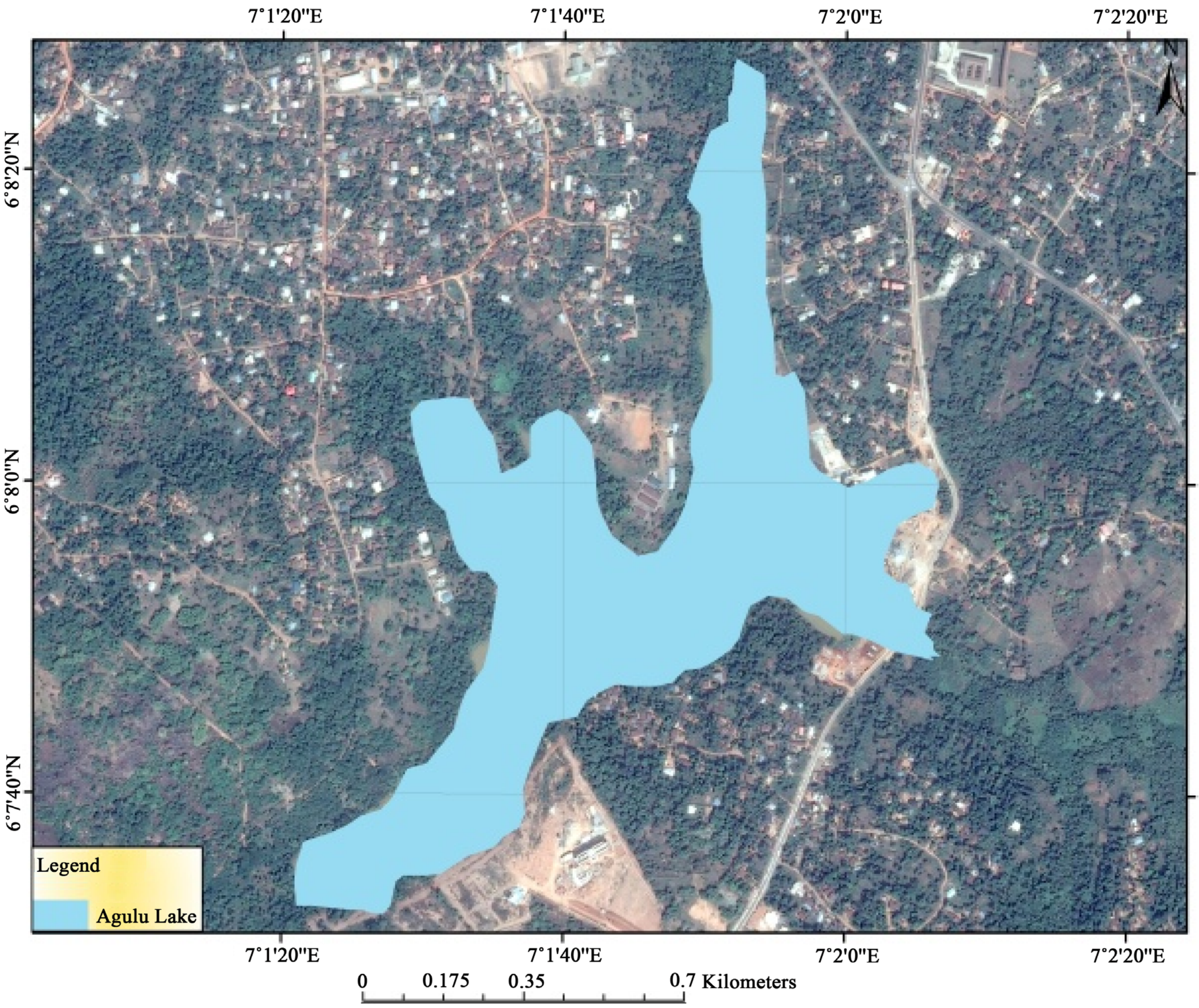

Figure 11. Agulu lake 1978 (0.6177 km^2).

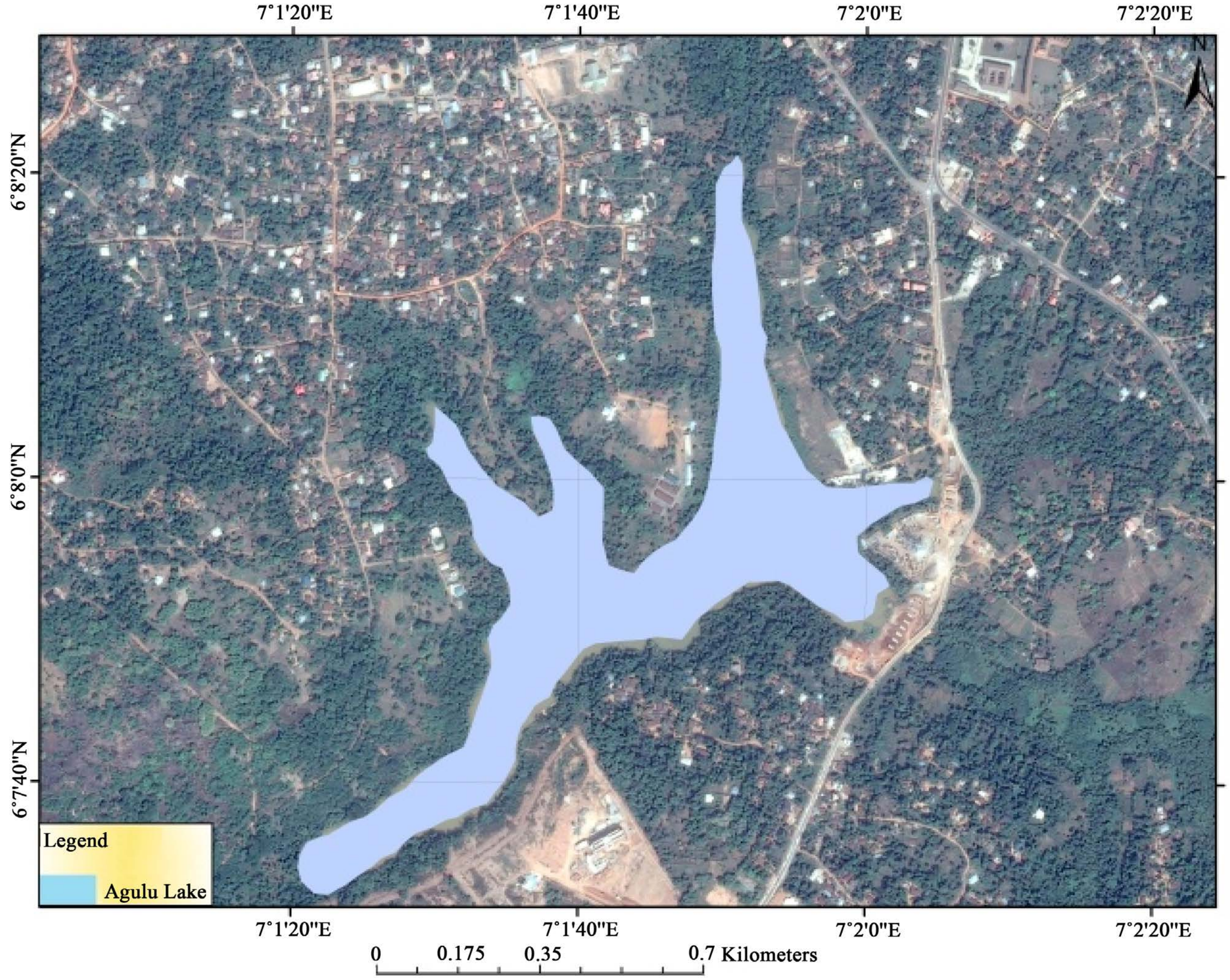

Figure 12. Agulu lake 2008 (0.3746 km²).

3.2. Discussion

Multiple correlation and regression was performed to examine the extent of relationships between surface area of agulu lake and climatic variables namely: rainfall, evaporation and temperature in the past 36 years. The multiple correlation analysis yielded a correlation coefficient of $r = 0.685$. This implies that the combined degree or strength of relationship between surface area of Agulu lake and the sets of independent variable of rainfall, temperature and open water evaporation is 0.685. The coefficient of multiple determination, R^2, is given as $R^2 = 0.47$. In addition, the value of the coefficient of multiple determination revealed that, out of 100% of numerous factors affecting the surface area of Agulu lake, 47% of such variations are explained by the combined variations of temperature, rainfall and evaporation. However, it showed that other factors such as anthropogenic activities [34]. around the lake, ratio of inflow into the lake and discharge rate from the lake into Idemili river contributing to the variations. To determine the precise mathematical form of the relationship between the dependent variable (surface area) and sets of

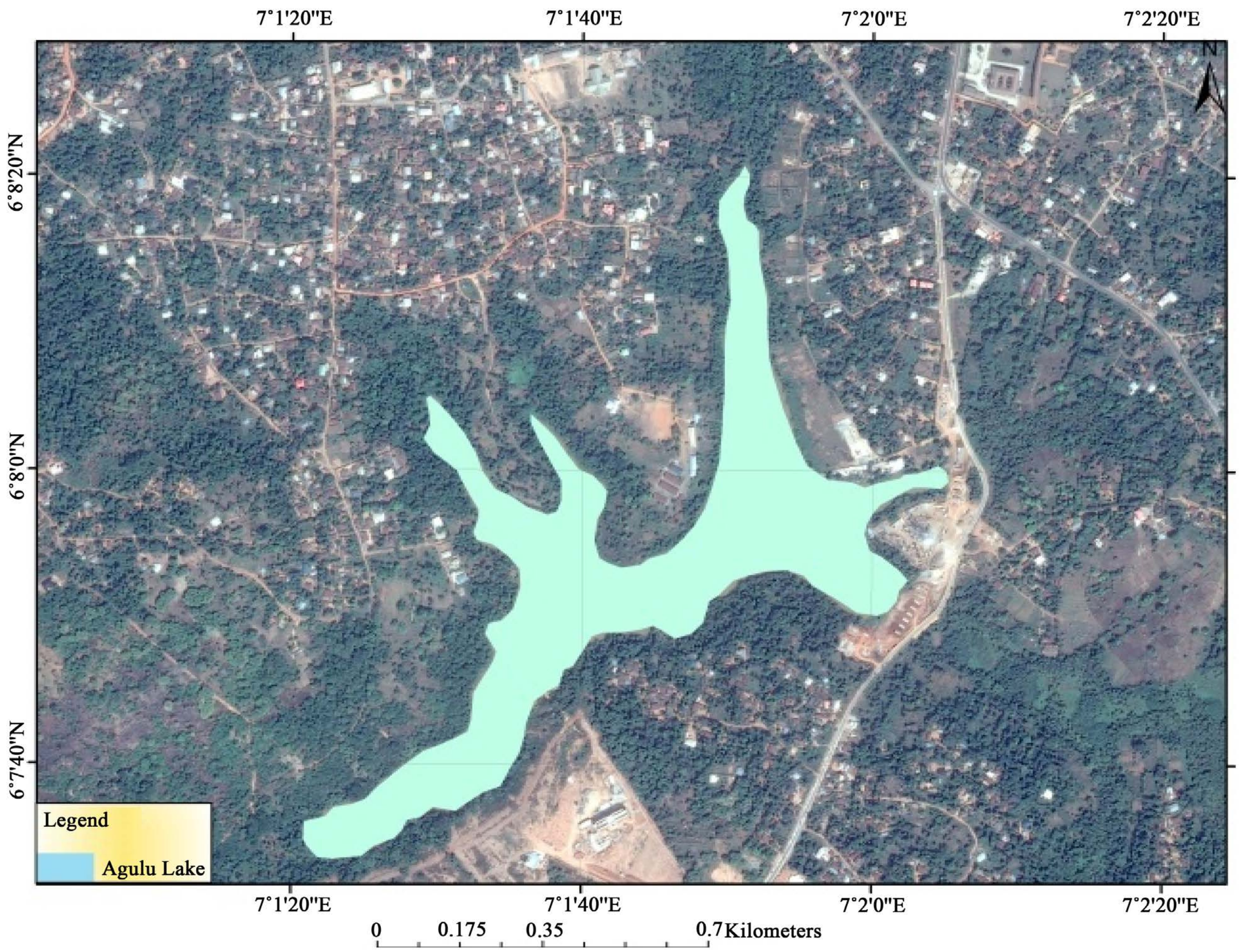

Figure 13. Agulu lake 2013(0.3583 km^2).

independent variable (rainfall, temperature and evaporation), a mathematical function was fitted to the sets of variables such that we can use values of the three independent variables to predict values of surface area of the lake. The multple regressive equation developed from this relationship is given below as follows:

$$Y = 3.619 - 0.000059X_1 - 0.0902X_2 - 0.00043X_3$$

where, Y = Surface area, X_1 = Rainfall, X_2 = Temperature and X_3 = Evaporation.

The regressive model was further used to predict for surface area for the period, 1978 to 2013. **Table 2** shows the values of predicted surface area for the lake.

The significance of the regression equation was tested by means of analysis of variance test. A null hypothesis is posited as: "there is no significant linear relationship between the dependent variable and the independent variables". At 0.05 level of confidence, the critical value of F from SNEDECOR's table is 2.90. Since F of 9.436 > 2.90, there is a significant linear relationship between surface area and the three independent variables. There was a good correlation between the predicted values and the original lake area data (r = 0.68) (**Table 3**).

Table 2. Showsvalues of observed and predicted surface area for the lake.

Year	Observ. Area (km^2)	Predicted est.
1978	0.618	0.53964
1988	0.482	0.428145
1998	0.423	0.336394
2008	0.375	0.50572
2013	0.358	0.464213

Table 3. Anova table.

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	0.115	3	0.038	9.436	0.000[b]
Residual	0.130	32	0.004		
Total	0.245	35			

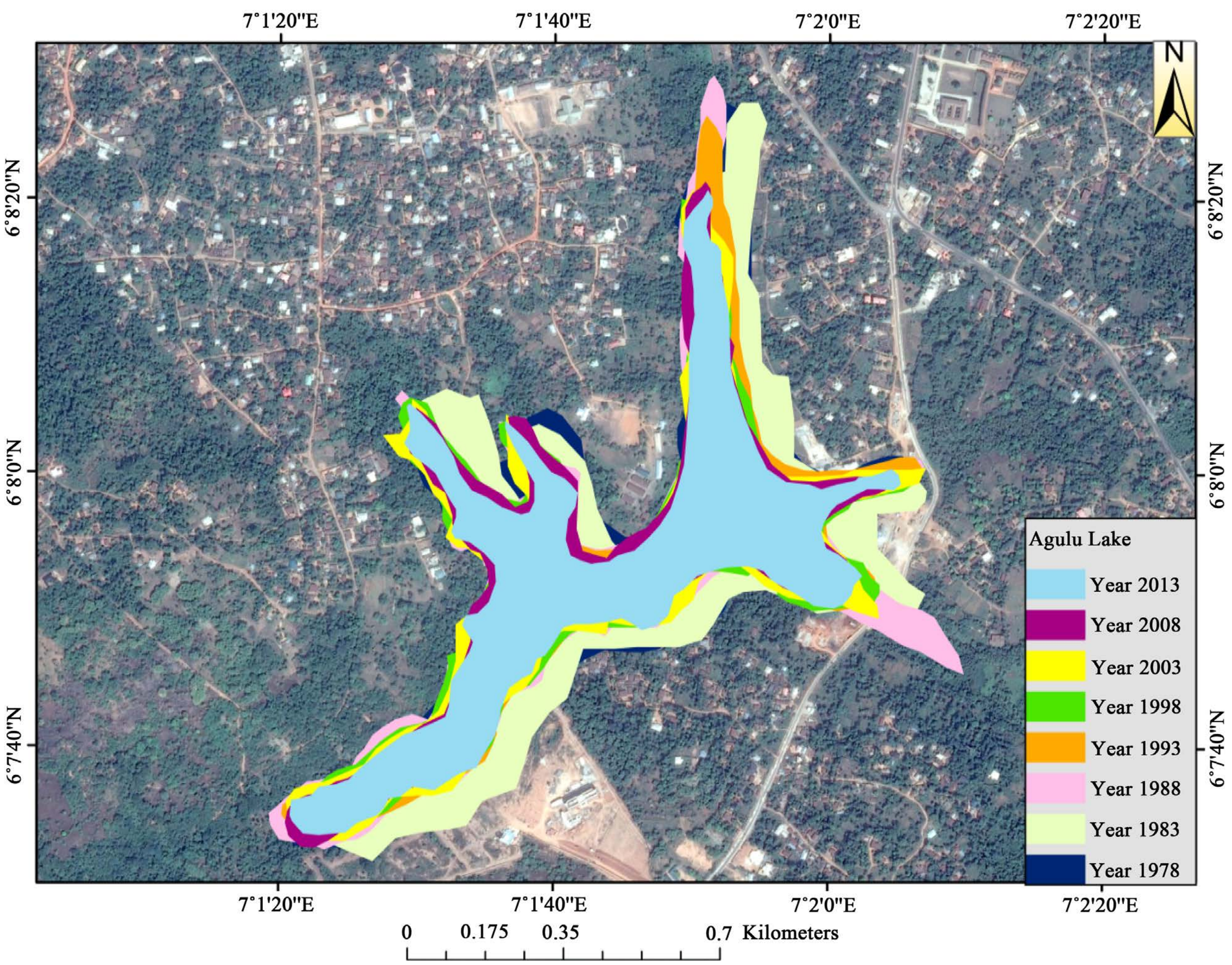

Figure 14. Agulu Lake change map (1978-2013).

Evaluating the Performance of the Model

The accuracy measure of this model was evaluated using the Nash-Sutcliffe efficiency (NSE) ratio [35].

4. Conclusion

This study has assessed the effects of climate variability and the potential contribution of human activities to the observed variations in the surface area of Agulu Lake in Anambra state using land based station data; a lake currently being converted into a tourist resort. The nature of physical relationship between this morphometric index and selected climatic variables (rainfall, evaporation and temperature) was established. A multiple regression model for the surface area change was derived using recent climate data. It has been shown that climate change effects are not independent of other human stresses on the system, nor are the effects of these stresses independent of climate change effects [4]. These anthropogenic influences and some other climatic variables have not been considered for this lake and so many other lakes and reservoirs in the country. Therefore, effort in this direction is encouraged by this paper. However, this work concludes that Agulu lake has decreased by 42% in its surface area between 1978-2013 and 47% of this reduction is accounted for by variations in temperature, precipitation and evaporation. The unexplained 53% is believed to be as a result of some other factors not taken into account in this research work.

5. Recommendations

Based on the foregoing, the following recommendations are made:

1) This paper has provided preliminary information on the current state of the lake and its potential response to changes in climate. The model gives a general behaviour of the lake's surface area to changes in climatic variables. Therefore, for ultimate performance of the model, it is recommended that this model be improved upon by considering other factors not considered in this study.

2) Since the state government is currently harnessing the tourism potentials of the lake, it is imperative that the potential threat posed by climate change on the long term economic viability of this project be acknowledged and concerted efforts be made by the government to address this potential threat. Climate oriented policies bordering on mitigation and adaptation and good conservation principles should be pursued and effort should be made towards provision of improved and efficient water supply scheme in the study area and environs to checkmate and avoid excessive water abstraction from the lake.

3) There is need for government to improve the network density of hydro-meteorological stations within and around inland water bodies scattered across the country for improved gathering of hydro-meteorological information. This will ensure accurate forecasting of the quantity and quality of these water resources. For instance, installation of gauging stations within the lake and along Idemili river will provide reliable information on lake water level and lake

discharge respectively; thus, ensuring effective monitoring of changes in the lake round the year and this will lead to improved modeling.

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