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RIVER ONA DISCHARGE MODELING USING GIS AND LOGARITHMIC TRANSFORMATION MODEL

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Abstract: Climate unpredictability and change in climatic parameters have direct influence on environment and human existence. A negative change in the climate, always have its corresponding dysfunctional impacts on man and the ecosystem globally or locally leading to flooding, poor agricultural yields, famine, and even death at some stages. Knowledge and information on the climatic variation parameters in an environment is very vital for environmental study assessment and proper planning. Therefore, evaluating the effect of weather variability on discharge of Ona River in Ibadan cannot be under–estimated. A methodology to evaluate river discharge exclusively from remotely sensed data was developed. Water surface width and maximum channel width measured from satellite images of Ona River was coupled with channel slope data obtained from topographic maps created using Shuttle Radar Topography Mission (SRTM) were used to estimate the discharge. Landsat images were acquired for the years 1990, 2000 and 2015, which were used to determine anthropogenic activities. SRTM and Quick bird were used to model environmental changes and effects on the discharge of Ona River. The weather change effects on water discharge from Ona River in Ibadan was examined in three phases; site observation and data collection which was done in 2015 to get weather and discharge data of Ona River for each month, model simulation of temperature to determine discharge was done using regression model analysis. The rainfall distribution is being revealed to have strong effect on the discharge rate ($R^2 = 0.77$) and that of temperature on discharge rate of Ona River ($R^2 = 0.80$). In 2015, the influence of rainfall on discharge rate was stronger ($R^2 = 0.85$) while the discharge was 2.88m^3/s. The monthly temperature–discharge gives a negative relationship ($R^2 = 0.55$). There is strong negative relationship between vegetation and rainfall, –0.7. It has been projected that in 2028, the discharge rate will be reduced to about 2.17 m^3/s. There is evidence of dynamic responses of rivers to precipitation rate, which implied a significant response between rainfall and discharge and the negative effect of anthropogenic activities on rivers. This result can be used to predict the discharge of rivers given weather and environmental factors.

Keywords: River Ona; discharge; GIS; logarithmic; model

INTRODUCTION

Climate change has been discovered to be one of the biggest threats to humanity, human security in addition to producing adverse environmental conditions such as rising sea level, drought, crop failure, degradation of water/air quality, heat waves (Emmanuel et al., 2015). Climate change and its effect on river discharges has been studied in different ways, ranging from different spatial scales to time series of diversified lengths in many periods. Modeling climate change and its effect on river discharge is usually achieved either by collecting climate data such as temperature and rainfall in hydrological models or by varying climate data series with expected changes (Singh and Bengtsson, 2004). Change in weather data and weather uncertainties have direct effect on environment and human existence. A negative change in the state of weather causes a retrospective effect on man and the ecosystem both locally and globally. Weather is the condition or state of an atmosphere of a particular place at a given time (Ayoade, 2004). It may also be said to be the aspects of the atmospheric state which is visible and experienced and which affect human activities. The weather conditions of any particular can be explained and understood with the aid of some meteorological elements such as precipitation, temperature, winds, pressure, sky state and humidity, which are factors triggers and influence the process of the atmosphere (Gbadegesin et al., 2020). Climate change is an overtime change observed from either natural variability or human activities according to the United Nations of Intergovernmental Panel on Climate Change (IPCC, 2011). While weather on the other hand is the day–to–day condition of the atmosphere, and its variation over minutes to weeks, climate can be expressed by statistical weather analysis or information that describes the abnormalities of weather for a specified interval at a given location. The weather of a certain location is usually averaged over a 30–year period to determine its climate (Gutro, 2005). Climate and have different implications on the economy because of the different phenomena they represent (Fisher et al., 2012). According to IPCC (2011), assets and people in most countries are increasingly vulnerable to extreme weather. It was observed that the nature these extreme conditions have changed over the past 50 years, and may likely remain as this century progresses. However, there is uncertainty on exactly how the frequency and strength of extreme weather events might change. Adaptation measures taken in the near future therefore need to be resilient to a broad range of future climates (Howden, 2011).

In a recent assessment, IPCC (2011) mentioned that there is possibility that Africa will be warm during this century, noting that the drier subtropical regions will be warmer than the moist tropics. There is likelihood for the decrease in annual rainfall throughout most of the region, except the eastern Africa, where annual rainfall is projected to increase. These physical changes in the environment are expected to have devastating effect on agricultural production, such as millet and maize, which are staple foods. In addition, acute soil erosion and land degradation are also effect of land climate change to be considered (Oyiga et al., 2011). The effect of climate change may be weaker or stronger, permanent or temporary, favorable or adverse, harmful, primary (direct) or secondary (indirect) impact on soil processes. Among these processes soil moisture regime plays a distinguished role

(Adeoye et al., 2018) as it influences the amount of water supply in plants, the air and heat regimes, biological activity and plant nutrient status of soil (Montgomery, 2007).The erosion process, sediment delivery and sediment transportation are important components and measures of the functioning of the earth system. Erosion and sediment redistribution processes are the primary drivers of landscape development and vital in soil development (Philippe et al., 2014; Ojo, et al., 2018). Furthermore, high sediment loads can result in pollution and habitat degradation in river system (Islam and Tanaka, 2014). For instance, reservoir capacity of Awara dam has greatly reduced due to continuous sedimentation and siltation. There have been struggles in most countries because of water stress emanating from water borne sewerage, irrigation demands and industrial pollution. These pressures will be significantly exacerbated by climate change, which in reduced rainfall and increasing temperatures for many regions, also reducing the quantity of water available for drinking, household chores, agriculture and industry purposes. The more the need for water due to climate change, the more effective balancing water demands will become so important, most especially in areas where there are pressing demands for industrial uses over other uses like drinking supplies. High temperatures affect the quantity of runoff that negatively, hereby, reducing the quantity of groundwater also which is the major source of water supply in some parts of the nation. Similarly, reduced rainfall, especially in the north would further compound the inability of the zone to meet people's water demand (Idogho et al., 2014). In Africa, several factors are responsible for the variability in weather, one of it is deforestation. In addition, the agriculture and industry that replace the forests often cause an extra problem by producing carbon emissions of their own (Chakravarty et al., 2012). Another factor is the growing population, as the population grows, there are more people who need food, livestock and energy, and this increased demand leads to increased emissions (McMichael et al., 2007). According to Heinrich (2009) the northern part of Nigeria may increase its dependence on ground water sources because of low rate of precipitation experienced unlike the south–western Nigeria.

APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM (GIS) TO WATER RESOURCES

GIS is a very important tool used to address various water resources related issues like the quality of water, ground water contamination, ground water movement, river restoration, flood prediction and management on a local, regional, national or even global scale (ESRI, 2012). GIS can analyze the current situation, model and stimulate different scenarios for predicting the future, project new information to enhance decision–making and watershed management (Yoo et. al., 2004). It can also be employed in making a suitable decision in critical scenario, evaluating the effects of land use/cover, soil type, vegetation, topography, water quality and geology. Hydrology is a common field that recently employed GIS and Remote Sensing (RS) to tackle different issues within the field. There is mainly as a result of its integration can help the hydrological cycle and all related processes. In addition, it could enhance the possibility of a three dimensional approach for distributed models. GIS has a great ability to integrate data from multiple sources as long as they all have the same spatial reference. For instance, it can combine data from sources such as boreholes and wells, subsurface isopach maps, structure contour, surface geology maps, and satellite imagery. This ability allows all of these data to be used simultaneously to develop a more comprehensive model. Such models could assist geographers to gain a deeper understanding of the movement of different surface (or subsurface) waters and their interactions (Ziliaskopoulos and Waller, 2000; Olaniyan, et al., 2015).

GIS system uses data acquired from Remote Sensing and other sources to build new geo–referenced databases in specific referable forms. Within the map conversion process, some cells might represent pits or holes. These cells should be removed before running the model otherwise; water would accumulate in these cells when drainage patterns are being extracted. The whole map forms a stream network, which will define the flow direction and ultimately determine the outlets of the basin. Simulated runoff can be compared to the measured runoff at basin level for return periods of 10 and 50 years. However, the results often indicate that the generated model is not biased in over–predicting /under–predicting the runoff. Baiyinbaoligao et. al. (2011) and Olaniyan, et al., (2015) employed GIS for modeling the rainfall–runoff process in the Kuronagi River based on two rainfall stations. Since rainfall–runoff could be modeled based on different methods, they engaged the distributed Kinematic Wave hydrological model to calculate the two rainfall–runoff events in 2005 and 2006. They used ESRI's Arc View version 8.3 and its Spatial Analyst extension module to carry out the flow direction, flow accumulation, and stream network as features. A 50 m DEM spatial data issued by Japan Geographical Survey Institute in 1996 was used to produce the digital basin of the Kuronagi River (Baiyinbaoligao et. al., 2011).The approaches vary from a simple sensitivity analysis of hydrology to the changes observed in climate inputs to the study of palaeo climatic data, spatial shifting of current climates towards polar region. Because of its physically based nature, the latter approach is arguably the most attractive. Therefore, this study aimed at determining the weather change effects on water discharge from Ona River in Ibadan in three phases; site observation and data collection between 1990 and 2000, predicted for some years and resulted into maps.

METHODOLOGY

The method used for this work involved GIS tools in the analysis and evaluation of rainfall and temperature effect on discharge of Ona River. In–situ analysis was done, alongside extraction of images through Quick bird, Landsat and DEM of the Ibadan for previous years before 2015.

— The Study Area

Spatially, the study area has a tropical wet and dry climate and is strongly influenced by the West African monsoon climate, marked by a distinct seasonal shift in the wind pattern (Odewunmi et al, 2013). Ona River is one of the major rivers in Ibadan, South Western, Nigeria and lies between Latitude 7° 15′ 49″ and 7° 45′ 21″ N longitude 3° 57′ 58″ and 4° 08′ 20″ E (Andem, et. al., 2012; Bello et al., 2019). The river has a length of about 8 km and an area of about 28.5 Km^2 and it flows through the low–density western part of Ibadan. The river flows in a north–south direction from its source at Ido Local Government Area where it is dammed and flows through Apata Ganga (Ibadan South–West Local Government Area) to Oluyole Local Government (Andem, et. al., 2012). Figure 1 depicts the study area in relation to Oyo State, Nigeria.

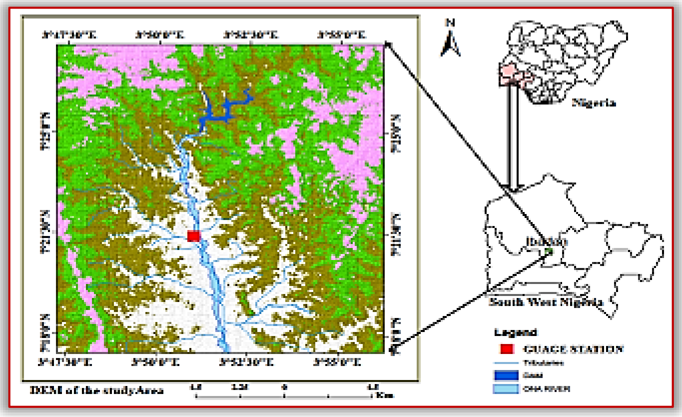

Figure 1: Map of Study Area in relation to Oyo State, Nigeria (adapted from Andem, et. al., 2012)

— Data Acquisition

The data used for this study are temperature, rainfall and discharge data between 1990–1999 and were obtained from meteorological station of Forestry Research Institute of Nigeria (FRIN), Ibadan office. The discharge data for 1990 to 1999 were obtained from Eleyele Dam gauge station. The River Discharge rate of 10 years (1990 to 1999) were used due to its availability, while an in–situ discharge data of 2015 were collected at a distinct point along the river course. Satellite images; Landsat, Shuttle Radar Topography Mission (STRM), and Quick bird were obtained and utilized to model environmental changes and their effects on the discharge of Ona River. The Landsat image was used to determine anthropogenic activities within the study area. The Digital Elevation Model (DEM) was used to show the slope and flow direction of the river and its distributaries, while the Quick bird image was use to delineate the study area.

— Methods

The methods used to include data preparation, image processing, mapping, and modeling as outlined by Otieno et al., (2013).

— Data preparation

Ona River basin was generated using Landsat images covered by path 191 and row 55. The providers; NASA have already rectified these satellite images used for this study, while the downloaded DEM and Landsat images of the study area were clipped into a shape file.

— Image Processing

To process the images, the spectral respond pattern was first developed for easy identification of remotely sensed features using IDRISI 17.0 software. A simultaneous query of all the images included in a raster image group file, in order to obtain quantitative information from images, digital number was converted to physical quantities, radiance and brightness temperature.

$$L\lambda = \left(\frac{L_{MAX}\lambda - L_{MIN}\lambda}{Q_{CAL}\lambda}\right) Q_{CAL} + L_{MIN}\boldsymbol{\lambda} \qquad (1)$$

where;

$L\lambda$ = Spectral radiance at the sensor's aperture [W/ (m^{2}sr μm)]

The above expression does not consider the atmospheric effects, therefore there was need to convert images from radiance to reflectance measures, using equation 2 (Gyanesh et al, 2009).

$$\rho\lambda = \frac{\pi.TOAr.d^2}{E_{SUN}\lambda.Cos\theta_{sz}} \qquad (2)$$

where;

$\rho\lambda$ = Planetary TOA reflectance (unit less),

π = Mathematical constant approximately equal to 3.14159 (unit less),

$L\lambda$ = Spectral radiance at the sensors aperture [w/ (m^{2}sr μm)],

d^2 = The earth–Sun distance (Astronomical unit),

E_{SUN} = Mean exoatmospheric solar irradiance [w/ (m^{2}sr μm)],

θ_{SZ}= the solar zenith angle (degree),

The cosine of this angle is equal to the sine of the sun elevation θ_{SE},

Therefore, $\theta_{SZ} = 90 - \theta_{SE}$.

— Prediction of Discharge using Logarithmic Transformation Model

To project temperature into the future year 2028, logarithmic transformation model of Brian Field et al, 1993 was used:

$$\log_e P((t-n)) = \log_e B + n\log(1+r) \qquad (3)$$

To project discharge into the future using equation 3.4 (Brian et al, 1993).

$$P_{(t-n)} = (1+r)^n P_{(t)} \qquad (4)$$

where;

$P_{(t-n)}$= the discharge to be forecast at time t+n

$P_{(t)}$= the discharge at time t – the base year,

r = annual growth rate

The ratio K was calculated using equation 5

$$k = \frac{P_{(t-n)}}{P_t} \qquad (5)$$

The mean annual rate value r is 0.00425 using the equation 3.6

$$r = \text{antilog}\{\frac{\log P_{(t+1)} - \log P_{(t)}}{n}\} - 1 \qquad (6)$$

RESULTS AND DISCUSSION

The discharge in–situ measurement of River–Ona in 2015 is as shown in Table 1. The discharge between January to March and October to December are relatively low compared to the months, but January and February remained constant because the depth is also constant due to lack or inadequate precipitation. It was observed that the discharge reduced in August, which is meant to be one of the peak periods, this is traceable to seize in rain during the period but the discharge increased in September as the discharge measurement were affected by the depth, width area and distance. The time depends on the depth since the width (8m) and distance (3m) remained constant, the more the depth, the lesser time taken for the float to get to the 3m mark. The average discharge data and average weather data between 1990 and 1999 as displayed in Table 2. The rate of discharge measured in 1996 and 1999 were the highest due to the high rainfall observed in those years, 1990 was a drought year and the corresponding discharge (0.59) was low also, also 1998 whose discharge was 2.05 m^3/s. There is an increase in the discharge as 2015 which was collected as 2.88 m^3/s.

Table 1: Discharge in–situ measurement of River–Ona (2015)

Date	Depth (m)	Width (m)	Area (m^2)	Distance (m)	Time (s)	Velocity(m/s)	Discharge (m^3/s)
Jan	1.2	8	9.6	3	12.1	0.24	2.30
Feb	1.2	8	9.6	3	12.1	0.24	2.30
Mar	1.25	8	10	3	11.2	0.26	2.60
Apr	1.28	8	10.24	3	10.8	0.28	2.84
May	1.4	8	11.2	3	9.42	0.318	3.56
Jun	1.5	8	12	3	9.12	0.33	3.96
Jul	1.59	8	12.72	3	9.0	0.33	4.239
Aug	1.48	8	11.84	3	10.92	0.274	3.253
Sept	1.52	8	12.16	3	9.12	0.33	4.013
Oct	1.11	8	8.88	3	12.46	0.241	2.138
Nov	0.96	8	7.68	3	13.1	0.229	1.759
Dec	0.92	8	7.36	3	13.7	0.219	1.612

Table 2: Discharge and Weather Data of the study area 1990 to 1999

Date	Discharge (m^3/s)	Temperature (^0C)	Rainfall (mm)
1990	0.59	24.33	12.25
1991	0.71	23.12	398.77
1992	0.48	24.75	97.83
1993	0.48	24.59	131.23
1994	0.39	25.90	91.3
1995	0.78	22.59	422.6
1996	0.83	22.32	525.5
1997	0.77	22.17	413.33
1998	0.38	25.17	90.68
1999	2.05	21.83	556.71

— Modeling the Relationship between the Weather Elements and Discharge

To model the relationship between discharge and weather elements like temperature and rainfall, the variables were regressed and the discharge served as the dependent variable all through. The R^2 values of the regressions in Figures 2, 3, 4, 5and 6 show good fits. 77% of the variation in discharge of Ona River is explained by the independent variable; rainfall as shown in Figure 2.

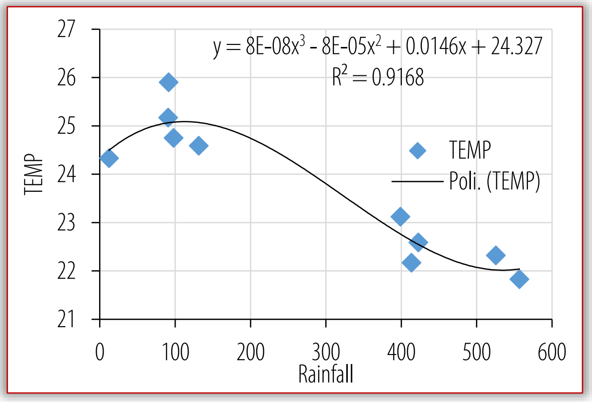

Figure 2: Temperature and rainfall Relationship

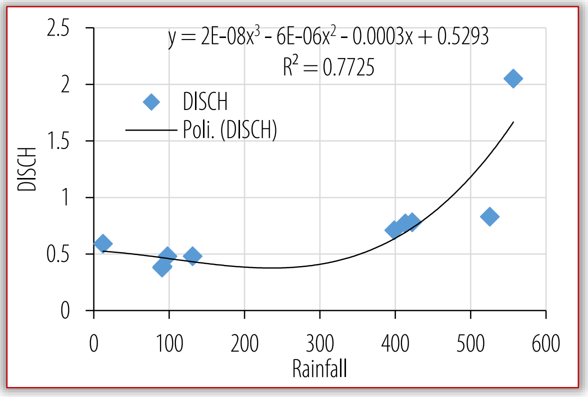

Figure 3: Rainfall and Discharge Relationship

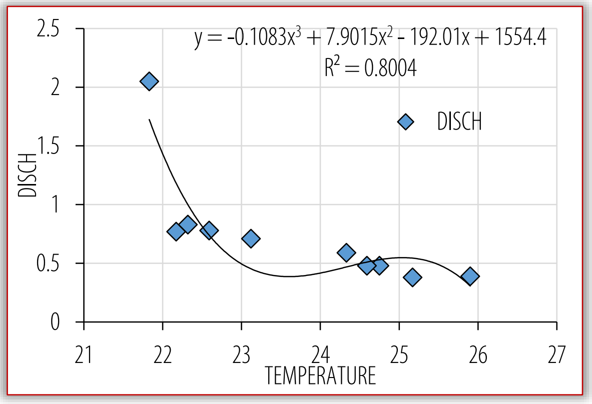

Figure 4: Temperature and Discharge Relationship

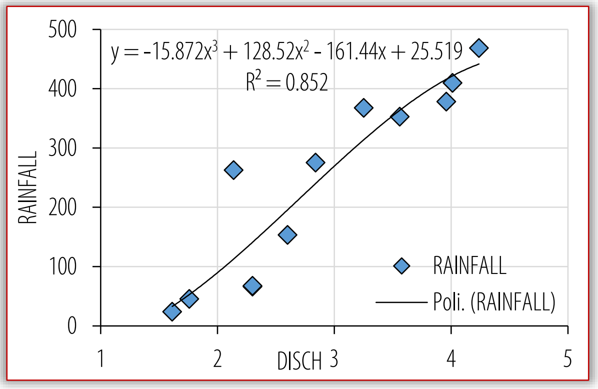

Figure 5: 2015 Monthly Rainfall–Discharges

The effect of temperature as displayed in Figure 3 is stronger with about a negative value of 80%. Result also shows that a strong negative relationship exists between temperature and rainfall distribution.

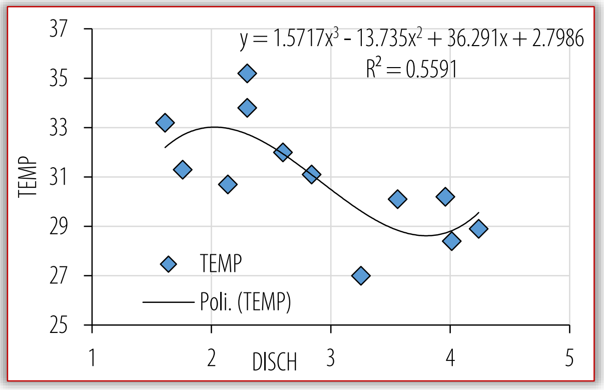

Figure 6: 2015 Twelve Months Temperature–Discharge Observations

The monthly discharge and weather parameters of 2015 regressions give strong positive relationship between rainfall and discharge, but negative relationship between temperature and discharge.

Temperature and rainfall relationship is $y = 8E–08x^3 – 8E–05x^2 + 0.0146x + 24.327$ with $R^2 = 0.9168$ as shown in Figure 2, while Figure 3 show the rainfall and discharge relationship of $y = 2E–08x^3 – 6E–06x^2 – 0.0003x + 0.5293$ with $R^2 = 0.7725$. Temperature and discharge relationship yield $y = –0.1083x^3 + 7.9015x^2 – 192.01x + 1554.4$ with $R^2 = 0.8004$ as displayed in Figure 5, while the 2015 Monthly Rainfall–Discharge gavey $= –0.1083x^3 + 7.9015x^2 – 192.01x + 1554.4$ with $R^2 = 0.8004$.2015 Twelve Months Temperature–Discharge observations gave y = 1.5717x3 – 13.735x2 + 36.291x + 2.7986 with $R^2 = 0.5591$ as shown in Figure 6.

— Significance F–value

In this study, the Significance F–values are 0.018697 and 0.019802 between temperature and discharge and between rainfall and discharge, respectively. Significance F shows that the results are reliable (statistically significant) since these values are less than 0.05, therefore result can be said to be good enough.

— Projection of Discharge using Geometric Trend Model

The projected temperature for 2028 is as shown in the Table 3. Applying equations 4, 5 and 6, the temperature was predicted to rise up to about 35.02°C, substituting this in equation 7 as **t** it was possible to determine the future trend of Ona River discharge for another 13 years. The projection gives a discharge value of 2.17m³/sby year 2028. There is a decrease when compared with the 2015 discharge; this may not be unconnected to loss of water from the river due to higher evaporation rate that might be caused by expected increased temperature.

$$Q = 11.668 - 0.2713t \quad (7)$$

Table 3: Projected Temperature for 2028

Date	Mean temperature	Ratio(k)	Annual Rate (r)
1989	23.33	1.3	0.002
2002	30.22	1.07	0.006
2015	32.40	1.08	0.005
2028	35.02	–	–

DISCUSSION

The effects of weather variation are obvious on River Ona and its tributaries are because of increase in the amount of rainfall and temperature thus resulting to higher annual river discharges over the years. Therefore, gradual decrease in rainfall over the years consequently leads to decrease in the mean annual river discharges, this implies that river discharges increase because of wetter climate (higher temperature and higher rainfall amount).

These results correspond with the results by Arnell (2002), Singh& Bengtsson (2004) and Olaniyan et al., (2015) stating that increment of precipitation is primarily due to discharge–runoff rather than evaporation, because the amount of evaporation is nearly constant due to the already saturated land surface condition.

The study by Arnell (2002) and Adewale et al., (2010) concluded that the effects of climate change on river discharges in the scenario period would be influenced by changes in the use of water affecting the hydrological system. This will probably increase the actual evapotranspiration, Ea and reduce river discharges from the affected areas (Brooks, 1983; Liu et al., 2005; Bello et al., 2019).

The rate of annual discharges will increase the width and depth of natural watercourses by increasing erosion according to regime theory (Ojo, et al., 2018). It could also lead to the damage the drainage networks. It could also increase the fluxes of nonpoint source pollution and sediment to the river channel and this can increase flood frequency and flood risk.

Over the years, discharge–runoff severity increases and the drainage network in River Ona is badly affected, as increase discharge will cause more floods, which would have some effect on farming along the riverbanks. Mean annual river discharge increased because of higher intensity of rainwater to the river (Otieno, et al., 2013); therefore, there is need for preventive measures to be taken to reduce flood risk.

CONCLUSIONS

This study evaluated the effect of temperature and rainfall variation on the flow of Ona River using Remote Sensing and Geographical Information System (GIS) techniques. The results revealed that the dynamic response of rivers to precipitation rate is higher during the raining season, as there is a significant relationship between rainfall and river discharge, thus affecting the discharge rate of the river.Continous data collection of discharge, temperature, rainfall, and other parameters should be carried out by all hydrological stations in order to help environmental scientists and policy makers to regulate such activities, which could affect the river course. Further studies can be carried out to establish the impact of extreme weather variations on the river discharge. The findings from this study used to predict the discharge of a particular river given the weather and environmental factors.

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