Climate Variability in Relation to Floodplain Erosion and Water Quality Characteristics of the Ikpa River Basin, Nigeria

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Submitted to

International Environmental Research Institute (IERI)
Gwangju Institute of Science and Technology (GIST), South Korea

JANUARY 2021

CLIMATE VARIABILITY IN RELATION TO FLOODPLAIN EROSION AND WATER QUALITY CHARACTERISTICS OF THE IKPA RIVER BASIN, NIGERIA

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PROJECT REPORT

Executive Summary

This report presents the findings on the International Environmental Research Institute funded commissioned research project in 2018 on the topic "Climate Variability in relation to flood plain erosion and water quality characteristics of Ikpa River Basin, Nigeria." The project fitted into the thematic area of "Climate change measurement and modelling". The aim of the project was to ascertain the extent climate variables have impacted quality status of a major watershed in Nigeria as a case study for Sub-Saharan Africa.

The study obtained information through primary and secondary data acquisition. Data on climate was obtained from Nigerian Meteorological Station located in the University of Uyo. Maps of Ikpa river basin showing its areal extent/catchment limit, streams, rivers, settlements, water and sediment sampled points, land use, land cover, etc. were produced using Shuttle Radar Topographic Mission [SRTM] and Landsat TM data. This was carried out with geospatial technologies particularly Geographical Information System [GIS], remote sensing and global positioning system [GPS]. The Co-ordination of Information on the Environment (CORINE) model was adopted for the erosion risk assessment while the water quality index model was used to evaluate the water quality.

The results revealed that rainfall is the most important climatic parameter to assess the climate variability trend in the region and the most important contributor to surface water quality. The region has tended to record colder weather regimes in recent years. The soil erosion risk assessment revealed that because of land cover change, between 1986 and 2018, more than half of the area with high erosion risk potential was experiencing high actual erosion risk. This has contributed to the poor quality of surface water in the basin.

The report is laid out in chapters with chapter one giving the background, aim and objectives of the study. Chapter two discusses in detail the study design, approaches and methods used. Chapter three presents the results and discussion while Chapter four is the conclusion, and further work. Supplementary information is in the Appendixes. The Centre is grateful for the funding received to carry out this research which has added to the literature authentic information on climate change impact in a developing world perspective.

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CHAPTER ONE
INTRODUCTION

1.1 Background of the Research

Although the effects of climate change are expected to be more pronounced in highly vulnerable regions such as Africa, the knowledge gaps that exist further portends the inability of the region to proffer suitable adaption and/or mitigation measures. The impacts of climate change on food security and livelihoods in relation to urbanization in African have been subject of recent studies (Ford et al. 2015; Henderson et al., 2017). An overview of climate change impacts in Nigeria indicates general decrease in rainfall patterns over the past 105 years (Odjugo, 2010). However, increasing rainfall events are recorded in the coastal areas of the Niger Delta Region (Odjugo, 2010).

According to a report by the Intergovernmental Panel on Climate Change (IPCC, 2013), the rural underprivileged in developing countries are the most exposed to the effect of climate change which causes an intensification of rainfall variability, thus resulting in river flow fluctuation and a higher frequency of drought or floods. The increased or decreased annual rainfall in various area affect the annual and seasonal runoff and hence water quality. Twisa and Buchroithner (2019) analyzed the trend in annual and seasonal rainfall time series in the Wami River basin to investigate the significant changes in the pattern during the period 1983-2017 and how they affect the access of water supply service in rural areas. Water points were found to be significantly affected by seasonal changes both in terms of availability and quality of water and concluded that there exist a strong relationship between rural water service and seasons.

The global climate has changed rapidly with the global mean temperature increasing by 0.7 °C within the last century (IPCC, 2007). However, the rates of change are significantly different among regions (IPCC, 2007). This is primarily due to the varied types of land surfaces with different surface albedo, evapotranspiration and carbon cycle affecting the climate in different ways (Meissner et al., 2003; Snyder et al., 2004). Several studies have been carried out at different temporal scales and in different part of the globe. An example is Hasanean (2001) who examined trends and periodicity of air temperature from eight meteorological stations in the east Mediterranean and observed positive significant trends in Malta and Tripoli, and negative trend in Amman. Turkes et al. (2002) evaluated mean, maximum and minimum air temperature data in Turkey during the period 1929–1999. Their analysis revealed spatiotemporal patterns of long-term trends, change points, and significant warming and cooling periods. Similarly, Easterling (1997) and Fan et al. (2010) reported separately that diurnal temperature range (DTR) has been on the decrease in most region of the world. In another study

Karl et al. (1993) analyzed temperature data from 37% of global land mass and found high increment in the minimum compared to the maximum temperature. Studies on the spatio-temporal variability and trend in temperature are very limited in Africa. Increasing flood risk is now being recognized as the most important sectoral threat from climate change in most parts of the region which has prompted public debate on the apparent increased frequency of extreme, and in particular, on perceived increase in rainfall intensities (Oriola, 1994).

Some studies have adduced extreme rainfall to be the major cause of flood worldwide. Such studies include Adekunle (2001) and Ologunorisa (2004). Many researchers have also identified the characteristics of extreme rainfall that are associated with flood frequency to include duration, intensity, frequency, seasonality, variability, trend and fluctuation (Ologunorisa, 2004). Eludoyin et al. (2009) studied monthly rainfall distribution in Nigeria between 1985-1994 and 1995-2004 and noticed some fluctuations in most months within the decades. Ayanlade (2009) also investigated the seasonal rainfall variability in Guinea savannah part of Nigeria and concluded that rainfall variability continues to be on the increase as an element of climate change. The present study predicted renewed incision of gully erosion in the Ikpa River Basin, Niger Delta, Nigeria.

The Ikpa River Basin is a major watershed in the urban area of Uyo, the capital city of Akwa Ibom State, Nigeria. The river serves as a major source of water for irrigation and fishing purposes for the benefit of the city. Several studies have been carried out to assess the water quality status of this important surface water resource (Dennis et al., 2013; Inam et al. 2015; 2016). These studies largely ignored factors such as temperature, rainfall and erosion events in relation to measured qualitative parameters as well as temporal trends. Such climate-dependent factors have been found to have varying degree on water quality status of surface water bodies (Delpla et al., 2009).

1.2. Aim and Objectives of the Research

This research project aims to ascertain the extent to which climatic variables have impacted the quality status and floodplain erosion of Ikpa River Basin in Nigeria as a case study for Sub-Saharan Africa. The research project should give insights on any measures (policy, education and awareness or technological intervention) that must be taken to mitigate impacts.

In achieving this aim, the following specific objectives apply:

- review of the levels of quality parameters in water of study area from secondary and primary data;
- subjecting the data to advanced geostatistical analysis, modelling and simulation

to establish information on spatiotemporal variations; predictions of future trends, source tracking and fate of these chemicals;

- compare and map the levels of nutrients and contaminants between streams/rivers/sub-basin in order to identify hotspots and spatial variations.
- monitor and determine land use/land cover changes and drivers of such changes within the river basin in order to assess and predict spatiotemporal variations in erosion risk and water quality.
- determine and map the location and number of streams/rivers that are polluted, the sources of such pollution and the settlements/population of people/aquatic biota that are at risk
- dissemination of research findings to stakeholders through engagement as well as publication in peer reviewed journals.

CHAPTER TWO

RESEARCH DESIGN APPROACHES AND METHODS

2.1 Location of the Study Area

Ikpa River Basin is located between latitudes $5°0'3.80''$ N and $5°16'49.12''$ N of the Equator, longitude $7°46'34.9''$ E and $8°3'11.9''$ E, of the Greenwich Meridian (Fig. 2). It covers an area of approximately $501.35km^2$.

Fig. 1: location of the study area

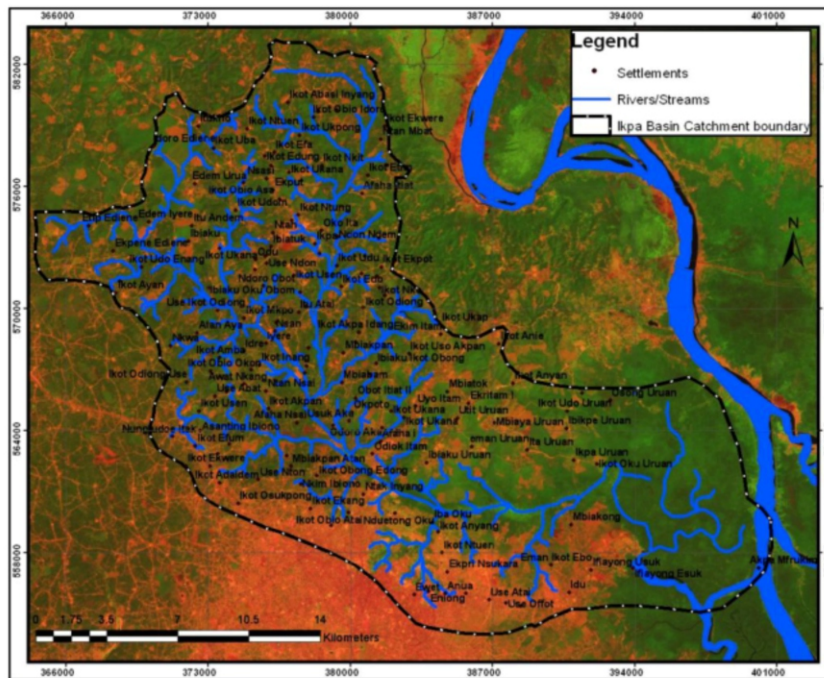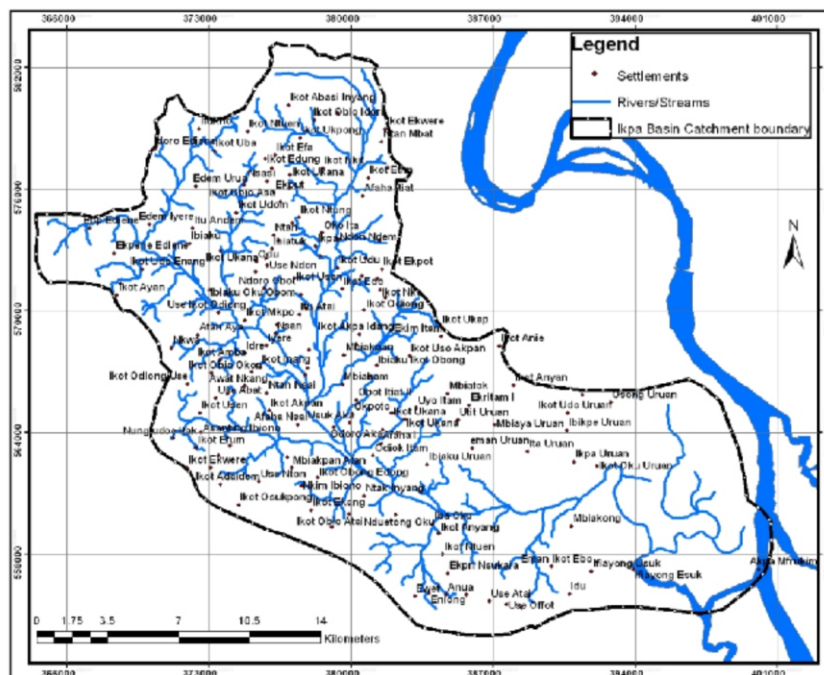Fig. 2a: Satellite [LANDSAT 8-January 2018] imagery of the location

Fig. 2b: Stream orders within the Ikpa Basin

2.2 Data Acquisition and Analysis

Both primary and secondary data was used in this study. Data on climate was obtained from Nigerian Meteorological Station located in the University of Uyo. Maps of Ikpa river basin showing its areal extent/catchment limit, streams, rivers, settlements, water

and sediment sampled points, landuse/land cover, etc. were produced using Shuttle Radar Topographic Mission [SRTM] and Landsat TM data. This was carried out with geospatial technologies particularly Geographical Information System [GIS], remote sensing and global positioning system [GPS]. Thereafter, morphometric characteristics of the basin namely: stream number, stream order, stream length, bifurcation ratio, drainage texture, drainage intensity, drainage density, infiltration number, stream frequency, texture ratio, elongation ratio, circularity ratio, and form factor ratio and compactness ratio were determined using the standard mathematical formulae. The SRTM data was used for modeling the river basin and morphometric analysis while the landsat TM satellite imagery was used for landuse/land cover mapping and change analysis for erosion risk assessment among other things. It is well established that the influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosion characteristics (Angillieri, 2008; Ozdemir and Bird, 2009; Alton and Alton, 2011).

2.2.1 Erosion risk assessment

There are many expert-based and model-based approaches that have been used for the development of erosion risk maps of various parts of Europe. Of these models, the Co-ordination of Information on the Environment (CORINE) model was adopted in this study because the required datasets were available although they were outdated and had to be compiled and updated from different sources. The required database parameters were soil erodibility, erosivity, topography (slope), and land cover. The methodology considered two different indices of soil erosion risk. They were potential soil erosion risk and actual soil erosion risk. Fig 3 indicates the logic behind the methodology used in CORINE model.

2.3 Water quality analysis and assessment

In this study, data on physiochemical properties of surface water within the Ikpa River basin were collected from secondary sources such as published journal articles and completed research projects archived in the University of Uyo library. The list of the sources of data are presented in Appendix I. These data were used to determine the water quality index. Water quality index is a mathematical model for representing water quality data in simple terms (e.g., Excellent, good, bad, etc.); it reflects the level of water quality in rivers, streams, and lakes (Lumbet al., 2011).

The Water Quality Index (WQI) for Ikpa river was calculated from at least nine physio-chemical parameters, namely: biological oxygen demand (BOD), total dissolved solids (TDS), pH, dissolved oxygen (DO), turbidity, PO_4, NO_3, chlorides, total hydrocarbon (TH), electrical conductivity (EC), and alkalinity. The WQI was calculated using the weighted arithmetic water quality index method in which water quality parameters are

multiplied by a weighting factor and are then aggregated using a simple arithmetic mean as shown in equations (1) to (3) (Ewaid and Abed, 2017).
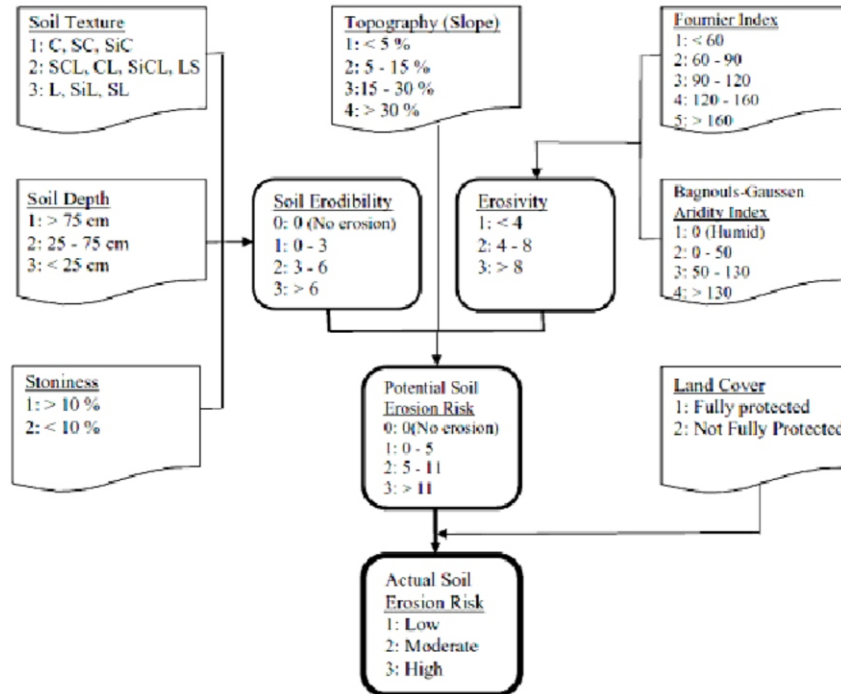

Fig 3: Flow diagram of CORINE methodology (Source: CORINE, 1992).

Moreover, soil erosion is one of the major agents of water and land degradation and as such, poses among other things severe limitations to water security. The main factors affecting the amount of soil erosion include vegetation cover, topography, soil, and climate. In order to determine erosion risk areas, erosion risk maps were generated based on these factors using the most common empirical erosion prediction model-the Co-ordination of information on the Environment (CORINE). The CORINE model was developed based on Universal Soil Loss Equation (USLE) which is well known methodology in soil erosion prediction studies (Wischmeier, 1976). The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to control the problem to reduce the risk of water pollution.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 Morphometric Characteristics of Ikpa river basin

The morphometric parameters evaluated with reference to erosion assessment include stream number, stream order, stream length, bifurcation ratio, drainage texture, drainage density, drainage intensity, infiltration number, stream frequency, texture ratio, elongation ratio, circularity ratio, and form factor ratio and compactness ratio. Fig. 4 shows details of the stream order. Also, with this map most of the other parameters can be determined. The summary of geomorphometric parameters for the entire basin is presented on Tables 1 and 2 for descriptive purposes.
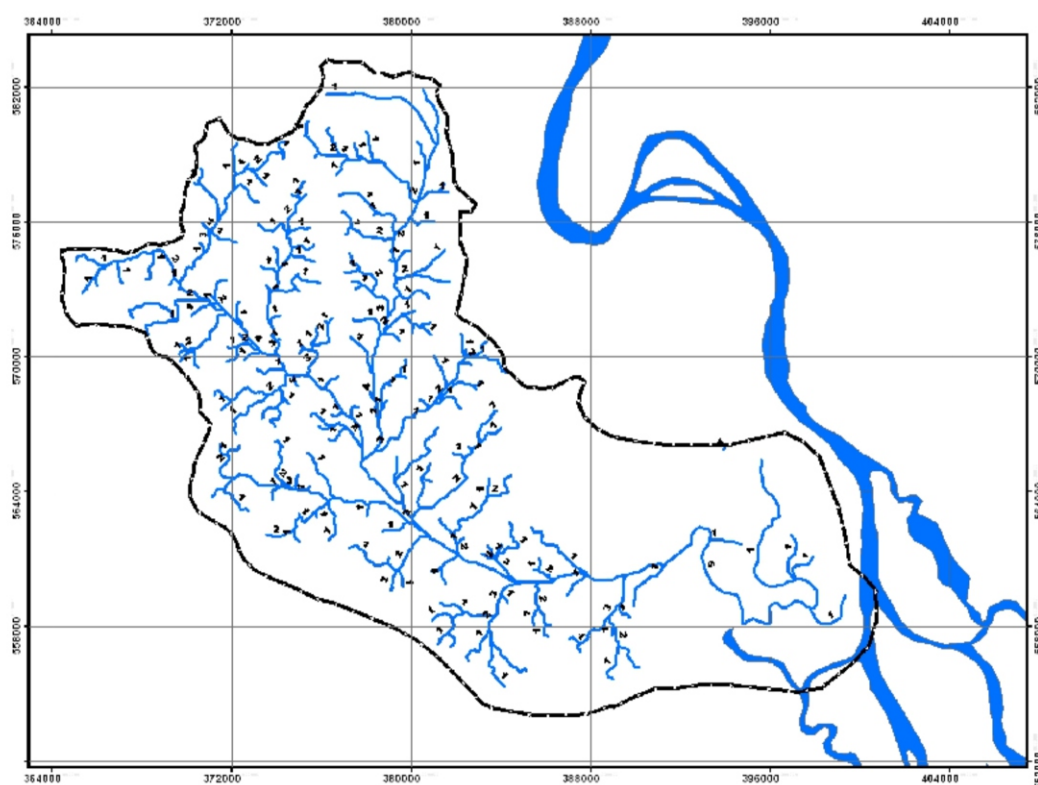

Fig. 4: Streams in Ikpa basin and their order

Table 1: Linear Aspect of the Drainage Basin

Stream Order	No. of Streams	Total Length (Km)	Mean Length (Km)	Rb	Log (NU)	Log (LU)
1	193	206.73	1.07	-	2.29	2.32
2	57	88.30	1.55	3.39	1.76	1.95
3	17	45.19	2.66	3.35	1.23	1.66
4	2	17.26	8.63	8.50	0.30	1.24
5	1	24.86	24.86	2.00	0.00	1.40

Table 2: Areal Aspect of the Drainage Basin

Areal Aspect	Values
Area (Sq. Km)	501.35
Perimeter (Km)	114.58
Drainage Density (Dd)	0.76
Stream Length (Lu)	382.34
Stream Frequency (Fs)	0.54
Mean Stream Length	1.42
Drainage Intensity	0.41
Mean Length of Overland Flow	0.66
Form Factor (Ff)	0.03
Lemiscate (K)	6.60
Circulatory Ratio (Rc)	0.08
Elongation Ratio (Re)	1.0

Table 1 shows that Ikpa basin has a total stream number of 270 grouped into five [5] stream order. The total stream length is 382.34km. Streams of relatively smaller lengths indicate that the area is with high slopes. Longer lengths are indicative of flatter gradient. Usually, the total length of stream segments is highest in first order streams, and it decreases as the stream order increases as in the present case. This brings out strong assumption that the basin is subjected to erosion and that some areas of the basin are characterized by variation in lithology and topography. Furthermore, mean stream length (Lsm) is a characteristic property related to the drainage network components and its associated basin surfaces. It is noted from Table 1 that Lsm varies from 1.07 to 24.86 and that Lsm of any given order is greater than that of the lower order and less than that of its next higher order. This deviation might be due to change in topographic elevation and slope of the basin. Also noted from Table 1 is the fact that the

basin has a relatively high bifurcation ratio. The lower values of Rb are characteristics of the sub-watersheds which have suffered less structural disturbances and the drainage patterns has not been distorted because of the structural disturbances. In the present study, the higher values of Rb indicates strong structural control on the drainage pattern while the lower values are indicative of sub-watersheds that are not affected by structural disturbances.

It is obvious from Table 2 that the perimeter of Ikpa river basin is approximately 114.58km and the area 501.35 sq. km. The drainage density is 0.76. It indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channels for the whole basin. The total number of stream segments of all orders per unit area is known as stream frequency. The stream frequency (Fs) value of the basin is 0.54. The value of stream frequency (Fs) of the basin exhibits positive correlation with drainage density of the area. This indicates that with increase in stream numbers there is an increase in drainage density.

Table 2 also shows that the form factor (Rf) value of the study area is 0.03. This indicates that the basin is elongated in shape. The elongated basin with low form factor indicates that the basin has a flatter peak of flow for longer duration. Circulatory ratio (Rc) is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. In the study area, the Rc value is 0.08, indicating that the basin is elongated in shape having low discharge of runoff and highly permeability of sub soil conditions. Elongation ratio (Re) is a very significant index in the analysis of the basin shape which helps to give idea about the hydrological character of a drainage basin. That of Ikpa basin is 1.0. The length of overland flow (Lg) approximately equals to half of reciprocal of drainage density. It is the length of water over the ground before it gets concentrated into definite stream channels. The length of overland flow (Lg values) of the study area is 0.66, indicating young topography.

3.2.   Land use and Land Cover change

Several regions around the world are currently undergoing rapid changes in land use/land cover. These changes have attracted attention because of the effects on erosion, increased run-off and flooding, increasing CO_2 concentration, climatological changes and biodiversity loss. Figures 5 , 6 and 7 reveal changes that took place between 1986 (i.e the period before Akwa Ibom State was created) and 2018 (the period after its creation).

The land use/land cover within the watershed has great impacts on the water quality of rivers. The water quality of rivers may degrade due to the changes in the land cover

patterns within the watershed as human activities increase (Ngoye and Machiwa 2004; Sliva and Williams 2001). Changes in the land cover and land management practices have been regarded as the key influencing factors behind the alteration of the hydrological system, which lead to the change in runoff as well as the water quality (Yong and Chen, 2002; Bai et al., 2010).
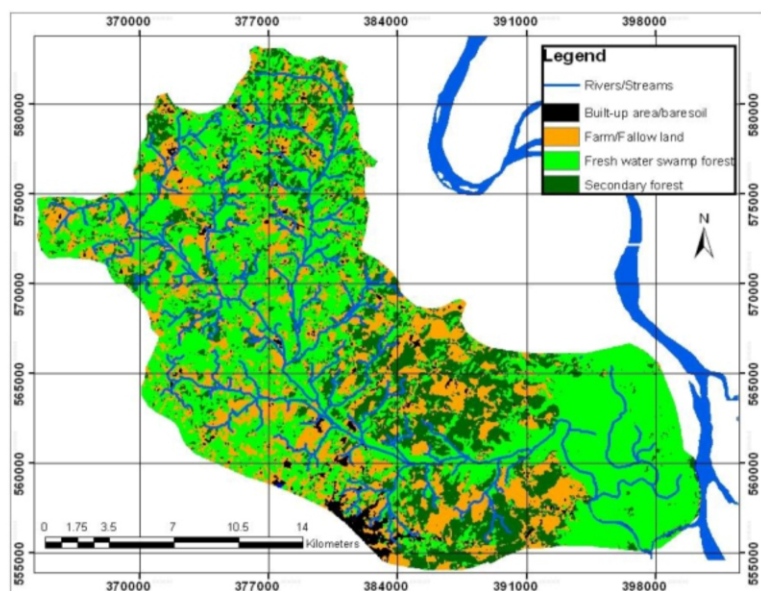

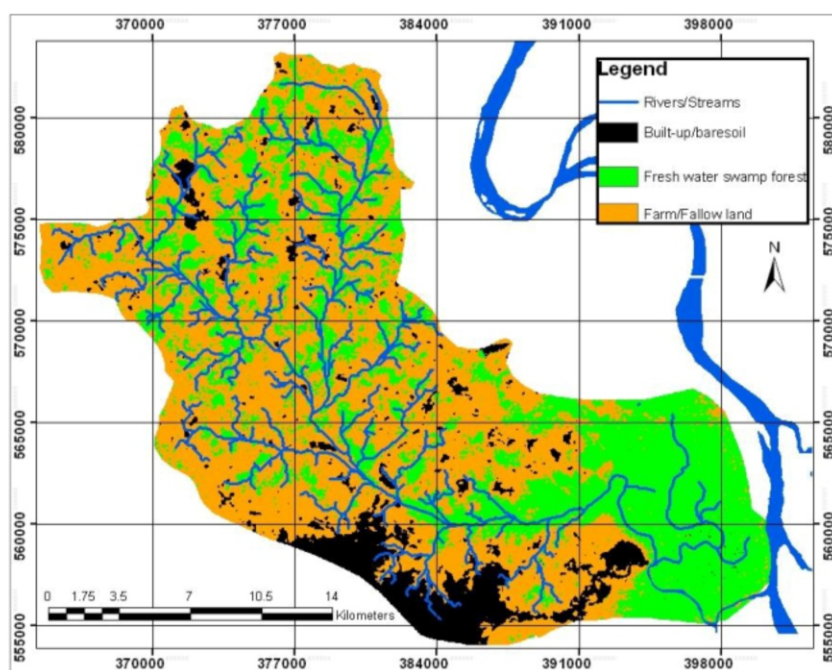
Fig. 5: Landuse/land cover 1986

Fig. 6: Landuse/land cover 2007

During the period between 1983 and 1986, high temperatures were recorded (Fig. 11). During this period the temperature peaked during the dry season between January and March. Lowest temperatures were recorded recently, between 2012 and 2016, especially during rainy seasons (Jul-Aug). The result implies that the region is recording colder seasons in recent times, most prominently July, August and September (Fig. 11).

Based on the analyses, among the elements of climate considered, rainfall is the most variable in the study area. This is in line with the findings of previous studies that among all the climatic elements, rainfall is the most variable element in Nigeria, both temporally and spatially and such variations can have significant impacts on human activities, rate of soil erosion, surface water quality among other things (Mortimore and Adams, 2001). Observed variation can be attributed to a number of natural and anthropogenic factors such as deforestation, industrialization and urbanization to mention just a few.
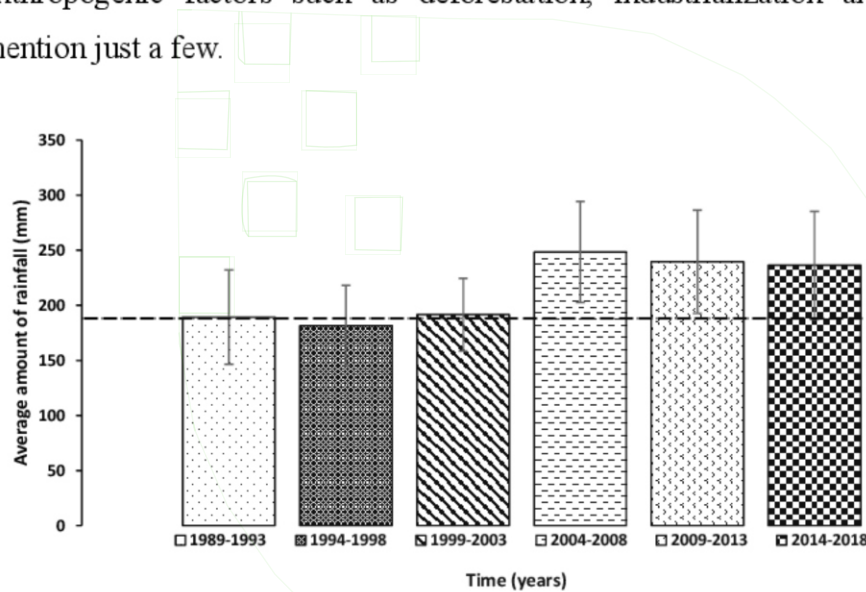

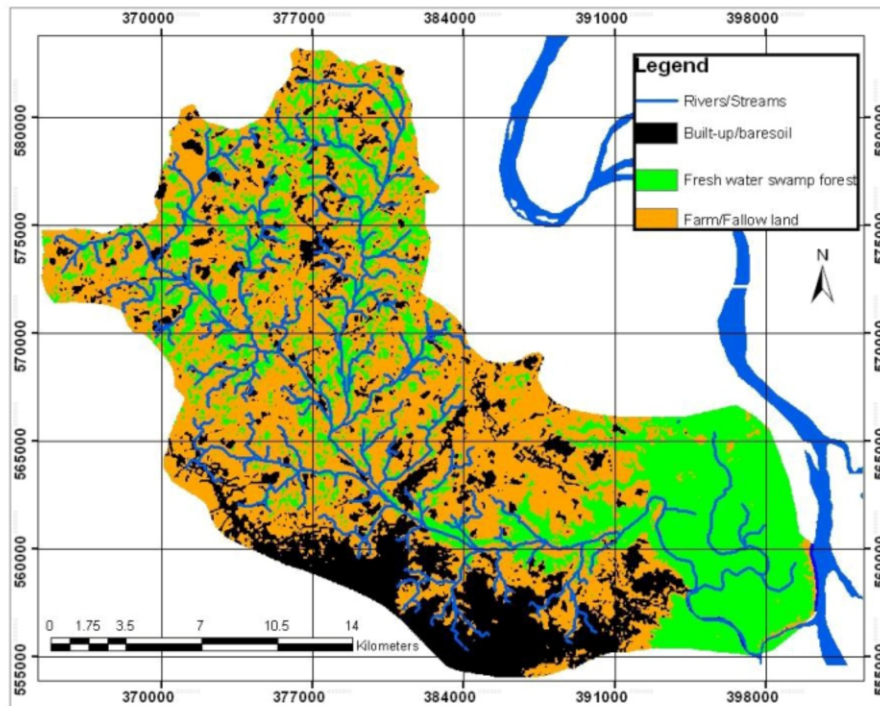Fig. 8: Trend of mean rainfall over 30 years period in the study area

Fig. 7: Land use/land cover 2018

It is obvious from these maps that because of the increased population and development activities the area attracted, there was increase in size of farm/fallow land and built up areas/baresoil. This resulted in increase deforestation and with increase in rainfall, increase in erosion and the consequent degradation of surface water quality in the basin.

3.3 Climate variability

The trend of mean rainfall data between 1989 and 2018 are presented in Fig. 8. There seems to be a general increase in the amount of rainfall above 190 mm from early 2000's to2018. The average rainfall between 2004 and 2018 was more than that obtained between 1989 and 2003. The data presented for each range of years are statistically different at p=0.05. Rainfall variabilities are better displayed in the rainy season between May and October (Fig. 9). This period revealed high variability between the data sets as presented in Fig. 4. However, in the last five years, the average annual rainfall peaked above 500 mm, which is the highest in the past 30 years. This was closely followed by the data for years 2009-2013.

Relative humidity is one of the most varied climate parameters in the study area. The curves are generally similar (Fig. 10). However, a sharp drop is observed for the relative humidity between July and December in 2014 through 2018.
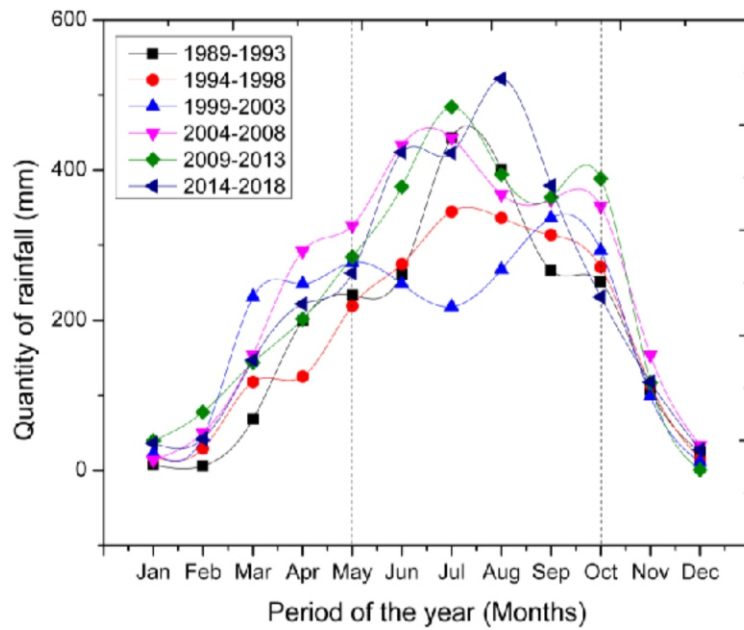
Fig. 9: Monthly variabilities in mean rainfall data over 30 years period
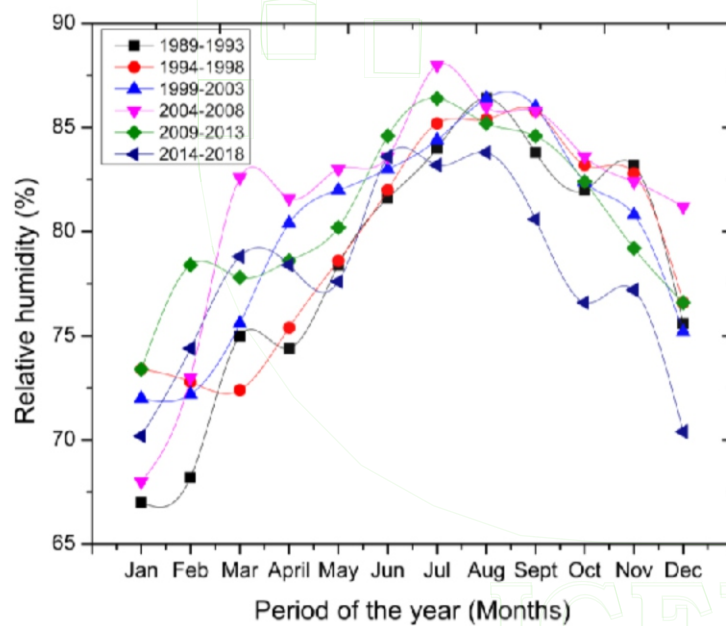
Fig. 10: Trend of mean humidity over 30 years period in the study area
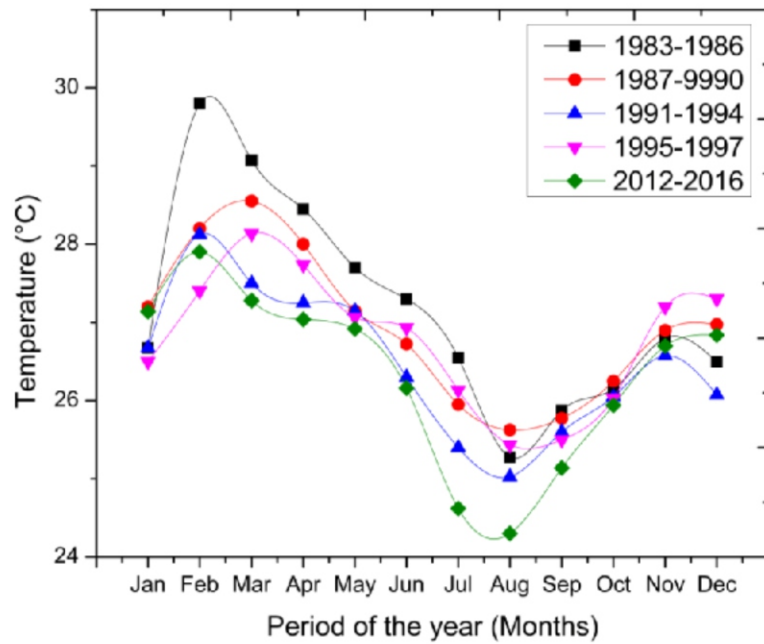
Fig. 11: Trend of temperature over 30 years period in the study area

3.4 Erosion risk in Ikpa River Basin

The result of erosion risk analysis is presented in Fig 12. Based on computations from Fig. 8, about 70% of the study area has high potential erosion risk. While, about 52% of the study area has high actual erosion risk. This implies that because of changes in land cover between 1986 and 2018, more than half of the area with high erosion risk potential was experiencing high actual erosion risk. Since studies revealed that the main activity in this section of the river is erosion and transportation (Allan 2004; UNEP 2008; Wohl 2018), one can safely state that these high actual erosion risk areas are the sources of materials (pollutants) found/eroded into streams/rivers in the area.
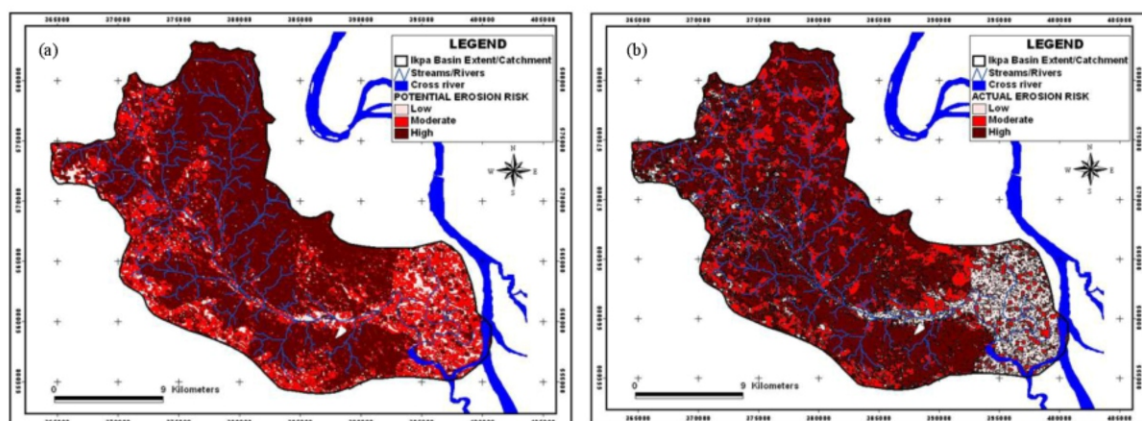
Fig. 12: Potential (a) and actual (b) erosion risk in the Ikpa River Basin

3.5 Water quality Index of Ikpa River Basin

The summary of yearly mean of the physicochemical parameters are presented in Appendix II. Temperature data ranged from 24.4 °C to 29.35 °C, with the highest in 2004, electrical conductivity values ranged from 0.063 µs/cm to 297.14 µs/cm with the highest in 2013. Values for TDS ranged from 0.058 mg/l to 452.5 mg/l with the highest in 2000 while pH ranged from ranged from 5.5-7.9 with the highest in 2004. Total suspended solids ranged from 0.001 mg/l to 334.94 mg/l with the highest in 2016, while the BOD ranged from 0.09 mg/l to 7.12 mg/l with the highest in 2001. Alkalinity ranged from 0.27 to 280.01 mg/l with the highest in 2017. Dissolved oxygen ranged from 1.6 mg/l to 15.534 mg/l with the highest in 2013. Calcium ranged from 1.64 mg/l to 64.91 mg/l with the highest in 2017 while nitrate ranged from 0.027 mg/l to 53.65 mg/l with the highest in 2012. Phosphate ranged from 0.18 mg/l to 50.99 mg/l with the highest in 2005 while sulphate ranged from 0.07 to 290.22 mg/l with the highest value in 2016. Chloride had the highest value in 2016, ranged from 0.13mg/l to 92.17mg/l.

In Table 2, the annual water quality index of Ikpa river basin between 1994 and 2017 is presented based on the classification by Ewaid and Abed (2017). The result revealed that out of the 16 years water quality index results, 9years accounted for poor water quality, 2 accounted for good water quality, 2 accounted for unsuitable and 3for very poor. Most of the years had unsafe water quality for domestic and other uses The WQI was not computed for years with water quality parameters less than 13 because the parameters were assumed to be incomplete for the model to be applied. When considering individual years, a trend could not be established for the WQI. However, when the data were grouped at interval of 4 years, the WQI gradually increased (worsened) between 2004 and 2013 (Fig. 13). During the same period, highest rate of rainfall was recorded (Fig. 14). This implies that increased rainfall contributed to poor surface water quality in the river basin. The grouped data were statistically different at p=0.05.
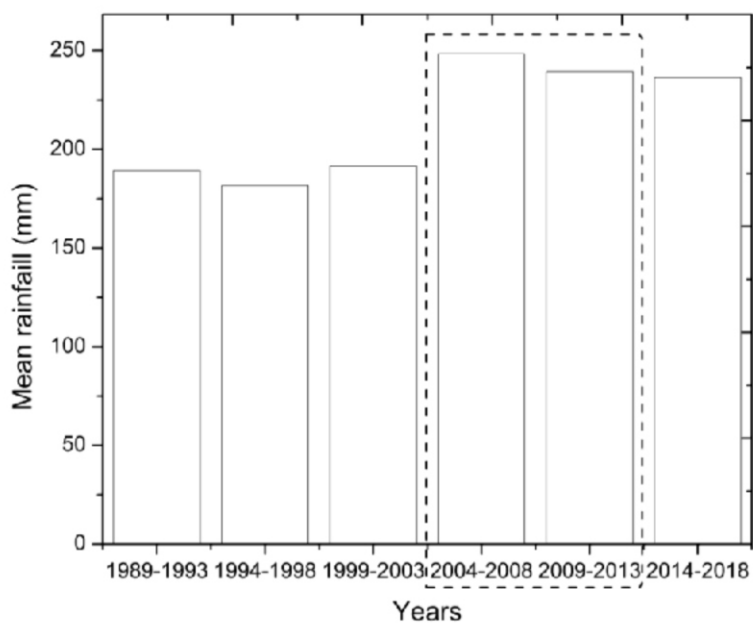
Fig. 13: Analogy of rainfall in the study area
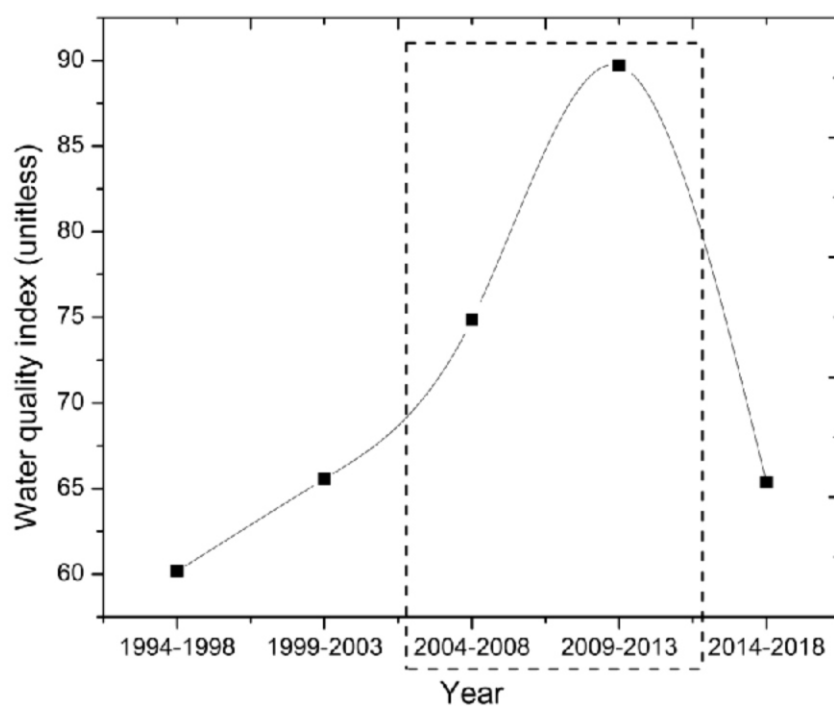
Fig. 14: Trend of water quality index of the study area

The relationship between climatic parameters and water quality index revealed that each relate differently. The correlation coefficient of 0.42 for the relationship between temperature and water quality index showed that the relationship was moderate, while 0.193 for relationship between humidity and water quality shows that the relationship was very weak, and 0.507 for relationship between rainfall and water quality showed

that the relationship was relatively strong. The correlation between water quality and temperature is significant, between water quality and rainfall is strongly significant (since $p=0.05$, $p<0.05$) but the relationship with humidity was not statistically significant since $p>0.05$.

Table 3: Annual Water Quality Index of Ikpa River Basin

Year	Water quality index	Remark
2017	75.39	Very poor
2016	58.69	Poor
2015	58.92	Poor
2014	68.52	Poor
2013	77.26	Very poor
2012	135.63	Unsuitable
2010	56.23	Poor
2008	57.94	Poor
2007	61.25	Poor
2006	67.11	Poor
2005	128.29	Unsuitable
2004	59.68	Poor
2001	88.80	Very poor
2000	42.32	Good
1998	63.79	Poor
1997	67.39	Poor
1994	49.33	Good

CHAPTER FOUR

CONCLUSIONS AND FURTHER WORK

4.1 Conclusions

The aim of this study was to ascertain the influence of climate variability, land cover/land use, and soil erosion risk on the water quality status of surface water in Ikpa River basin. It is obvious from the findings/result of the study that, high rainfall and soil erosion have over the years contributed to degrading the surface water quality. This was through anthropogenic activities including, agricultural, industrial, municipal wastes and other pollutants entering the river system through direct discharges or surface runoff. There is therefore the need to control changes in land cover to reduce soil erosion risk and the pollution of surface.

4.2 Further Work

It is suggested that to provide more insights into the climate variability impacts it would be useful to:

I.   Compare/map the levels of nutrients and contaminants between streams/rivers/sub-basin to identify hotspots.
II. Monitor/determine landuse/land cover changes and drivers of such changes within the river basin to assess and predict spatiotemporal variations in erosion risk and water quality.
III. Determine/map the location and number of streams/rivers that are polluted, the sources of such pollution and the settlements/population of people/aquatic biota that are at risk.

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Inam E., Offiong N., Essien J., Kang S., Kang S.-Y. &Antia B. 2016 Polycyclic aromatic hydrocarbons loads and potential risks in freshwater ecosystem of the Ikpa River Basin , Niger Delta —Nigeria. *Environmental Monitoring and Assessment, 188*, 49. https://doi.org/10.1007/s10661-015-5038-9.

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Appendix I

References of data sources

S/N	Year	Source	Source type
1.	2019	Daniel, G. D. (2019) Water quality index of selected rivers in Ikpa River Basin. Undergraduate Thesis, University of Uyo, Nigeria.	Thesis
2.	2019	Imikan, J. J. (2019). Water quality index of selected surface water in Ikpa River Basin. Undergraduate Thesis, University of Uyo, Nigeria.	Thesis
3.	2019	Ebong, U. V. (2018) Quantification and risk assessment of poly chlorinated biphenyl in waster and sediment from Ikpa River Basis, Akwa Ibom State. Unpublished Master's Thesis, University of Uyo, Nigeria.	Thesis
4.	2019	Udofia, G. E. (2018) Crude oil and polycyclic aromatic hydrocarbons degradability of bacteria and yeasts from "Black Water" ecosystem of Eniong River, Itu – Nigeria. PhD Thesis, University of Uyo, Nigeria.	Thesis
5.	2018	Umo, I. S., Ike, M. C. and Ukwe, I. G. (2018) Dimensionless geomorphometry and discharge in the Ikpa River Basin, Nigeria. *Asian Journal of Geographical Research,* 1(1), 1-13. DOI: https://doi.org/10.9734/AJGR/2018/40098	Journal
6.	2018	Akpan A. W., Ayotunde E. O., Etteokon, S. E. (2018) Spatial trend in the heavy metal concentration of Ikpa River, Akwa Ibom State, Nigeria. *International Journal of Fisheries and Aquatic Research,* 4(1), 6-12.	Journal
7.	2018	Inam, E., Etuk, I. B., Offiong, N. O., Kim, K., K, S. and Essien, J. (2018) Distribution and ecological risks of polycyclic aromatic hydrocarbons (PAHs) in sediments of different tropical water ecosystems in Niger Delta, Nigeria. *Environmental Earth Sciences,* 77: 216. DOI: https://doi.org/10.1007/s12665-018-7396-4	Journal
8.	2017	Samuel E. E., (2017) Studies on the abundance and distribution of micro-benthic fauna and relation to some physio-chemical and heavy metal parameters of Ikpa River. AKS. MSc Thesis, University of Uyo, Nigeria	Thesis
9.	2017	Donald I. I. (2017) Microbiological and physiochemical properties of municipal solid waste dumpsite in Uyo, Nigeria: Ecological Risk Assessment. PhD Thesis, University of Uyo. Nigeria.	Thesis
10.	2017	Ekpenyong, M. A. (2017) Studies on the physicochemical characteristics and plankton of Nwaniba River, AKS. MSc Thesis, University of Uyo, Nigeria.	Thesis
11.	2017	Ezemonye, M. N., Umo, I. S., Ojinma, C. C. and Ike, M. C. (2017) Geomorphometric parameters of Ikpa River and its implications for the planning of fluvial hazards in the northeast of Akwa Ibom State. *Journal of Geography, Environment and Earth Science International,* 11(1): 1-12. DOI: https://doi.org/10.9734/JGEESI/2017/34674	Journal
12.	2017	Federal Ministry of Niger Delta Affairs (2017). Environmental Impact Assessment (EIA) Report for the Construction of Mbak Atai Itu – Okoita – Arochukwu Road, Akwa Ibom/ Abia States. Federal Ministry of Niger Delta Affairs, Abuja, Nigeria.	Report
13.	2016	Edet, A. E. (2016) Trace metals levels and fluxes in water and sediment from Ishiet river in Uruan, AKS. MSc Thesis, University of Uyo, Nigeria.	Thesis
14.	2016	Inam, E., Offiong, N., Essien, J.,Kang, S., Kang S. Y and Antia, B. (2016) Polycyclic aromatic hydrocarbons loads and potential risks in freshwater ecosystem of the Ikpa River Basin, Niger Delta – Nigeria. *Environ Monit Assess,* 188: 49. DOI: 10.1007/s10661-015-5038-9	Journal
15.	2016	Ogbemudia F. O. and Ita R. E. (2016) Macrophate abundance and water quality status of three impacted inlet streams along Ikpa river basin, Akwa Ibom state, Nigeria. *Tropical Freshwater Biology* 25(75-77)	Journal

16.	2015	Ekpenyong, R. E. (2015) An assessment of the concentration of heavy metals in surface water within Akwa Ibom state, Nigeria. *IOSR Journal of Applied Physics*, 7(3): 08-13. DOI: https://doi.org/10.9790/4861-07310813	Journal
17.	2015	Enyiekere, G. (2015) Abundance and affinity of some heterotrophic and autotrophic bacterial communities in humic freshwater ecosystem of Eniong River, south south Nigeria. MSc Thesis, University of Uyo, Nigeria.	Thesis
18.	2015	Udoh O. O. (2015) Absorption of methylene blue from aqueous solution by humic acid. extracted from surface water sediment from Eniong River, Nigeria. MSc Thesis, University of Uyo, Nigeria.	Thesis
19.	2014	Egbomuche, R. C., (2014). Microbiology and physiochemistry of humic freshwater ecosystem of Eniong river, Itu, Nigeria. Unpublished Master's Dissertation, University of Uyo 09/PG/FS/MC/006.	Thesis
20.	2013	Essien O. E and Ubit Francis (2013) Investigation of Ikpa river water quality with consideration for domestic and agricultural uses. *Journal of Agricultural Research* 2(11) 319-320.	Journal
21.	2013	Federal Ministry of Environment (2013). Environmental Impact Assessment (EIA) of drainage and erosion in Ibiaku Itam in Itu Local Government Area of Akwa Ibom State (Draft Report). Federal Ministry of Environment, Abuja, Nigeria.	Report
22.	2013	Udo, G. E. (2013) Physicochemical characteristics and speciation studies of Itu River. BSc Thesis, University of Uyo, Nigeria.	Thesis
23.	2013	Bassey O. B. (2013). Water quality parameters and indices for Ikpa river in Akwa Ibom state, Nigeria. *International Journal of Engineering Research and Technology*, 2(9), 25-26.	Journal
24.	2013	Dennis, E. I., Essien, R. A. and Udoh, U. H. (2013) Dynamics of heavy metal runoff from farmland around Ikpa River Basin, Nigeria. *Applied Ecology and Environmental Sciences*, 1(6), 143-148. DOI: https://doi.org/10.12691/aees-1-6-7	Journal
25.	2012	Ekpo, I. E., Chude, L. A., Onuoha, G. C. and Udoh, J. P. (2012) Studies on the physico-chemical characteristics and nutrients of a tropical rainforest river in southeast Nigeria. *AACL International Journal of the Bioflux Society*, 5(3), 142-162.	Journal
26.	2011	Ogban, P. I., Effiong, G. S., Obi, J. C. and Ibia, T. O. (2011) Characteristics, potentials, and constraints of wetland soils for agricultural development in Akwa Ibom State, South-Eastern Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, 7(2): 80-87.	Journal
27.	2010	Uko, I. R. (2010) Microbial density, diversity and physiochemistry of some lotic and lentic water bodies in Uyo wetlands, Akwa Ibom State. MSc Thesis, University of Uyo, Nigeria.	Thesis
28.	2010	Edet, T. C. (2010) seasonal variation of level of heavy metals in water, sediment and catfish from a sediment of Itu River in Akwa Ibom State. MSc Thesis, University of Uyo, Nigeria.	Thesis
29.	2008	Akwa Ibom State Ministry of Environment and Mineral Resources (2008). Environmental Impact Assessment (EIA) of Uyo Urban Drainage/Flood Control Project (Draft Final Report). Akwa Ibom State Ministry of Environment and Mineral Resources, Uyo, Nigeria.	Report
30.	2008	Edem C. (2008). Microbial ecology and physiochemistry of Ikpa river wetland, Uyo. Unpublished undergraduate thesis, University of Uyo 01/Pa/Na/MC/010	Thesis
31.	2005	Akwa Ibom State Ministry of Culture and Tourism (2005). Environmental Impact Assessment (EIA) of Ibom Hotel and Golf Resort (Preliminary Report). Akwa Ibom State Ministry of Culture and Tourism, Uyo, Nigeria.	Report
32.	2005	Akpan, M. M. (2005) Studies on the physiochemical and plankton component in	Thesis

the Lower Cross river, Nigeria. MSc Thesis, University of Uyo, Nigeria.

33.	2004	Esong, E. H. (2004) Comparative study on the effect of water treatment on the characteristics of water in Uyo municipality, Akwa Ibom State, Nigeria. MSc Thesis, University of Uyo, Nigeria.	Thesis
34.	2001	Akpan U. B. (2001) Study of the physiochemical Hydrology of Ikpa River. MSc Thesis, University of Uyo, Nigeria.	Thesis
35.	1998	Thompson, P. I. (1998) Ecological studies on the Benthic fishes of Iba-Oku stream Uyo, Nigeria. MSc Thesis, University of Uyo, Nigeria.	Thesis
36.	1997	Udoessien, E. I. & Inam, E. J. (1997) Water quality and some physicochemical parameters of Iba Oku stream in Uyo, Akwa Ibom State, Nigeria. *Tropical Journal of Environmental Science*, (Nigeria), 1: 33-55.	Journal
37.	1997	Umoh, S. W. (1997) Effects of rubber processing effluents on the physiochemical characteristics of Ikpa River at Ntak Inyang. MSc Thesis, University of Uyo, Nigeria.	Thesis
38.	1997	Ekong, C. I. (1997) Variation of some heavy metal levels in sediment and water from Ikpa River in Itu Local Government Area, Akwa Ibom State, Nigeria. MSc Thesis, University of Uyo, Nigeria.	Thesis

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Appendix II

Physicochemical characteristics of Ikpa River Basin (1994–2019)

Parameters	Year																				
	1994	1997	1998	2000	2001	2002	2004	2005	2006	2007	2008	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Temperature	26.99	26.25	26.04	27.83	26.57	28.33	29.35	26.97	25.55	NA	27	24.9	NA	24.4	27.7	27.5	28.8	26.3	26.9	NA	NA
EC, μs/cm	31.8	0.063	0.088		2.94		7.95	17.49	54.37	NA		0.09	NA	246.8	297.1	85.1	41	39.5	95.4	NA	NA
TDS, mg/l	1.43	0.058	28.7	452.5	19.15	66.67	32	23.84	125.8	NA	0.16	0.16	NA	146.3	55.83	19	1.46	100.6	25.98	NA	NA
pH	6.11	6.88	6.9	6.4	6.9	5.88	7.95	6.65	6.69	NA	6.94	5.9	4.9	6.3	5.54	6.5	6.6	5.5	6.56	NA	NA
TSS, mg/l	1.55	0.01	18.09		50.49		20.0	216.9	382.3	24		1.83	NA	201.2	21.33	12.5	5.57	334.9	38.0	NA	NA
BOD, mg/l	1.51	1.09	2.25	0.09	7.12	6.79	3.27	4.06	3.79		2.03		NA	2.09	7.01	NA	0.39	2.75	2.62	NA	NA
Alkalinity	0.27	1.6	16.75	50	12.95	18.67	26	18.00	NA	48	1.43	4.52	NA	32.3	58.7	NA		88.7	280.0	NA	NA
DO, mg/l	6.66	1.8	3.84	5.86	8.16	1.6	10.21	3.69	4.66	NA	3.69		5.86	3.87	5.3	6.0	7.47	7.67	15.53	NA	NA
Ca, mg/l	NA	NA	NA	NA	NA	2.86	30.25	NA	NA	NA	NA	NA	NA	NA	1.63	NA	5.87	26.1	46.9	NA	NA
Nitrate, NO_3^-, mg/l	2.02	NA	3.3	0.03	12.54	NA	NA	37.3	1.03	NA	0.21	0.26	NA	53.65	19.9	23.4	16.45	2.86	14.4	NA	NA
Phosphate, PO_4^{3-}, mg/l	NA	NA	0.2	NA	0.82	NA	NA	50.99	1.11	NA	0.25	NA	0.18	15.76	0.81	2.17	1.89	0.19	5.51	NA	NA
Sulphate, SO_4^{2-}, mg/l	0.07	0.9	41	3.91	3.59	NA	290.2	5.09	6.28	NA	0.25	0.12	NA	0.7	22.0	16	15.6	51.87	4.73	NA	NA
Mg, mg/l	NA	NA	NA	NA	0.11	3.55	NA	NA	NA	NA	NA	NA	3.67	NA	1.27	NA	1.87	7.12	1.12	NA	NA
Cl^{-1}, mg/l	4.98	NA	27.1	41.5	0.78	NA	16.1	NA	21.59	NA	0.65	2.11	6.28	NA	22.7	0.13	0.17	92.2	0.13	NA	NA
WQI	49.33	67.39	63.79	42.52	88.8	NC	59.68	128.3	67.11	NC	57.94	56.23	NC	153.6	77.26	68.5	58.9	58.7	754.6	NC	NC

NA -not available;   NC – Not computed due to incomplete data

Appendix III
Published Paper

Inam, E., Ekpenyong, R., Offiong, N.-A., Udotong, U., Benjamin, M., & William, N. (2020). Climate variability, land cover change and soil erosion risk implications for water quality of a humid tropical river basin in sub-Saharan Africa. *Water Practice and Technology*, *16*(1), 263–275. https://doi.org/10.2166/wpt.2020.116