



## **Climate Variability and Influent Streams in The Kwa Iboe River Basin of South-East Nigeria**

*by*

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### **Abstract**

*This study examined the impacts of climate variability on influent streams in Kwa Iboe River Basin of south-east Nigeria. It covered the Ibom Sub-Basin of Kwa Iboe River Basin, where the sampling fraction concept was employed to select three streams for the study. Random sampling technique was employed in administering 288 copies of structured questionnaire to households in the sample communities. Hypothesis was formulated and tested using Climate elasticity of streamflow index. The study revealed changes in the Stream order, bifurcation ratio, basin size, basin length, lemniscate's factor and form factor of the basin between 1989 and 2019. Stream number dropped from 32 to 30 between 1989 and 2019. The research revealed that annual mean temperature and precipitation has changed over the period. Annual mean temperature dropped between 1989 and 2019. Annual mean precipitation also increased between 2010 and 2019. It also showed that the amount of runoff is highly sensitive to changes in climate. Implementation of water use efficiency, mainstreaming climate change adaptation, sharing knowledge on climate and planned dredging of streams are recommendations for adaptive management of streams.*

**Key words:** Climate Variability, Influent Streams, Temperature, Precipitation

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### **1. Introduction**

Climate variability, primarily the result of the widespread use of fossil fuels, represents the greatest environmental threat to humanity. According to IPCC (2014), climate change is seen as a statistically significant variation in the mean state of the climate or in its variability persisting over an extended period, typically decades or longer. The changes could be seen with respect to a significant change in perceived temperature of the region, the amount of rainfall experienced in the region, duration of exposure of the ground to sunlight etc. Climate change may be due to natural internal processes, natural external fossils, or persistent anthropogenic induced changes in

atmospheric composition or land use. The change may occur over periods ranging from decades to millennia (Abiodun, Salami and Tadross, 2011; Ekanem, 2010). Many studies have suggested that future climate change will involve greater extremes of weather, including more high-intensity rainfall events (IPCC, 2014). This is likely to lead to an increase in flooding and other hydrological alterations, particularly while a channel adjusts to the differing flow regime.

Impacts of climate change are broadly classified into environmental, agricultural, economic, health and other socio-economic according to United Nations Framework Convention on Climate Change (UNCCC, 2003). The key socio-economic sectors that are most likely to be impacted by climate change are well-being, land-use change, forestry, energy, flora and fauna. According to the 4th assessment report of the Intergovernmental Panel on Climate Change, Africa is likely to become warmer than the rest of the earth with an increase in average surface temperature of about 3.4<sup>0</sup>c by the end of the 21<sup>st</sup> century relative to the period between 1980 and 1990 (IPCC, 2014). As a result of the above, it is imperative to study, analyze and understand the impacts of this climate related changes on our hydrological cycle.

According to Vorosmarty et al., 2010, Streams cover about 0.8% of the Earth's surface, but deliver many critical goods and services to human beings. The world's available water supply from streams is also distributed unevenly around the globe due to the facts that some streams are disappearing (Dudgeon et al., 2005 and Malmqvist and Rundle, 2001). According to William (1988), streams which intermittently cease to flow and run dry are representative of the world's river systems than those with perennial flows. These temporary streams are a truly global phenomenon (Larned, Darty, Arscott, and Tockner, 2010). Their spatial and temporal extent is likely to further increase resulting from the combined effects of altered land use pattern, climate change and increased water extraction for human uses (Meehl, Stocker and Collins, 2007; Palmer, Reidy-Liermann and Nilsson, 2008).

Influents streams are stream that reduce in width and breadth as it flows along river course. There are streams that decrease in size over time. There are popularly described as disappearing streams.

Dry streambeds are defined as the channels of temporary streams during the dry phase that can be exposed during periods of drought. They are habitats in their own right and differ from adjacent riparian and other terrestrial habitats in their substrate composition, topography, microclimate, vegetation cover, inundation frequency, and biota (Steward, Marshall and Sheldon, 2011). Disappearing or dry streambeds are subject to flow disturbances that mobilize, deposit, and scour bed sediment. A temporary streambed can be dry for much of the time and may only be aquatic for a brief period after a flood or a period of heavy rainfall (Datry, Arscott and Sabater, 2011). They can also be exposed to intense solar radiation, wind and extreme temperatures (Steward, Marshall and Sheldon, 2011). Dry streambeds may be devoid of vegetation. Although often linked with negative connotations, dry riverbeds are associated with a range of important societal and ecological values. Unfortunately, dry streambeds have been largely ignored by aquatic and terrestrial ecologists, probably because they are perceived regions; they can be where

the greatest diversity and density of vegetation is found to be outside the domain of their respective disciplines.

Several studies have investigated the impacts of climate change on the hydrology of a watershed. Hubbard and Hotchkiss (1997) used RegCM (Giorgi et al. 1993) to assess the impacts of climate change on water resources in the Missouri River Basin. They found a dramatic increase in water yield (100 percent or more) for the northern region of the basin while the southern region decreased up to 80 percent. Lettenmaier et al. (1999), in their study of six North American watersheds of various sizes representing a variety of physiographic and geographic conditions, used the output from three transient GCMs and one equilibrium (double carbon dioxide) GCM to evaluate the potential effects of climate change. They found that the water yield decreased by 6, 24, and 34 percent for the transient climate scenarios and increased by 2 percent for the 2×CO<sub>2</sub> scenario. They also suggested that altered precipitation causes generally higher correlation with runoff changes than do temperature changes.

Numerous studies have documented the sensitivity of streamflow to climate changes for basins across the world (Fu et al., 2007; Chiew, 2006; Arnell, 2002; Sankarasubramanian et al., 2001; McCarthy et al., 2001; Yates and Strzepek, 1998; Fu and Liu, 1991). Most of these studies involves estimating the precipitation elasticity of streamflow, which was introduced by Schaake (1990) for evaluating the sensitivity of streamflow to changes in climate. Dooge et al. (1999) termed it a sensitivity factor and Kuhnel et al. (1991) termed it a magnification factor. Fu, Charles and Chen (2007) extended the single parameter precipitation elasticity of streamflow index into a two parameter climate elasticity index, as a function of both precipitation and temperature, in order to assess climatic effects on annual streamflow. Application of the proposed index to two basins indicates that the single parameter precipitation elasticity index may give a general relationship between precipitation and streamflow in some cases, but that it cannot reflect the complicated non-linear relationship among streamflow, precipitation and temperature. The study revealed that, for the Spokane River basin the climate elasticity of streamflow index varies from 2.4 to 0.2, for a precipitation increase of 20%, as temperature varies from 1C lower to 1.8C higher than the long term mean. Thus a 20% precipitation increase may result in a streamflow increase of 48% if the temperature is 1C lower but only a 4% increase if the temperature is 1.8C higher than the long-term mean.

Bawden et. al. (2014) studied the spatiotemporal analysis of hydrological trends and variability in the Athabasca Lake region, using morphometric analysis. The results revealed that 22% of the total rivers are disappearing in the study area, with additional 38% shrinking at an alarming rate. Chen et. al. (2011) conducted a study of the hydrological impacts of climate change for a Canadian Watershed. Results from the study demonstrate that climate change has contributed to the increase of shrinking and disappearance of streams in the watershed by 46%. The study also noted that water shortage will be less a problem than increases in runoff, flooding, or sea level rise; as shrinking stream at a watershed, increases the amount of water in another watershed. While Udofia and Udofia (2018) conducted a morphometric analysis of disappearing streams and its implications for water resources utilization and management in middle

Enyong Basin and showed the disappearance of 5 streams in the Ibom sub-basin, Kwabena (2013) studied the impact of climate change on streamflow in selected river basins in Ghana using Soil and Water Assessment Tool (SWAT) model. His results showed a decrease of 22% and 50% for estimated streamflow of White Volta basin for 2020s and 2050s respectively, as well as a decrease of 22% and 46% of estimated streamflow of the Pra basin for 2020s and 2050s respectively. These results underscore the need to put in place appropriate adaptive measures to foster resilience to climate change in order to enhance water security within the two basins. Berhane (2011) assessed the potential impacts of climate change on the flow of the main headwaters of the Nile River: Equatorial Lakes Region and Blue Nile Basins using the SWAT model. Result from the study demonstrates that the hydrology of the basin is very sensitive to climate change with 104%, 33% and 77% of the baseline increase to the surface runoff, lateral flow and water yield. Similarly, Park et. al. (2011) assessed the future of climate change impacts on water quantity and quality for a mountainous dam watershed in South Korea using SWAT. The impacts of projected future climate change scenarios on the evapotranspiration, groundwater recharge, and streamflow were increases of +23.1%, +28.1%, and +39.8%, respectively.

Vogel et al. (1999) used a regional multivariate regression model to document that a 10% increase in precipitation leads, on average, to a 19% increase in annual streamflow for the entire upper Colorado River system, of which the Animas River is only a small subbasin. Treating the entire upper Colorado River as a single basin, Revelle and Waggoner (1983) report an at-site multivariate regression relationship among streamflow, precipitation and temperature such that a 10% increase in annual precipitation leads to an 11% increase in streamflow.

Manoj-Jha, Richard and Steve (2003) evaluate the impact of climate change on stream flow in the Upper Mississippi River Basin (UMRB) by using a regional climate model (RCM) coupled with a hydrologic model, the Soil and Water Assessment Tool (SWAT). The SWAT model was calibrated and validated against measured stream flow data using observed weather data and inputs from the Environmental Protection Agency's BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) geographical information/database system. The combined performance of the SWAT and RCM was examined using observed weather data as a lateral boundary condition in the RCM. The SWAT and RCM were found to perform well, especially on an annual basis. The potential impacts of climate change on water yield and other hydrologic budget components were then quantified by driving SWAT with current and future climates. A 21 percent increase in future precipitation simulated by the RCM produced an 18 percent increase in snowfall, a 51 percent increase in surface runoff, and a 43 percent increase in groundwater recharge, resulting in a 50 percent net increase in total water yield in the UMRB on an annual basis. Uncertainty analysis showed that the simulated change in stream flow substantially exceeded model biases of the combined modeling system (with the largest bias being 18 percent), giving us relatively high confidence in the results.

A major study of 900 rivers published in the American Meteorological Society's (AMS) *Journal of Climate* in 2009 concluded that flows into the oceans have decreased

significantly over the last 50 years, with that trend predicted to continue (Gracia, 2008). According to global-scale projections, hydrological variability will not change uniformly across the globe. For example, it is predicted that 30-year floods will occur more frequently over 50% of the globe (Dankers et al., 2014) and that increased hydrological droughts will occur over 40% of the analyzed land area (Prudhomme et al., 2014). In addition to the effects of catchment properties, the spatial variations of hydrological variability changes are determined by climate related changes. For example, drought increase is generally located where precipitation decreases; however, drought can still increase in some areas with increased precipitation if stronger evaporation is driven by temperature increase (Prudhomme et al., 2014). Thus, the mechanisms by which climate variability influences hydrological variability should be analyzed.

## **2. Objectives of the Study**

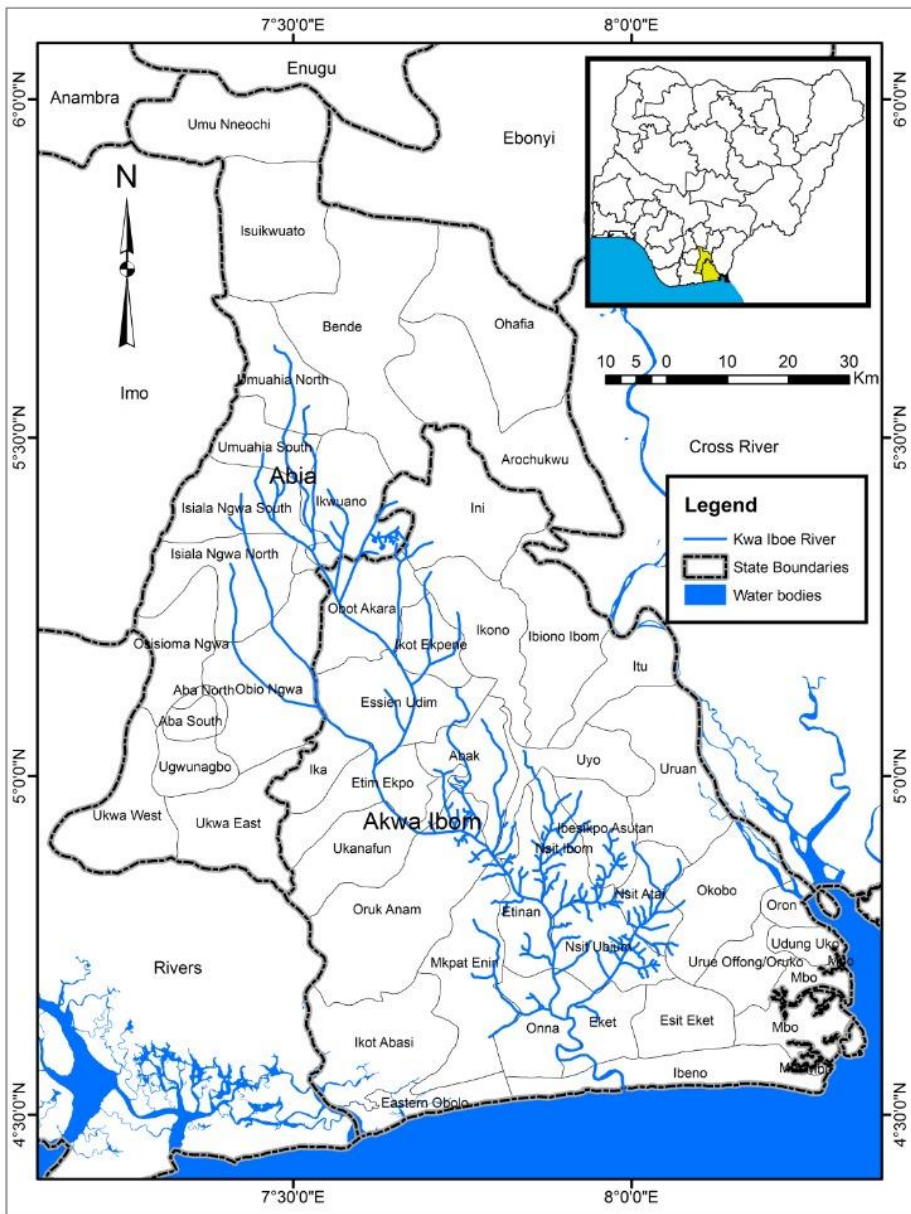
The aim of this research was to assess the impacts of climate related variations on influent streams in Kwa Iboe River Basin, with the following specific objectives:

- i. To examine the contributions of precipitation and temperature to the shrinking/disappearance of streams in the drainage basin
- ii. examine the sensitivity of runoff to changes in climatic variables in the drainage basin
- iii. analyze the impacts of Climate Variability on Influent Streams in the drainage basin

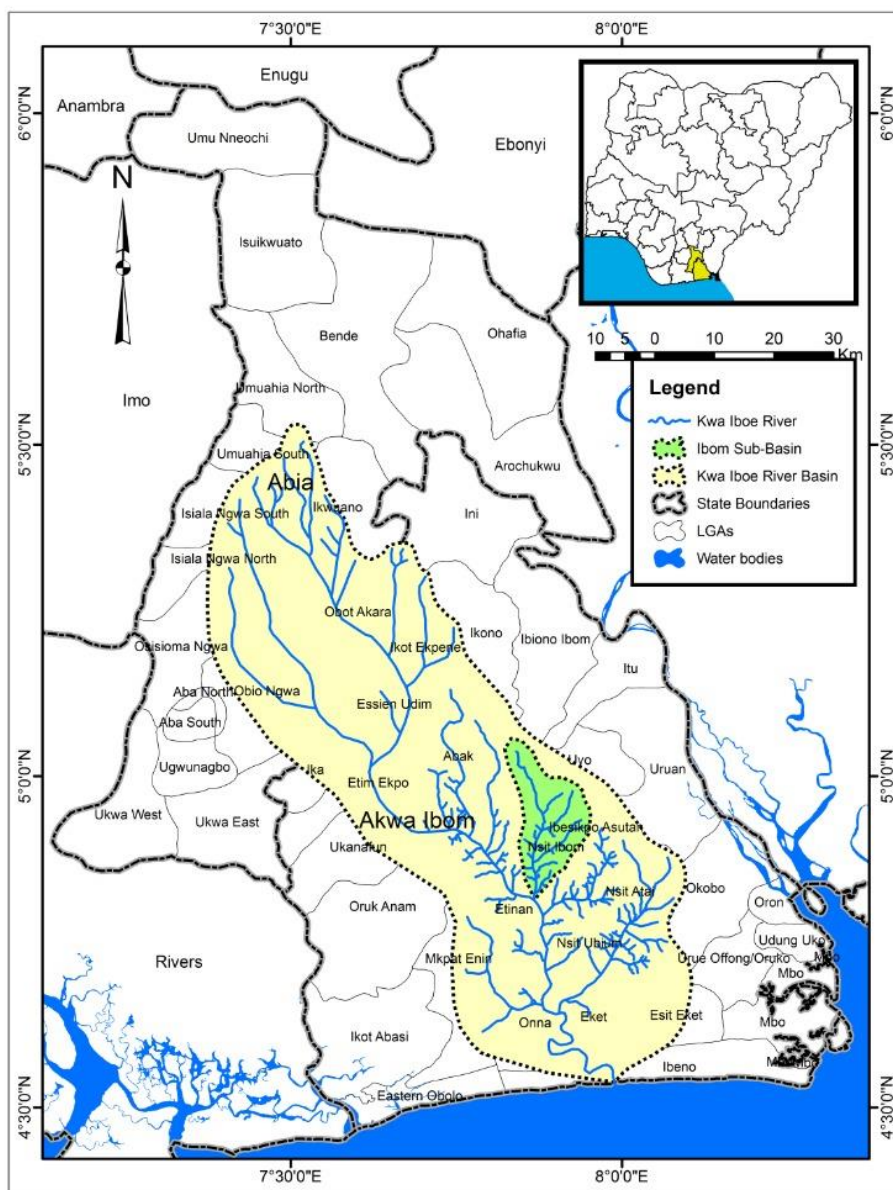
## **3. The Study Area**

The Kwa Iboe River has developed into a sizeable basin; its catchment area occupies the entire western and central parts of Abia State and a unification of elongated segment of Akwa Ibom State down the south. The relief pattern consists of low lying plain and riverine environments with no portion rising above 175 meters above sea level (Usoro, 2010). It is important to acknowledge that the Abia State segment of Kwa Iboe River covers four LGAs of Isuikwuato, Umuahia North, Umuahia South and Ikwuano while the Akwa Ibom State segment covers up to 13 LGAs including Obot Akara, Ikot Ekpene, Essien Udim, Etim Ekpo, Ukanafun, Oruk Anam, Etinan, Nsit Ubium, Nsit Ibom, Onna, Eket and Ibeno LGAs. Kwa Iboe River flows in the south eastern direction towards the Atlantic Ocean and traverses over 100 communities covering four (5) and thirteen (13) LGAs of Abia and Akwa Ibom States respectively. The water flows through Umuahia North and Umuahia South Local Government Areas and dissects the landscape as it cascades through Ikwuano LGA and enters into Akwa Ibom State at Usaka community in Obot Akara LGA. Usaka community is located on latitude  $05^{\circ}17' 31.4$  and longitude  $007^{\circ}33' 08.3$  and on an elevation of about 65 meters above mean sea level.

Rainfall pattern within the catchment region is usually very high with annual average ranging from 2000mm to 3000mm (NIMET, 2018). Rainfall usually lasted for about 9-11 months on a yearly basis. The maximum possible insolation ranged from 800 – 900day/1, while the maximum possible sunshine hours varied between 11 and 12 hours.



**Figure 1.1: Location Map of Kwa Iboe River**  
 Source: Made from DEM (2014)



**Figure 1.3: Map of Kwa Iboe River Basin with Iboim Sub-Basin**  
 Source: Made from DEM (2014)

## 5. Materials and Methods

In order to gather appropriate information from respondents, which will aid in analyzing the impacts of Climate variability on influent streams in Kwa Iboe River Basin, Survey Design was adopted.

Data for this work were from primary and secondary source. Its primary data were obtained from the field specifically from structured questionnaire, direct observation and Participatory Rural Appraisal (PRA).

S/N	DATA	NATURE	VARIABLES	SOURCE
1	Demographic characteristics of the respondents	Primary	Sex, Age, Marital status, Education, Family size, Occupation	Structured Questionnaire
2	Extent of influent streams in the drainage basin	Secondary	Stream length, Stream number, etc.	Digital Elevation Model (DEM) of 1989-2018
3	Climate	Secondary	Mean annual rainfall (P) and Mean annual temperatures (T).	NIMET (2018), UNIUYO Metrological Station (2018), Ibom International Airport Metrological Station (2018)
4	Streamflow	Secondary	Stream discharge and Stream flow	Cross River Basin Development Authority (2018)

Descriptive statistics technique was employed to reduce the mass of raw data to a point it can be easily understood, while an inferential statistics technique was employed to test the hypothesis set for this study. The hypothesis stated to guide the work was:  
H<sub>0</sub>: There is no significant effect of climate variability on influent streams in the drainage basin

To test the hypothesis, the streamflow-precipitation-temperature relationship model using the ArcGIS Geostatistical Analyst Package was used to analyse the impact of climate variability on Influent Streams in the drainage basin. The streamflow-precipitation-temperature relationship is converted into a climate elasticity of streamflow index:

$$e_{P,\delta T} = \left( \frac{Q_{P,\delta T} - \bar{Q} \bar{P}}{P_{P,\delta T} - \bar{P} \bar{Q}} \right)$$

where:  $\delta T = (T - \bar{T})$  is the temperature departure.

The climate elasticity of streamflow index is a conditional precipitation elasticity of streamflow index accounting for the effects of temperature from temperature-precipitation plane. As a function of precipitation and temperature, it can be used to assess the climatic effects of joint precipitation and temperature changes on hydrological regimes at basin scales.

**6. Results and Discussion**

**Table 1.1 Mean Annual Streamflow, Temperature and Precipitation 1989 - 2019**

Year	Mean streamflow (mm)	Mean Precipitation (mm)	Mean Temperature (°c)
1989	2488	2247.79	26
2019	2533	3172.80	30

Source: CRBDA (2018), NIMET (2018), UNIUYO (2018), Ibom International Airport (2018)

The long-term mean annual precipitation, streamflow and temperature are 2710 mm (P), 2512 mm (Q), and 28°C (T), respectively. The annual percentage departure of streamflow, temperature and precipitation were calculated for the basin. Thus:



$$\left(\frac{P_t - P}{P} \times 100\%\right) = 17\%$$

$$\left(\frac{Q_t - Q}{Q} \times 100\%\right) = 0.8\%$$

$$\delta T = (T - \bar{T}) = 2^\circ\text{C}$$

This showed that a 17% decrease in precipitation resulted in a 0.8% decrease in streamflow at a mean temperature, but a 1.6% decrease in streamflow if the temperature increased by 4.0°C. Hence, Streamflow was positively related to precipitation but negatively related to temperature, with the annual percentage departure of streamflow greater than the annual percentage departure of temperature. Thus, streamflow was more sensitive to temperature changes when precipitation increased. If the precipitation remained the same, the streamflow would not respond to temperature change within a +1°C range. However, a 2°C increase in temperature alone resulted in a streamflow decrease of 0.8%.

Using the climate elasticity of streamflow index to compute the climate elasticity of streamflow for this scenario gave about 0.80.

That is:

$$e_{P,\delta T} = \left(\frac{Q_{P,\delta T} - \bar{Q} \bar{P}}{P_{P,\delta T} - \bar{P} \bar{Q}}\right)$$

$$e_{P,\delta T} = 0.80$$

The Climate elasticity of streamflow index of 0.80 ~ 1 showed a complete joint contribution of the two independent variables X<sub>1</sub> and X<sub>2</sub> (Precipitation and Temperature) on the shrinking/disappearance of streams. Meaning that Climate elasticity of streamflow was dependent on precipitation and temperature changes. The effect of climate change on streamflow depended on regional precipitation and temperature change. It usually increased with temperature as precipitation decreased, and decreased with temperature as precipitation increased.

### ***Climate Variability on Influent Streams In the Drainage Basin***

Findings on climate variability impacts on influent streams revealed that annual mean temperature and precipitation has change over the period. Between 1989 and 1999 the annual mean temperature was 28°C, but it has increased to 30°C between 2010 and 2019 (NIMET, 2018). Annual mean Precipitation also changed from 2247.8 mm between 1989 and 1999, to 3172.8 mm between 2010 and 2019 respectively. Number of rainy days has also decreased from 256 to 227 rainy days, but with higher intensity of rainfall. Climate variability impacts in the basin include increased temperature, higher intensity of rainfall (in the rainy season), drought, increased flooding and erosion. The study revealed that the amount of runoff is highly sensitive to changes in climate, even small changes in the amount of precipitation or in the temperature (affecting the amount of evaporation) can have a big influence on it. It was also revealed that changes in climate alter the suitability of a region for different species, and changes their competitiveness within an ecosystem so that even relatively small changes in the composition of the ecosystem.

The result of the hypothesis test showed that climate variability impacted significantly on influent streams. The results showed that climate elasticity of streamflow varied with temperature. It usually increases with temperature as precipitation decreases and decreases with temperature as precipitation increases. Increases in temperature always reduce streamflow for a fixed precipitation scenario; increases the climate elasticity of streamflow for decreasing precipitation and decrease the climate elasticity of streamflow for increasing precipitation scenario. This result meant that water availability in the basin was likely to be more critical in the future if current global warming projections are correct. The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC,2007) stated that for the next two decades, a warming of about 0.2°C per decade is projected for a range of IPCC Special Report on Emission Scenario (SRES). Even if the concentration of all greenhouse gases and aerosol had been kept constant at year 2000, a further warming of about 0.1°C per decade would be expected. Furthermore, based on recent global model simulations, nearly all land areas will warm more rapidly than the global average, and warming is expected to be greatest over land for most high northern latitudes (IPCC, 2007). This will have serious consequences for urban water supply, agricultural, industry development, and ecological systems.

## 7. Conclusion and Recommendation

Water resource planning and management increasingly need to incorporate the impacts of global climate variability in order to accurately predict its impacts on influent streams, as well as future water supplies. Findings demonstrated that streamflow is highly sensitive to changes in climate, especially increase in temperature. Further findings revealed that anthropogenic activities contribute greatly to the shrinking/disappearance of streams. The unsustainable exploration and exploitation of natural resources and lack of landuse planning along water ways is the major cause of influent streams. The availability of streams plays vital role in the sustainability of ecosystem stability and other environmental and socioeconomic functions. If neglected, influent streams can impact negatively on the availability of water for both domestic and industrial purpose, livelihood of the rural dwellers and the survival of aquatic species of fauna and flora.

## 8. References

- Abiodun, B. J., Salami, A. T. & Tadross, M. (2011) “ Climate Change Scenarios for Nigeria: Understanding Biophysical Impacts” , Climate Systems Analysis Group, Cape Town, for Building Nigeria's Response to Climate Change Project, Nigerian Environmental Study/Action Team (NEST), Ibadan, Nigeria
- Arnell, N. W. (2011) Uncertainty in the relationship between climate forcing and hydrological response in UK catchments, *Hydrol. Earth Syst. Sci.*, 15, 897– 912, <https://doi.org/10.5194/hess-15-897-2011>.
- Arnell, N. W. and Gosling, S. N. (2014) The impacts of climate change on river flood risk at the global scale, *Climatic Change*, 134, 387– 401, <https://doi.org/10.1007/s10584-014-1084-5>.
- Bawden, A. J., Linton, H. C., Burn, D. H., and Prowse, T. D. (2014) A spatiotemporal analysis of hydrological trends and variability in the Athabasca River region, Canada, *J. Hydrol.*, 509, 333– 342, <https://doi.org/10.1016/j.jhydrol.2013.11.051>.

- Berhane, F. G. (2011) “ Model based assessment of potential impacts of climate change on the flow of the main headwaters of the Nile River: Equatorial Lakes Region and Blue Nile Basins” , University of Connecticut Graduate School, Master's Theses Paper 167, [http://digitalcommons.uconn.edu/gs\\_theses/167](http://digitalcommons.uconn.edu/gs_theses/167)
- Chen, J., Brissette, F. P., Poulin, A., and Leconte, R. (2011) Overall uncertainty study of the hydrological impacts of climate change for a Canadian watershed, *Water Resources. Res.*, 47, W12509, <https://doi.org/10.1029/2011WR010602>,
- Chiew, F. H. S. (2006), Estimation of rainfall elasticity of streamflow in Australia, *Hydrol. Sci. J.*, 51, 613 – 625.
- Daily Nation (2009). Wild Animals at Risk as Rivers Dry Up. Retrieved on 30 August 2015 from [www.nation.co.ke/news/-/1056/638302/-/view/printVersion/-/cj3ngd/-/index.html](http://www.nation.co.ke/news/-/1056/638302/-/view/printVersion/-/cj3ngd/-/index.html)
- Dankers, R., Arnell, N. W., Clark, D. B., Falloon, P. D., Fekete, B. M., Gosling, S. N., Heinke, J., Kim, H., Masaki, Y., Satoh, Y., Stacke, T., Wada, Y., and Wisser, D. (2014) First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble, *P. Natl. Acad. Sci. USA*, 111, 3257– 3261, <https://doi.org/10.1073/pnas.1302078110>
- Datry, T., Arscott, D. and Sabater, S. (2011). Recent Perspectives on Temporary River Ecology, *Aquatic Science*, 73:453 – 57.
- Dooge, J. C. I., M. Bruen, and B. Parmentier (1999), A simple model for estimating the sensitivity of runoff to long-term changes in precipitation without a change in vegetation, *Adv. Water Resour.*, 23, 153– 163
- Dooge, J. C. I., M. Bruen, and B. Parmentier (1999), A simple model for estimating the sensitivity of runoff to long-term changes in precipitation without a change in vegetation, *Adv. Water Resour.*, 23, 153 – 163.
- Dooge, J. C. I., Sensitivity of runoff to climate change (1992): A Hortonian approach, *Bull. Am. Meteorol. Soc.*, 73(12), 2013– 2024
- Dugeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L. J. & Sullivan, C. A. (2005). Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. *Biological Reviews of the Cambridge Philosophical Society*, 81:163.
- Ekanem, E. M. (2010). Climate Characteristics. In: Usoro, E. J. and Akpan, P. A. (eds) *Akwa Ibom State: A Geographical Perspective. Enugu: Immaculate Publications Limited.*
- Fu, G., S. P. Charles, N. R. Viney, S. Chen, and J. Q. Wu (2007), Impacts of climate variability on streamflow in the Yellow River, *Hydrol. Processes*, 21, 3431 – 3439, doi:10.1002/hyp.6574
- Garcia, D. (2008). The climate security divides: Bridging human and national security in Africa. *African Security Review*, 17(3), 1–17. <http://doi.org/10.1080/10246029.2008>.
- Giorgi, F., M.R. Marinucci, G.T. Bates, and G. De Canio. (1993). “ Development of a Second-Generation Regional Climate Model (RegCM2).” Part I: Boundary-Layer and Radiative Transfer. *Mon. Wea. Rev.*, 121: 2794-2813.
- Graham, L. P. (2004). Climate Change Effects on River Flows to the Baltic Sea. *Journal of the Human Environment*, 33(4 – 5):235 – 248.
- Hubbard, C.M., and R.H. Hotchkiss. (1997). “ Hydrologic Modeling of the Missouri River in Climate Change Model.” Paper presented at the American Water Resources Association Symposium. Keystone, CO, June.
- IPCC (2007), Summary for policymakers in *Climate Change 2007: The Physical Science Basis. Contribution of working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M.

- Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. Miller, Cambridge University Press, Cambridge, U. K. and New York.
- IPCC (2014). Jimenez, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Conley, P. Döll, T. Jiang, and S.S. Mwakalila. Freshwater resources. In: *Climate Change 2014: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.) Cambridge University Press.
- Jalloh, A., Nelson, G. C., Thomas, T. S., Zougmore, R., and Roy-Macauley, H. (2013). West African agriculture and climate change: A comprehensive analysis. IFPRI Research Monograph. <http://doi.org/10.2499/9780896292048>
- Kuhnel, V., J. C. I. Dooge, J. P. J. O’Kane, and R. J. Romanowicz (1991), Partial analysis applied to scale problems in surface moisture fluxes, *Surv. Geophys.*, 12, 221 – 247.
- Kwabena, K. (2013) ‘ Impact of climate change on streamflow in selected river basins in Ghana’ , *Hydrological Sciences Journal*, 58:4, 2013, pp773-788.
- Larned, S. T., Datry T., Arscott, D. B. and Tockner, K. (2010). Emerging Concepts in Temporary River Ecology. *Freshwater Biology*, 55:717 – 738.
- Lettenmaier, D.P., A.W. Wood, R.N. Palmer, E.F. Wood, and E.Z. Stakhiv. (1999). “ Water Resources Implications of Global Warming: A U.S. Regional Perspective.” *Clim. Change* 43: 537-79.
- Malmqvist, B. and Rundle, S. (2001). Threats to the Running Water Ecosystems of the World. *Environmental Conversation*, 29:123 – 153.
- Manoj-Jha, T. Y., Richard, E. and Steve, M. K. (2003). *Impact of Climate Change on Stream Flow in the Upper Mississippi River Basin (UMRB)*, Cambridge University Press, Cambridge, UK.
- McCarthy, J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White (2001), *Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge Univ. Press, Cambridge, UK.
- Meehl, G. A., Stocker, T. F. and Collins, W. D. (2007). Global Climate Projections. In: Solomon, S., Qin, D., Manning, M, et al. (eds). *Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.
- Palmer, M. A.; Reidy-Liermann, C. A. and Nilsson C. (2008). Climate Change and the World’ s River Basins: Anticipating Management Options. *Front Ecol Environ*, 6:81 – 89.
- Park, J. Y., Park M. J., Ahn S. R., Park G. A., Yi, v., Kim G. S., R. Srinivasan, and Kim S. J. (2011) “ Climate change impacts on water quantity and quality for a mountainous dam watershed in South Korea using SWAT” , *Transactions of the ASABE* Vol. 54(5): 1725-1737
- Prudhomme, J. W., Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., Dankers, R., Eisner, S., Fekete, B. M., ColonGonzalez, F. J., Gosling, S. N., Kim, H., Liu, X., Masaki, Y., Portmann, F. T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L., and Kabat, P. (2014) Multimodel assessment of water scarcity under climate change, *P. Natl. Acad. Sci. USA*, 111, 3245– 3250, <https://doi.org/10.1073/pnas.1222460110>

- Revelle, R. R., and P. E. Waggoner(1983), Effects of a carbon dioxide induced climatic change on water supplies in the western United States, in *Changing Climate*, pp. 419– 432, Nat. Acad., Washington,D. C.
- Sankarasubramanian, A.( 2001), Hydroclimatology of the United States, Ph.D. dissertation, Tufts Univ., Medford, Mass.
- Sankarasubramanian, A., Vogel, R. M., & Limbrunner, J. F. (2001). Climate elasticity of streamflow in the United States. *Water Resources Research*, 37(6), 1771-1781
- Schaake, J. C., From climate to flow, in *Climate Change and U.S. Water Resources*, edited by P. E. Waggoner, chap. 8, pp. 177– 206, John Wiley, New York, 1990
- Steward, A. L., Marshall, J. C. and Sheldon, F. (2011). Terrestrial Invertebrates of Dry Riverbeds are not Simply Subsets of Riparian Assemblages. *Aquatic Science* 73:552 – 66.
- Udofia, E. S. and E. P. Udofia (2018) Disappearing Streams and Implication for Water Resources Utilization and Management in Middle Enyong Basin in Akwa Ibom State, Nigeria. *International Journal of Social Sciences, University of Uyo*.
- UNCCC (United Nations framework convention on climate change) (2003), Nigeria’ s first national communication. Ministry of Environment, Federal Republic of Nigeria
- Uniuyo Meteorological Station (2018), University of Uyo, Uyo, Akwa Ibom State, Nigeria
- Usoro, E. J. (2010) Relief of Akwa Ibom State. In Usoro and Akpan (eds). *Akwa Ibom State: Its Geographical Perspective. A Special Publication of the Department of Geography and Regional Planning, University of Uyo, Nigeria. Immaculate Publication Limited.*
- Vogel, R. M., Y. Tsai, and J. F. Limbrunner (1998), The regional persistence and variability of annual streamflow in the United States, *Water Resour. Res.*, 34(12), 3445– 3459
- Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R. and Davies, P. M. (2010). Global Threats to Human Water Security and River Biodiversity. *Nature*, 467:555 – 561.
- Williams, W. D. (1988). Limnological Imbalances: An Antipodean Viewpoint. *Freshwater Biology*, 20:407 – 20.
- Yates, D. N., and K. M. Strzepek (1998), Modeling the Nile basin under climatic change, *J. Hydrol. Eng.*, 3, 98 – 108.