Estimation of stream discharge of ungauged basins using NRCS-CN and remote sensing methods: A case study of Okhuwan and Okhaihe catchments, Benin City, Edo State, Nigeria

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The study aims to utilize the NRCS-CN and remote sensing methods in estimating streamflow of Okhuwan and Okhaihe catchments. Remote sensing data, coupled with GIS techniques were used to estimate seasonal rainfall and streamflow. Measured rainfall data was collected from the Nigerian Meteorological Service, while field measurement of streamflow was carried to generate baseline data. Measured rainfall and streamflow were correlated with estimated rainfall and streamflows as indicators of our model effectiveness. The coefficients of determination between estimated rainfall and measured rainfall ranged from 0.67 to 0.77 in Okhuwan basin and from 0.71 to 0.75 in Okhaihe basin, suggesting good correlation in both data as well as suitability of use for streamflow estimation. Stream flow rises sharply with the onset of the rainy season in April and persists till July and August with streamflow, reaching a maximum of 174.0 and 237.3 m³/s in Okhuwan and Okhaihe, respectively. Regression residuals were within small range, an indication that measured and estimated data exhibit some closeness particularly in low discharge values. Very strong positive relationship was observed between measured and estimated streamflow. Overall findings showed that in the absence of hydrological information, regional models can serve for data generation.

Key words: Streamflow estimation, River Basin, hydrological data, NRCS-CN, river flooding.

INTRODUCTION

Increase in the frequency and magnitude of river flooding is a common climate-related hazard. According to the Intergovernmental Panel on Climate Change (IPCC), recent climate change has had a significant impact on the magnitude and frequency of extreme hydrological events in many regions of the world (IPCC, 2014). Eccles et al.
(2019) found that tropical and subtropical regions are often subjected to some of the worst flooding and this may be exacerbated under climate change. Developing countries in these regions are worst hit due to poor infrastructure, government instability and poor health care system. In Nigeria, for example, the growing population and urbanisation are putting increased pressure on available water resources such that there is competition across multiple sectors for water resources and access to water is restricted even in areas of the country where water is abundant (Nwankwoala, 2014; Merem et al., 2017; Ngene et al., 2021). Surface water pollution due to urban expansion and urban storm water runoff have also been on the increase, thus making surface water unsafe for human (Butu et al., 2020a, b; Ezemonye et al., 2016a). Studies have reported high prevalence of waterborne diseases such as cholera, diarrhoea, dysentery, hepatitis, etc., among Nigerians (Oguntoke et al., 2009; Raji and Ibrahim, 2011; Taiwo et al., 2012). The intensity of extreme precipitation events is predicted to increase throughout most parts of the world under climate change, potentially leading to an increase in the magnitude of extreme flows (Grosman et al., 2005; Eccles et al., 2019; Maghsood et al., 2019). Rainfall variation is projected to continue to increase. Precipitation in southern areas is expected to rise and rising sea levels are expected to exacerbate flooding and submersion of coastal lands (Akande et al., 2017; Ebele and Emodi, 2016).

Benin city which is characterized by tropical climate has also witnessed an increase in flood incidents and gully erosion since the late 20th century, which marks period of unprecedented increase in global temperature (Morice et al., 2012; Hegerl et al., 2018). Emeribe et al. (2021) found that the problem of flood in the city is compounded by improper solid waste management and unplanned housing and the ranges from submergence of physical infrastructures, loss of agricultural lands/farms. To tackle the problem of climate-change related flooding, adequate streamflow records are necessary for the design of water resources projects and water management in river basins (Nrunthya and Srinivas, 2015, Ezemonye et al., 2016b; Fasipe and Izinyon, 2021). Regrettably, streamflow data for most basins in most developing countries are either unavailable or inadequate at sites selected for planning water resources projects (Young, 2006; Mishra and Coulibaly, 2009; Razavi and Coulibaly, 2013; Ezemonye et al., 2016b). According to Sivapalan et al. (2003), ungauged basins are ones with inadequate records (in both data quantity and quality) of hydrological observations.

Fasipe and Izinyon (2021) have attributed it to poorly gauged river basins, low density of hydrological gauging stations, breakdown and lack of gauging equipment, inadequate trained manpower, vandalization of gauging instruments, insufficient funding for the sector, inaccessible sites, etc., present serious challenge to sustainable water resources planning, design, and management in developing countries including Nigeria. The implications are that most water resources projects in Nigeria fail to meet their long-term objectives. Faced with these challenges, scientists have developed alternative methods for estimating discharge data for ungauged basins, including extrapolation of streamflow records from the nearest, similar gauged catchment; regression-based techniques (usually employing climatic and drainage basin explanatory variables as part of a Regional Flood Frequency Analysis); and more sophisticated, physically-based hydrological models based on curve number (Ezemonye et al., 2016b). The Soil Conservation Service Curve Number (SCS-CN), now the Natural Resource Conservation Service-Curve Number (NRCS-CN) is the prominent and the most widely accepted amongst methods for estimating runoff over time (Mishra et al., 2003; SCS, 2004; Tirkey et al., 2014; Banasik et al., 2014; Verma et al., 2017). Curve number quantitatively describes land cover and soil condition that affects the runoff process. Other benefits of the curve number include convenience of its application and the capability of incorporating certain watershed attributes such as soil type, land use, antecedent moisture condition and other hydrologic conditions that have been enhanced with the use of remote sensing methods and GIS (Mishra et al., 2005; Sahu et al., 2012; Verma et al., 2017). Though, it has some weaknesses like having no provision for spatial scale effects, high sensitivity to low CN and antecedent conditions, it is still a commonly used method today in hydrologic and hydraulic studies (Singh et al., 2015), especially in developing countries where streamflow data availability remains a huge setback towards hydrological modelling and model development. The present study therefore aims at assessing the effectiveness of the regional NRCS-CN method in predicting streamflow at inadequately gauged Okhuwan and Okhai river basins in Benin City, Edo State.

MATERIALS AND METHODS

Study area

The study area is in Edo State, Nigeria and located in the tropical rainforest belt of Nigeria and so has abundant rainfall and high temperature (Figure 1). The rains are usually of high intensity with double maxima and a little dry season in August commonly referred to as “August Break” (Atedhor et al., 2011). Rainfall in the area is a result of the interaction between the tropical maritime and tropical continental air masses which meet along the Inter-Tropical Discontinuity (ITD) that mark the limit for the advance or retreat of either the rainy season or dry season. The ITD is usually at its farthest location near the coast around January but advances inland, as far north as southern Niger Republic around July/August. This is the period where every part of Nigeria is under the effect of
the rainy season. The annual rainfall amount in the area ranges from 1800 to 2780 mm (Oguntoyinbo, 1982) with an annual mean temperature of about 28°C (Iyalomhe and Cirella, 2018).

The area is underlain by deeply weathered sedimentary rock dominated by the Benin Formation (Ogunkule et al., 1980). This geological formation is generally characterized by top lateraled reddish brown clayey sand. It also has friable loose white sands, pebbly sandy and clay sands with basal ferruginised sandstone (Aziegbe, 2006). The soil of the area has been described by Odemero (1992) as dark reddish brown with a top cover of 0.0-50 cm which is very fertile. It can be described as sandy-loam with 75-80% sand, average of 7% silt and 13% clay. The tropical rainforest vegetation of the area is gradually being lost due to urbanization and agriculture (Odemero, 1992; Iyalomhe and Cirella, 2018), a development which can increase the volume and frequency of storm water runoff. The main drainage of the area comprises
Osiamo River and other minor streams.

Data collection

Rainfall data

Spatial rainfall data was collected from the Climate Prediction Centre of the United States Agency for International Development (USAID) for a period of 28 years (1990-2017). The data is a raster data in “bil” file format, which covers the African continent with the following extent: -20° to +55° longitudes by - 40° to +40° latitudes (Novella and Thiw, 2016). A reliability test for the data using Pearson’s product moment correlation was performed with conventional data collected from the Nigerian Meteorological Service (NIMET) for the same period. Thus, only points in the catchments with positive correlation coefficient (r) of 0.6 and above were chosen for analysis in this study, nine points in Okhawan Basin and eight points in Okhaihe Basin.

Field measurement of streamflow (Baseline data)

In order to assess the effectiveness of estimated streamflow, field measurement of streamflow was carried out for 12 months (January – December, 2017). Field measurement became necessary as available hydrological data for the study area was last collected in 2000 (BORBDA, 2000). This archival record was also characterized by missing data for most years. Gauge heights were established along accessible points downstream of the basin. The gauge height readings were plotted against discharge readings on a logarithmic scale to obtain a rating curve, where discharge values for the different gauge heights were obtained. The water stage was converted to streamflow graphically by the average curve fitting the scatter plot between water level (as ordinate) and discharge (as abscissa). The method considers discharge as a unique function of the stage (Braca, 2008). The choice of this method is based on the fact that the study basins are both a natural stream and is assumed to have uniform flow pattern. The ratings typically follow a power curve of the form given in Equation 1, according to Rantz (1982) and Herschy (1999).

\[ Q = C(h - \alpha)^{\alpha} \]  

(1)

where \( Q \) is the discharge, \( h \) is the stage and \( C, \alpha, \alpha \) are calibration coefficients. \( C \) is the discharge when the effective depth of flow (h-\( \alpha \)) is equal to 1; \( \alpha \) is the gauge height of zero flow; \( \alpha \) is the slope of the rating curve (on logarithmic paper); \( (h - \alpha) \) is the effective depth of water on the control.

Catchment delineation and characteristics

The topographical features of the study area such as basin area, slope, elevation and land use classification and drainage characteristics were extracted from the Digital Elevation Model (DEM) of the catchment using ArcGIS 9.3 software. The SRTM DEM data, of 30-m spatial resolution was downloaded from the earth explorer website (http: //earth explorer. usgs.gov/). The ‘Hydrological Tool’ from the Spatial Analyst module in ArcMap environment generated the catchment hydrological features. The first step was to fill all the voids within the DEM raster data followed by the flow accumulation and flow direction amongst others in the ArcMap.

For the unavailability of soil database for Edo State, the Harmonized World Soil Database (HWSD) was used to obtain soil texture attribute, a requirement to generate Runoff Curve Number of SCS Curve. The Harmonized World Soil database is a product of the Food and Agriculture Organization (FAO) of the United Nations and the International Institute for Applied Systems Analysis (IIASA) in partnership with the European Soil Database (ESDB). The dataset is available in ArcGIS “dbf” format.

Stream flow estimation by computation method

To achieve spatial patterns in seasonal stream flow, GIS tool was used to generate points along the river basins and then assigning to these points, town names closer to them. The Soil Conservation Service (SCS)-curve number (CN) method was adopted to obtain streamflow values at different points on the streams in the study area. The SCS-CN method is based on the water balance equation and on the fundamental assumption that the ratio of runoff to effective rainfall is the same as the ratio of actual retention to potential retention (Soulis et al., 2009).

Determination of curve number factor

The first step in SCS-based method of estimating stream flow is to compute the coefficient of runoff which is based on 4 factors (Table 1). All factors are usually given scores which determine the extent to which the basin accommodates the runoff, also known as runoff curve number (Table 1). The remotely sensed data (raster file format) and GIS were used to generate information on land use, land cover, hydrological soil type and ground surface condition of the study area. The data were integrated into a GIS environment, to obtain runoff curve numbers for the streams at different points along the basins, which form input data for the SCS model. In computing the curve number, land use, soil texture, elevation/slope and storage were overlain to determine the CN values for each point along the streams. The generation of these layers and the overlaying operation were done by using ArcGIS.

Method for calculation of stream flow

The first step in estimating streamflow using the SCS-CN method is to calculate the depth of excess rain as given in Equation 2:

\[ Q_d = \frac{(P_t - I_a)^2}{P_t - I_a + S} \]  

(2)

where \( Q \) is the depth of excess rain (cm), \( P_t \) is the total rain (cm), \( I_a \) is the starting absorbance (mm), and \( S \) is the highest potential of flow delay. A constant value of \( I_a = 0.2S \) was chosen according to Hawkins (1993). Thus, Equation 2 can be re-written as shown in Equation 3:

\[ Q_d = \frac{(P_t - 0.2S)^2}{P_t - 0.8S} \]  

(3)

where \( S \) can be calculated from CN through the formulation of
Table 1. Runoff Curve Number or SCS Curve Number.

| Characteristics | I Extreme CN (100) | II High CN (75) | III Normal CN (50) | IV Low CN (25) |
|-----------------|-------------------|-----------------|-------------------|----------------|
| Relief (A)      | Mountainous area  | Hilly with slope| Rolling terrain    | Relatively flat|
|                 | Slope >30% (30-40)| Slope 10-30% (25-32) | Slope 5-10% (17-24) | Slope 0-5%(5-16) |
| Soil Infiltration (B) | Rocky, thin soil mantle (17-20) | Clay, slow infiltration (12-16) | Prairie soil, loam, deep soil mantle(7-11) | Sand, deep soil, rapid infiltration (2-6) |
| Vegetative cover (C) | No effective cover, plant cover bare (17-20) | Less than 10% of area under good cover (12-16) | 50% of area in good grassland, woodland (7-11) | 90% of area in good grassland. Woodland (2-6) |
| Surface storage (D) | No surface detention, no pond (17-20) | Small drainage way (12-16) | Lakes, ponds and marshes less than 2% (7-11) | Large number of lakes, ponds and marshes (2-6) |

CN = A+B+C+D = 100.
Source: Schwab et al. (1971).

Equation (4):

\[ S = 25.4 \left( \frac{1000}{CN} - 10 \right) \]  

NRCS-CN method for estimating peak discharge \( Q_p \)

The CN method is used for estimating peak runoff using the results from numerous mid-sized and homogenous catchment. The method has also been adopted by various authors and is known to have wider applicability (Nadal-Romero et al., 2007; Soulis and Valiantzas, 2013; Tirkey et al., 2014; Singh et al., 2015; Verma et al., 2017). The SCS-CN equation was originally developed by the USDA soil conservation service. However, owing to observed shortcomings, such as not being able to effectively predict seasonal discharge, researchers have attempted to modify the method (Mishra et al., 2005; Singh et al., 2015; Verma et al., 2017) by including other parameters such as length, on the assumption that season affects drainage density hence the adoption of NRCS-CN graphical method. This method describes peak runoff as Equation 5:

\[ Q_p = q_u A Q_d \]  

where \( Q_p \) is peak flow in m³/s, \( q_u \) is unit peak discharge in m³/s per cm of runoff per km² of area, \( A \) is area of the catchment in km² determined from DEM by using GIS method and \( Q_d \) is the 24-h rainfall excess in cm for a given return period and the computation is shown in Equation 2.

The parameter \( q_u \) can be obtained by the empirical equation established by NRCS (SCS, 2004) as shown in Equation 6:

\[ \log q_u = C_0 + C_1 \log t_c + C_2 (\log t_c)^2 - 2.366 \]  

where \( t_c \) is time of concentration in hours; \( C_0, C_1 \) and \( C_2 \) are regression constants obtained from NRCS standard tables in which \( I_a \) is the initial abstraction, evaluated according to Equation 7:

\[ I_a = 0.2 S \]  

when \( I_a/P < 0.1 \), values of \( C_0, C_1 \) and \( C_2 \) corresponding to \( I_a/P = 0.1 \) should be used and if \( I_a/P > 0.5 \), values of \( C_0, C_1 \) and \( C_2 \) corresponding to \( I_a/P = 0.5 \) should be used. For the study rainfall type, II applicable to tropical environment SCS (2004) was used.

Computation of time of concentration

Time of concentration \( t_c \) was computed by using the equation of kirpich (1940) given by:

\[ t_c = 0.0078 \frac{L^{0.0074}}{S^{0.385}} \]  

where \( t_c \) is in hours, \( L \) is the length of catchment in feet which is determined from the DEM and \( S \) is slope in gradient.

Test for reliability of estimated stream flow

To assess the reliability of the estimated runoff using the SCS-CN, the Pearson’s Product Moment Correlation statistic was performed at 0.05 level of significance for the degree of association between estimated values and measured stream flow data. The equation is given as follows:

\[ r_{xy} = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} \]
Table 2. Correlation of NIMET seasonal rainfall data with estimated rainfall data in Okhuwan Basin.

| Name of town | R  | R^2  | Adjusted R^2 | Standard Error | AVOVA F | Significant F |
|--------------|----|------|--------------|----------------|---------|---------------|
| Ekho         | 0.82 | 0.67 | 0.65        | 42.9           | 20.99   | 0.001         |
| Adoa         | 0.84 | 0.71 | 0.67        | 39.9           | 24.20   | 0.001         |
| Aduhanhan    | 0.85 | 0.73 | 0.70        | 39.8           | 26.73   | 0.0004        |
| Ugonoba      | 0.85 | 0.72 | 0.70        | 39.9           | 26.73   | 0.0004        |
| Oyaga        | 0.88 | 0.77 | 0.75        | 34.6           | 33.21   | 0.0002        |
| Evbouhuan    | 0.91 | 0.82 | 0.81        | 29.4           | 48.50   | 0.00001       |
| Abunwa       | 0.85 | 0.73 | 0.70        | 70.1           | 26.70   | 0.0004        |
| Udeni        | 0.85 | 0.72 | 0.70        | 70.1           | 26.70   | 0.0004        |
| Obadan       | 0.83 | 0.67 | 0.64        | 42.9           | 21.23   | 0.0009        |

Correlation and ANOVA, tested at 0.05 level of confidence.

Table 3. Correlation of NIMET seasonal rainfall data with estimated rainfall data in Okhaihe Basin.

| Name of town | R  | R^2  | Adjusted R^2 | Standard Error | AVOVA F | Significant F |
|--------------|----|------|--------------|----------------|---------|---------------|
| Okeze        | 0.84 | 0.71 | 0.68        | 39.92          | 24.19   | 0.0006        |
| Idumwhuna    | 0.85 | 0.73 | 0.70        | 38.38          | 26.67   | 0.0004        |
| Igueowieoba  | 0.85 | 0.73 | 0.70        | 38.37          | 26.67   | 0.0004        |
| Edopa/Odjeva | 0.84 | 0.71 | 0.68        | 38.20          | 24.70   | 0.0006        |
| Edumega      | 0.84 | 0.71 | 0.68        | 72.16          | 24.70   | 0.0006        |
| Ahor         | 0.84 | 0.71 | 0.68        | 72.16          | 24.70   | 0.0006        |
| Uhege        | 0.84 | 0.71 | 0.68        | 38.20          | 24.70   | 0.0006        |
| Ayen         | 0.86 | 0.75 | 0.72        | 35.54          | 29.36   | 0.0003        |

Correlation and ANOVA, tested at 0.05 level of confidence.

where $r_{xy}$ is the correlation coefficient, $x$ and $y$ are the 2 sets of observations.

All the analyses were performed by using mathematical tools in Excel spreadsheet at 0.05 level of significance (95% confidence level).

Test for significance of the correlation coefficient

To test the significance of the coefficient, this study employed the student's $t$ test, as follows:

$$ t = \frac{(\bar{x} - \bar{y})}{\sqrt{\frac{s_x^2 + s_y^2}{n + m}}} $$

(10)

where $\bar{x}$ and $\bar{y}$ are the means of the first and second datasets, respectively, and $m$ and $n$ are the number of observations in the first and second datasets, respectively. $S$ is the sample standard deviation (of the entire $m$ and $n$ observations).

RESULTS AND DISCUSSION

The results of the correlation analysis between the rainfall data from the USAID (CPC data) and the NIMET (point data) are presented in Tables 1 and 2. The correlation coefficients ($r$) are closer to +1, which signify that both variables move in the same direction. It also implies that these two variables have a very strong positive relationship which shows that the estimated seasonal rainfall and NIMET point data are strongly and positively related. The closer the value of $r$ is to 1, the stronger the linear relationship and vice-versa. Additionally, they are all significant at 0.05 significance level (Tables 2 and 3).

The coefficient of determination ($r^2$) is the determinable relationship and represents the percentage of variation in estimated values that can be explained by variations in NIMET data. Coefficient of determination values, ranged from 0.67 to 0.77 in Okhuwan and from 0.71 to 0.75 in Okhaihe, suggesting good correlation in both data. This might be attributed to the fact that the satellite estimated rainfall data of the USAID climatic Prediction Centre estimated for the area has been adequately verified for homogeneity by National Oceanic and Atmospheric Administration (NOAA) and the World Meteorological Organization (WMO) for consistency (Novella and Thiaw, 2016). Therefore, the estimated rainfall data are
considered suitable for the study. Curve number values of the study area are presented in Figures 2 and 3.

Predominant curve number values in the study area ranged from 26 to 48 covering about 83.97% of Okhuwan catchment and between 26 and 50 covering about 82.04% of Okhaihe catchment (Figures 2 and 3). This indicates that 42% of the catchments are heavily vegetated with the soils having very high infiltration capacity. That also showed the basins are in good hydrologic conditions and high vegetal cover, according to Verma et al. (2017). Vegetation root development improves the physical properties of soil, such as soil strength, structural stability, and aggregate stability, which can increase soil infiltration capacity, thus resulting in contributing to soil and water conservation (Martens, 2002; Casermeiro et al., 2004; Wang et al., 2016). This corroborates studies which have argued that the flow velocity, flow depth, Reynolds and Froude numbers

Figure 2. Curve number distribution for Okhuwan River Basin.
Figure 3. Curve Number distribution for Ohkaihe River Basin.

decrease with increasing grassland coverage, but increase the resistance coefficients (Wang et al., 2009; Xiao et al., 2009). For sparsely vegetated area, time for concentration is shorter and hence runoff moves downslope or ponds on the surface on level areas and most times are responsible for erosion. These catchment characteristics are very important as they influence the discharge characteristics of the catchments, such as discharge volume, rainfall amount, and time of concentration, runoff infiltration and peak flow. Hence, the
central and western parts of Okhuwan catchment, and the central and eastern part of Okhaihe catchment would generate more runoff due to its high CN values. The study area is predominantly loamy and sandy loam soil with small presence of clay, while 60.5% of the land use in Okhuwan catchment is predominantly light vegetation and farmland. The CN values of the study area also give some insight into the slope characteristic of the study area. The portions with strong slopes will lead to faster runoff flows which travel only a short distance before discharging into a stream. However, the portions with strong slopes are small in size and they have lower CN values covering less than 15% of the catchments. This conversely reflects Zhao et al. (2004) study that the faster the water flows across the land, the less time is available for infiltration, evapotranspiration, and surface storage. This leads to increased peak stream discharge owing to a

Seasonal distribution of estimated stream discharge

Mean seasonal distribution of measured and estimated stream discharges along the river stretches are presented in Figures 4 and 5. The mean value is based on monthly distributions of all the points in each river basin. The Figures reveals a rising limb which starts from April and reach saturation between June and July after provisions would have been made for evapotranspiration and moisture storage. This is then followed by runoff peak in July for Okhuwan basin and August in Okhaihe basin, accompanied by a sharp fall in runoff in October. Mean maximum streamflow values were 174.0 m$^3$/s (estimated), 321.8 m$^3$/s (measured) and 237.3 m$^3$/s (estimated) 310.8 m$^3$/s (measured) in decrease in lag time. Okhuwan and Okhaihe basins, respectively.
Table 4. Residuals of relationship between measured and mean estimated stream discharge values for all points (9 points) in Okhuwan Basin.

| Month | Measured discharge | Estimated discharge | Predicted discharge | Residual | Standard residual |
|-------|--------------------|---------------------|---------------------|----------|-------------------|
| Jan   | 79.034             | 66.50241813         | 85.70703808        | -19.20461994 | -1.691862288 |
| Feb   | 158.88             | 117.9326114         | 112.1065509        | 5.826060444  | 0.513256288    |
| March | 181.44             | 126.9293377         | 119.5655722        | 6.591067419  | 0.656722576    |
| April | 199.354            | 138.6958381         | 125.4884847        | 13.2073534   | 1.163523319    |
| May   | 220.544            | 143.7088837         | 132.4945423        | 11.21434137  | 0.987945677    |
| June  | 253.3116667        | 148.240402          | 143.3285282        | 4.911873829  | 0.432719529    |
| July  | 259.88             | 148.240402          | 143.3285282        | 4.911873829  | 0.432719529    |
| Aug   | 300.8233333        | 155.1381103         | 165.9811172        | -10.84300687 | -0.955232358   |
| Sept  | 251.57             | 130.7311387         | 142.7526803        | -1.21434137  | -0.095057291   |
| Oct   | 120.0666667        | 118.5275765         | 101.918727         | 6.50884956   | 1.463183666    |
| Nov   | 118.2433333        | 92.15021168         | 98.67083462        | -6.520622941 | -0.574444903   |
| Dec   | 65.95333333        | 76.1245069          | 81.38217236        | -5.257665378 | -0.463182599   |

Table 5. Residuals of relationship between measured and mean estimated stream discharge values for all points in Okhaihe basin (8 points across river basin).

| Month | Measured discharge | Estimated discharge | Predicted discharge | Residual | Standard residual |
|-------|--------------------|---------------------|---------------------|----------|-------------------|
| Jan   | 89.034             | 70.78484345         | 77.1551320          | -6.37028858 | -0.602715429 |
| Feb   | 118.88             | 93.4571220          | 99.94984166         | -4.693399362 | -0.444059036 |
| March | 121.44             | 102.9504214         | 99.94984166         | -2.69057291 | -0.283395409 |
| April | 159.354            | 125.8491147         | 126.6189344         | -0.769819765 | -0.072835358 |
| May   | 220.544            | 169.5802915         | 169.6606201         | 0.080310614  | 0.07958947    |
| June  | 243.3116667        | 201.8637189         | 185.6756101         | 16.18810879  | 1.531619362 |
| July  | 301.825            | 236.6248772         | 226.8344833         | 9.79039978   | 0.926306417   |
| Aug   | 310.8233333        | 237.2717251         | 233.1640023         | 4.107722743  | 0.386461611 |
| Sept  | 291.57             | 193.0025509         | 219.6210121         | -26.61846115 | -2.518466318 |
| Oct   | 95.47333333        | 84.9246112          | 81.68462452         | 3.23996669   | 0.306546547   |
| Nov   | 58.24333333        | 62.09263575         | 55.49666429         | 6.5957146    | 0.624068081   |
| Dec   | 45.95333333        | 42.46126954         | 46.85175343         | -4.390483889 | -0.415399137 |

Lowest stream flows were recorded in January for estimated (70.2 m³/s) and in December with streamflow amounts of 65.9 m³/s Okhuwan basin. In Okhaihe basins, the lowest streamflow volume was recorded in December, 45.9 m³/s (measured) and 42.5 m³/s (estimated). Both basins reached their field capacities in June and July and according to the Hortonian process, runoff will not occur until the soil reaches field capacity (that is, its maximum water holding capacity) (Horton, 1933). More so, Ayoade (1988) reported that only 50 to 60% of the water available for runoff in a given month actually runs off, while the remainder is delayed till the following month. The sharp recession in October is due to the decrease and cessation in rainfall as well as the low level of ground water contribution to total runoff owing to the geology of the study area. Aper (2006) also attributed this to high infiltration on the sedimentary formation (Benin Formation) which overlays the study area. The month of December marks the withdrawal of water from the basin as more water is withdrawn to meet vegetation water needs and evapotranspiration in the basin. Moisture deficit becomes significantly high in the study area from December to January which also corresponds to the peak of the dry season.

The observed variations in mean measured and estimated streamflow volume may be attributed to the varying effects on basin scale factors on runoff generation such as rainfall, basin slope, vegetation cover, basin area (Aper 2006, Ezemonye et al., 2016b). Although for low streamflow months, the values (measure and estimated) are closer compared to high discharge months. Residual and standard residual values of seasonal comparison of mean estimated and measured stream flows are presented in Tables 4 and 5. Values of
residuals are considered positive if they are above the regression line and negative if they are below the regression line, while zero if the regression line passes through the points. Anyadike (2009) shows that all residuals should be small and unstructured suggesting that the regression analysis has been successful in explaining the essential part of the variation of the dependent variables. From Tables 4 and 5, the residuals are within small range and thus it can be said that values of measured and estimated data exhibit some closeness, although this closeness is more pronounced in low discharge values.

In Figures 6 to 9, the residual pots are presented. The plot showed a random residual pattern, an indication, that the linear model provides a decent fit to the data. This means that our residual plot is a good fit for a linear model. In addition, there is a number of factors which might cause the rating curve not to give the actual discharge as shown in Figures 4 and 5, some of which will vary with time (Fenton and Keller, 2001). Boyer (1964) found that channel changing can result from modification due to dredging, bridge construction or vegetation growth which can affect rating curve. Similarly, due to unsteadiness in general, streamflow can change rapidly during a flood and the slope of the water surface will be different from that of a constant stage, depending on whether the discharge is increasing or decreasing (Simons and Richardson, 1962). The effect of this is for the trajectory of water in a flood event to appear as a loop on a stage-discharge diagram (Simons and Richardson, 1962).

Descriptive statistics of measured and estimated streamflow data are presented in Tables 6 and 7. In Okhuwan basin, the highest annual discharge volume was recorded in Obadan (2026.4 m$^3$/s). Other locations with significant streamflow volumes were Udeni and
Abunwa with annual streamflow amounts of 1804.3 and 1556.3 m$^3$/s, respectively. In Okhaihe basin, Ayen recorded the highest annual stream flow volume (1924.7 m$^3$/s), followed by Ahor and Edumega with annual stream discharge values of 1826.4 and 1730.3 m$^3$/s, respectively.

From these values it is seen that there is a relationship between streamflow volume and curve number factors in the study area. Thus, area with curve number from 46 to 48 also recorded the highest discharge volume. These areas are marked by expanding built up and urban activities. Information in Tables 6 and 7 are key for water resources planning and management, including flood management, water supply and irrigation projects. By understanding the various streamflow characteristics such as mean flow, peak flow and annual volumes, dams can be timed to provide artificial floods and enable a sharing of water between formal irrigation, informal small-scale irrigation, and other downstream users. More so, the estimated volume of peak flow segment for each of the location in the basin can also be converted to an aerial coverage of the floodplain. This is vital according to Kite (2001), in establishing possible extent of catchment development and water allocations for fisheries and in monitoring the effects of changes in the peak flow on aquatic and riparian environment. The results of Pearson Product moment correlation between measured and estimated streamflow are presented in Tables 8 and 9. It
Table 6. Descriptive statistics of monthly stream flow of individual point compared with measured results in Okhuwan Catchment.

| Town          | Streamflow | Mean | SR  | SD  | Var  | Range | Min  | Max  | Sum   |
|---------------|------------|------|-----|-----|------|-------|------|------|-------|
|               | Measured   |      |     |     |      |       |      |      |       |
| Ekhor         | 189.9      | 24.07| 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 121.8 | 8.85 | 30.7 | 939.2 | 95.7  | 58.7 | 154.4 | 1461.04 |
| Adoa          | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 116.1 | 6.8  | 23.4 | 547.8 | 77.4  | 67.0 | 144.4 | 1393.4 |
| Aduhanha      | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 118.7 | 8.6  | 29.9 | 893.3 | 96.8  | 56.5 | 153.3 | 1424.4 |
| Ugonoba       | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 118.7 | 8.5  | 29.4 | 864.0 | 80.0  | 63.6 | 143.6 | 1424.1 |
| Ogaga         | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 119.0 | 8.1  | 28.2 | 796.9 | 81.3  | 74.5 | 155.7 | 1428.5 |
| Evhouhuan     | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 118.6 | 7.9  | 27.4 | 752.7 | 82.1  | 73.7 | 155.8 | 1423.3 |
| Abunwa        | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 129.7 | 12.6 | 43.7 | 1912.7 | 141.2 | 61.7 | 203.0 | 1556.3 |
| Udeni         | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 150.4 | 13.6 | 47.2 | 2225.5 | 147.6 | 73.6 | 221.2 | 1804.3 |
| Obadan        | 189.9      | 24.07 | 83.23 | 6927.9 | 255.9 | 65.95 | 321.8 | 2279.0 |
|               | Estimated  | 168.9 | 15.0 | 51.9 | 2694.9 | 171.3 | 97.3 | 268.6 | 2026.4 |

*SR is standard error, SD is standard deviation, Var is sample variance.

Table 7. Descriptive statistics of monthly stream flow of individual point compared with measured results in Okhaihe Catchment.

| Town            | Streamflow | Mean | SR  | SD  | Var  | Range | Min  | Max  | Sum   |
|-----------------|------------|------|-----|-----|------|-------|------|------|-------|
| Okhualihe/Okeze | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 123.9 | 16.6 | 57.5 | 3303.1 | 166.8 | 37.4 | 204.2 | 1487.3 |
| Idumwhuna       | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 123.8 | 23.1 | 79.9 | 6391.9 | 250.1 | 38.6 | 288.7 | 1485.1 |
| Igueowieoba    | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 119.8 | 16.0 | 55.6 | 3089.9 | 149.2 | 44.9 | 194.1 | 1438.1 |
| Edopa/Odjeva   | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 124.6 | 20.4 | 70.7 | 4997.1 | 202.1 | 52.9 | 255.0 | 1495.6 |
| Edumega        | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 144.2 | 18.5 | 64.1 | 4104.6 | 202.7 | 48.9 | 251.5 | 1730.3 |
| Ahor           | Measured   | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
|                 | Estimated  | 152.2 | 26.6 | 92.3 | 8520.6 | 262.2 | 41.4 | 303.6 | 1826.4 |
Table 7. Contd.

| Town | Measured | Estimated |
|------|----------|-----------|
| Uhege | 171.4 | 28.2 | 97.7 | 9542.4 | 264.9 | 46.0 | 310.8 | 2056.5 |
| Ayen | 160.4 | 27.6 | 95.6 | 9136.5 | 264.9 | 38.0 | 302.9 | 1924.7 |

*SR is standard error, SD is standard deviation; Var is sample variance.

Table 8. Correlation of measured seasonal streamflow with estimated values in Okhuwan Basin.

| Name of town | R   | R²  | Adjusted R | Standard Error | ANOVA F | Significant F |
|--------------|-----|-----|------------|----------------|---------|---------------|
| Ekhor        | 0.77 | 0.60 | 0.56       | 55.18          | 15.024  | 0.003         |
| Adoa         | 0.88 | 0.77 | 0.74       | 42.24          | 32.7046 | 0.0002        |
| Aduhanhan    | 0.86 | 0.75 | 0.72       | 44.05          | 29.2796 | 0.0003        |
| Ugonoba      | 0.86 | 0.73 | 0.71       | 45.04          | 27.5719 | 0.0004        |
| Ogaga        | 0.94 | 0.88 | 0.87       | 30.15          | 73.848  | 0.000001      |
| Evbuohan     | 0.86 | 0.74 | 0.71       | 44.51          | 28.4619 | 0.0003        |
| Abunwa       | 0.90 | 0.81 | 0.80       | 37.68          | 43.6830 | 0.0001        |
| Udeni        | 0.79 | 0.62 | 0.59       | 53.55          | 16.576  | 0.002         |
| Obadan       | 0.79 | 0.62 | 0.59       | 53.48          | 16.644  | 0.002         |

Correlation and ANOVA, tested at 0.05 level of confidence.

Table 9. Correlation of Measured seasonal streamflow with estimated value in Okhiahe Basin.

| Name of town | R   | R²  | Adjusted R | Standard Error | ANOVA F | Significant F |
|--------------|-----|-----|------------|----------------|---------|---------------|
| Okhuihe/Okeze | 0.96 | 0.92 | 0.91       | 29.79          | 108.26  | 0.00001       |
| Idumwhuna    | 0.95 | 0.90 | 0.89       | 33.00          | 86.4087 | 0.00001       |
| Igueowieoba  | 0.97 | 0.94 | 0.94       | 24.20          | 169.264 | 0.00001       |
| Edopa/Odjeva | 0.87 | 0.76 | 0.74       | 49.86          | 32.2256 | 0.0002        |
| Edumega      | 0.98 | 0.96 | 0.95       | 20.88          | 230.69  | 0.00001       |
| Ahor         | 0.96 | 0.93 | 0.92       | 26.88          | 135.285 | 0.000001      |
| Uhege        | 0.83 | 0.69 | 0.66       | 57.24          | 22.0356 | 0.0008        |
| Ayen         | 0.99 | 0.98 | 0.97       | 15.92          | 404.058 | 0.000001      |

Correlation and ANOVA, tested at 0.05 level of confidence.

can be seen that there is a very strong positive relationship between measured and estimated streamflow at 0.05 statistical threshold.

The seasonal discharge and rainfall relationship of Okhuawan and Okhiahe basins are presented in Figures 10 and 11. The general trend depicts an increased in streamflow from the beginning of rainy season around April, attaining a peak between July and August for both basins. Seasonal streamflow responds particularly to seasonal pattern of rainfall distribution. This is expected as rainfall is one of the major elements of the hydrologic cycle and the primary source of runoff (Beven, 2001).

However, peak streamflow was not consistent with rainfall peak. This behaviour can be explained by variations in the local environmental factors as well as human activities (Raji et al., 2011). Also, the fact that streamflow peaked before rainfall, may be attributed to other factors like type of soils and land use activities in the basins (Pradhan et al., 2012). Unconsolidated soils allow water to infiltrate and so act as a store in a drainage basin.

Results of correlation matrix between rainfall and streamflow in the study area are presented in Tables 10 and 11. Positive values indicate a relationship between
Figure 10. Graphical seasonal patterns of rainfall and estimated discharge in Okhuwan Basin.

Figure 11. Graphical seasonal patterns of rainfall and estimated discharge in Okhaihe Basin.

Table 10. Correlation matrix of relationship between rainfall and streamflow in Okhuawan.

| Correlation | Rainfall | MS | Locations of estimated streamflow |
|-------------|----------|----|----------------------------------|
|             |          |    | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 | Point 6 | Point 7 | Point 8 | Point 9 |
| Rainfall    | 1.00     |    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| MS          | 0.84     | 1.00| 0.58    | 0.77    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 1     | 0.83     | 0.86| 0.89    | 0.98    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 2     | 0.76     | 0.86| 0.92    | 0.96    | 0.95    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 3     | 0.83     | 0.91| 0.84    | 0.86    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 4     | 0.89     | 0.79| 0.88    | 0.87    | 0.84    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 5     | 0.94     | 0.83| 0.71    | 0.86    | 0.87    | 0.84    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 6     | 0.79     | 0.90| 0.89    | 0.87    | 0.84    | 0.86    | 0.89    | 0.68    | 1.00    | 1.00    | 1.00    |
| Point 7     | 0.71     | 0.90| 0.86    | 0.87    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 8     | 0.89     | 0.89| 0.87    | 0.84    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |
| Point 9     | 0.84     | 0.86| 0.87    | 0.84    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    | 1.00    |

MS: Measured streamflow; Point 1: Ekhor; Point 2: Adoa; Point 3: Aduhanhan; Point 4: Ugonoba; Point 5: Ogaga; Point 6: Evhouhuan; Point 7: Abunwa; Point 8: Udeni; Point 9: Obadan
Table 11. Correlation matrix of relationship between rainfall and streamflow in Okhaihe.

| Correlation     | Rainfall (mm) | MS  | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 | Point 6 | Point 7 | Point 8 |
|-----------------|---------------|-----|---------|---------|---------|---------|---------|---------|---------|---------|
| Rainfall        | 1.00          |     |         |         |         |         |         |         |         |         |
| MS              | 0.86          | 1.00|         |         |         |         |         |         |         |         |
| Point 1         | 0.80          | 0.96| 1.00    |         |         |         |         |         |         |         |
| Point 2         | 0.79          | 0.95| 0.91    | 1.00    |         |         |         |         |         |         |
| Point 3         | 0.85          | 0.97| 0.96    | 0.95    | 1.00    |         |         |         |         |         |
| Point 4         | 0.72          | 0.87| 0.89    | 0.90    | 0.90    | 1.00    |         |         |         |         |
| Point 5         | 0.88          | 0.98| 0.95    | 0.93    | 0.97    | 0.92    | 1.00    |         |         |         |
| Point 6         | 0.87          | 0.96| 0.91    | 0.85    | 0.92    | 0.80    | 0.95    | 1.00    |         |         |
| Point 7         | 0.72          | 0.83| 0.84    | 0.90    | 0.90    | 0.85    | 0.83    | 0.71    | 1.00    |         |
| Point 8         | 0.82          | 0.99| 0.93    | 0.93    | 0.94    | 0.85    | 0.96    | 0.96    | 0.77    | 1.00    |

MS: Measured streamflow; Point 1: Okhuaihe/Okeze; Point 2: Idumhu; Point 3: Igueowieoba; Point 4: Edopa/Odjeva; Point 5: Edumega; Point 6: Ahor; Point 7: Uhege; Point 8: Ayen.

Figure 12. Spatial distribution of estimated discharge in Okhuwan Catchment.

rainfall and runoff such that as the rainfall increases, runoff also increases. As the value of \( r \) is nearer to +1, the correlation is said to be good. The rainfall-runoff relationship for the study area indicates a good correlation with \( r \) values ranging from 0.77 to 0.90. Spatial Patterns of Estimated Stream Flows are shown in Figures 12 and 13.

Conclusion

As uncontrolled deforestation, global warming and climate
change impacts persist with implications for environmental degradation and socio-economic losses, the need to develop alternative regional hydrological models for estimating streamflow of inadequately gauged river basins is now receiving great attention. Such models are considered key in predictive analysis for flood control...
and management project as well as other water resources development effort. Benin city has over the years witnessed unprecedented urban expansion and some of the consequences of this expansion is of urban and river floods. As a tropical environment, it is project that the frequency and magnitude of flood will increase over time. To adequately address the problem of floods, there is need for up-to-date information on basin characteristics as such information can be a key in building predictive model. In the absence of this information scientists are faced with new research challenge of developing alternative methods for estimating streamflow data for ungauged basins by using regional hydrological models. The present study therefore aims to assess the effectiveness of the regional NRCS-CN method in predicting streamflow at inadequately gauged Okhuwan and Okhai river basins in Benin City, Edo State. The two river catchments are parts of the Benin-Owena river basin under the administration of the Benin-Owena river Basin development authority and the latest hydrological information was available for 2001, a development that hinders sustainable water resources development and management within the basin. Results of rainfall-runoff analysis, coefficient of correlation, regression residual and correlation matrix showed positive relationship between measured and estimated streamflow at 0.05 statistical threshold, an indication that in the absent of hydrological information, regional models can be an alternative method for data generation.

CONFLICT OF INTERESTS
The authors have not declared any conflict of interests.

REFERENCES
Akande A, Costa AC, Mateu J, Henriques R (2017). Geospatial Analysis of Extreme Weather Events in Nigeria (1985– 2015) Using Self-Organizing Maps. Advances in Meteorology (2):1-11 https://doi.org/10.1155/2017/8576150
Anyadike RNC (2009). Statistical Methods for Social and Environmental Sciences. Spectrum Books Limited, Abuja
Aper JA (2006). Stream discharge characteristics in the Lower Benue Drainage basin. Unpublished Ph. D Thesis, University of Nigeria, Nsukka.
Atehdor GO, Odjugo PA, Uriri AE (2011). Changing rainfall and anthropogenic-induced flooding: Impacts and adaptation strategies in Benin City, Nigeria. Journal of Geography and regional planning 4(1):42-52.
Ayeade JO (1988). Tropical hydrology and water resources. Macmillan.
Aziegbé FL (2006). Channel and morphological response of two watersheds to urbanization in Benin City, Edo State, Nigeria. Journal of Human Ecology 20(3):177-182.
Banasiak K, Krajewski A, Sikorska A, Hejduck L (2014). Curve Number estimation for a small urban catchment from recorded rainfall-runoff events. Archives of Environmental Protection 40(3):75-86
Benin-Owena River Basin Development Authority, BORBDA (2000). Hydrological Year Book. Nigerian Ministry of Water Resources
Beven K (2001). How far can we go in distributed hydrological modelling? Hydrology and Earth System Sciences 5(1):1-12.
Boyer MC (1964). Streamflow measurement, Handbook of Applied Hydrology, Ed. V. T. Chow, Chapter 15, McGraw-Hill.
Bradley G (2008). Stage-discharge relationships in open channels: Practices and problems. Univ. degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale.
Butu AW, Bilal GN, Emeribe CN, Bichi AA (2020a). Physicochemical and Microbial Parameters in Domestic Water Sources in Billiri Local Government Area Gombe State, Nigeria. Journal of Forestry, Environment and Sustainable Development 6(1):123-141.
Butu AW, Ubachukwu NN, Emeribe CN, Odekun-George A, Bichi A (2020b). The Distribution and Load Duration Curves of Selected Pollutants in River Ekulu, Enugu Urban, Nigeria Journal of Resources Development and Management 64:36-46
Casermeiro MA, Molina JA, De la Cruz Caravaca MT, Costa JH, Massanet MH and Moreno PS (2004) Influence of runoff and sediment loss in soils of Mediterranean climate. Catena 57:91-107.
Ebele NE, Emodi NV (2016). Climate change and its impact in Nigerian economy. Journal of Scientific Research and Reports 10(6):1-13. http://www.journalssr.com/index.php/JSRR/article/view/21917/40737
Eccles R, Zhang H, Hamilton D (2019). A review of the effects of climate change on riverine flooding in subtropical and tropical regions. Climate change effects on flooding in the tropics and sub-tropics: a review Journal of Water and Climate Change 10(4):687-707.
Emeribe CN, Ezeh CU, Butu AW (2021). Climatic Water Balance Over Two Climatic Periods and Effect on Consumptive Water Need of Selected Crops in the Chad Basin, Nigeria. Agricultural Research 10(1):131-147. https://doi.org/10.1155/2020/40003-020-00475-2
Ezemonye MN, Emeribe CN, Anyadike RNC (2016b). Estimating Stream Discharge of Aboine River Basin of Southeast Nigeria Using Modified Thornthwaite Climatic Water Balance Model. Journal of Applied Science and Environmental Management 20(3):760-768
Ezemonye MN, Ositaum SI, Emeribe CN (2016a). Impact of Abattoir Waste on the Physico-Chemical Quality of Anwai River, Asaba Delta State, Nigeria. European Scientific Journal 12(20):288-298
Fasipe OA, Iznion OC (2021). Exponent determination in a poorly gauged basin system in Nigeria based on flow characteristics investigations and regionalization method. SN Applied Sciences 3(3):1-20. https://doi.org/10.1007/s42452-021-04302-3
Fenton JD, Keller RJ (2001). The Calculation of Streamflow from Measurements of stage Technical Report Report 01/6.
Groisman PY, Knight RW, Easterling DR, Karl TR, Hegerl GC and Razuvaev VANN (2005). Trends in intense precipitation in the climate record. Journal of Climate 18:1326-1350.
Hawkins RH (1993). Asymptotic determination of runoff curve numbers from data. Journal of Irrigation and Drainage Engineering 119(2):334-345.
Hegerl GC, Brönnimann S, Schurer A, Cowan T (2018). The early 20th century warming: anomalies, causes, and consequences. Wiley Interdisciplinary Reviews: Climate Change 9(4):522.
Herschy RW (1999). Uncertainties in hydrometric measurements. Hydrogen Principles and Practice pp. 355-370
Horton RE (1933). The role of infiltration in the hydrologic cycle. Eos, Transactions American Geophysical Union 14(1):446-460.
Intergovernmental Panel on Climate Change (IPCC) (2014). The Core Writing Team; Pachauri, R.K.; Meyer, L. (Eds.) Climate change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland P 151.
Iyalomhe FO, Cirella GT (2018). Flooding in Benin City, Nigeria, in: Climate Change; IPCC: Geneva, Switzerland P 151.
Jolyonm FQ, Cirella GT (2018). Flooding in Benin City, Nigeria, in: Conference Proceedings of the 2nd International Conference on Sustainability, Human Geography and Environment. Presented at the 2nd International Conference on Sustainability, Human Geography and Environment, PCS Publishing Co., Italy P 6.
Kirpich ZP (1940). Time of concentration of small agricultural watersheds. Water Resources, 10(1):362-369.
Kite G (2001). Modelling the Mekong: hydrological simulation for environmental impact studies. Journal of Hydrology 253(4):1-13.
