Vol. 13(3), pp. 165-183, July-September, 2021
DOI: 10.5897/IJWREE2021.1014
Article Number: DC6DD5967518
ISSN 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

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

Isagba E. S.[1], Izinyon O. C.[1], Emeribe C. N.[2*], Uwadia N. O.[2] and Ezeh C. U.[3]

[1]Department of Civil Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria.
[2]National Centre for Energy and Environment, Energy Commission of Nigeria, University of Benin, Benin, City, Edo State, Nigeria.
[3]Department of Geography, Faculty of Social Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria.

Received 9 July, 2021; Accepted 9 August, 2021

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 measure 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 m^3/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.

---

*Corresponding author. E-mail: emeribe.c@ncee.org.ng. Tel: +2348063581430.

(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 (Groisman 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 (Nruthya 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 Okhaihe 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

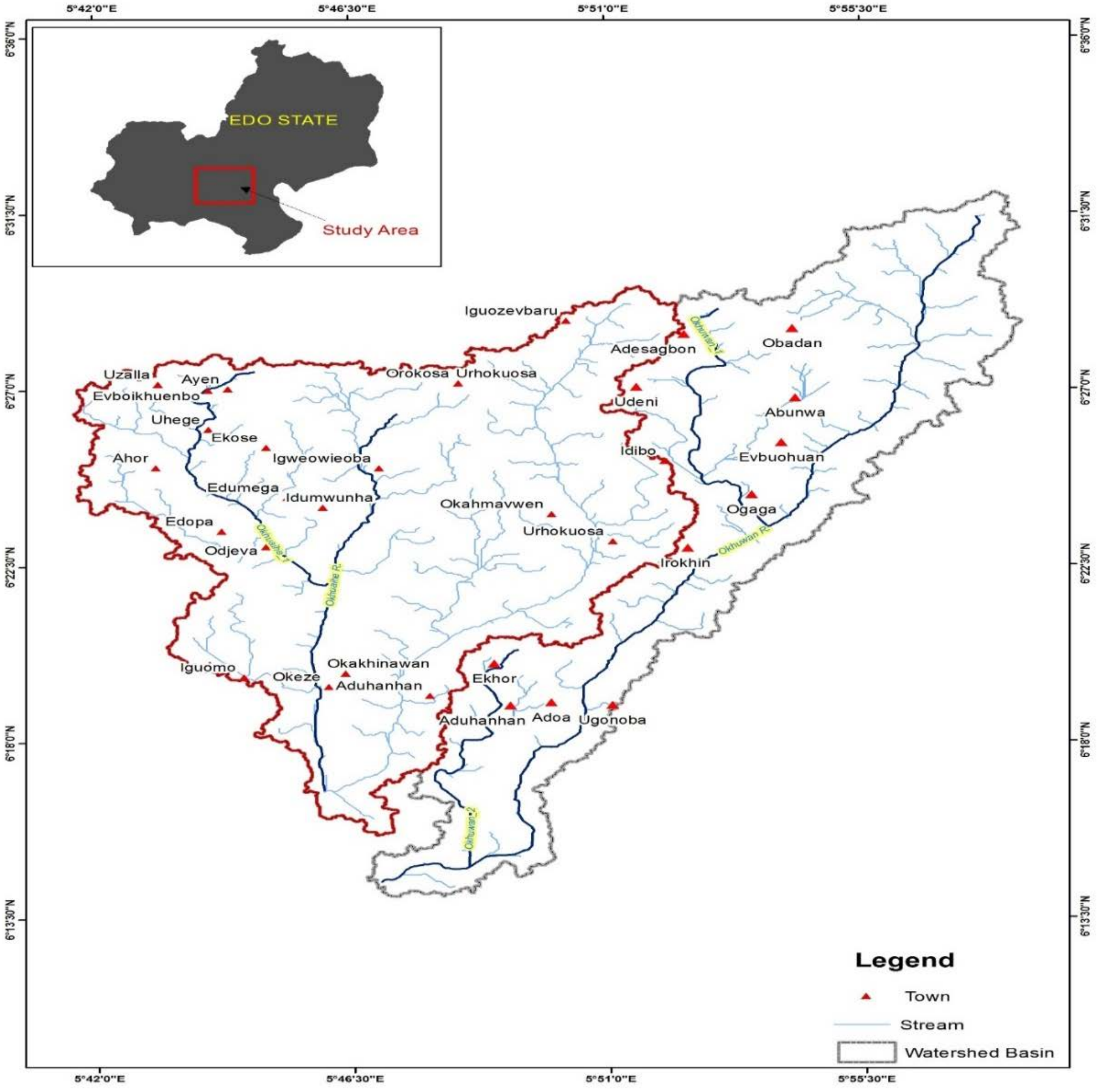

Figure 1. Okhuwan-Okhaihe catchment.

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 lateralized 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 Odemerho (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 (Odemerho, 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

Osiomo 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 Thiaw, 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 Okhuwan 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).

$$Q = C(h - a)^{\propto} \tag{1}$$

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

$$Q_d = \frac{(P_t - I_a)^2}{P_t - I_a + S} \tag{2}$$

where Q is the depth of excess rain (cm), P *is* the total rain (cm), *Ia*- 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:

$$Q_d = \left(\frac{P_t - 0.2S}{P_t - 0.8S}\right)^2 \tag{3}$$

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 Slope >30% (30-40)	Hilly with slope Slope 10-30% (25-32)	Rolling terrain Slope 5-10% (17-24)	Relatively flat 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):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (4)$$

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:

$$Q_p = q_u A Q_d \quad (5)$$

where (Q_p) is peak flow in m^3/s, q_u is unit peak discharge in m^3/s per cm of runoff per km^2 of area, A is area of the catchment in km^2 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.

$$Log q_u = C_0 + C_1 \log t_c + C_2 (\log t_c)^2 - 2.366 \quad (6)$$

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:

$$I_a = 0.2S \quad (7)$$

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:

$$t_c = 0.0078 \frac{L^{0.0078}}{S^{0.385}} \quad (8)$$

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:

$$r_{xy} = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2 \Sigma(y - \bar{y})^2}} \quad (9)$$

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*
Ekhor	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	0.700	39.9	26.73	0.0004
Ogaga	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:

$$t = \frac{(\bar{x}\,\bar{y})}{S\sqrt{\frac{1}{n}+\frac{1}{m}}} \qquad (10)$$

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

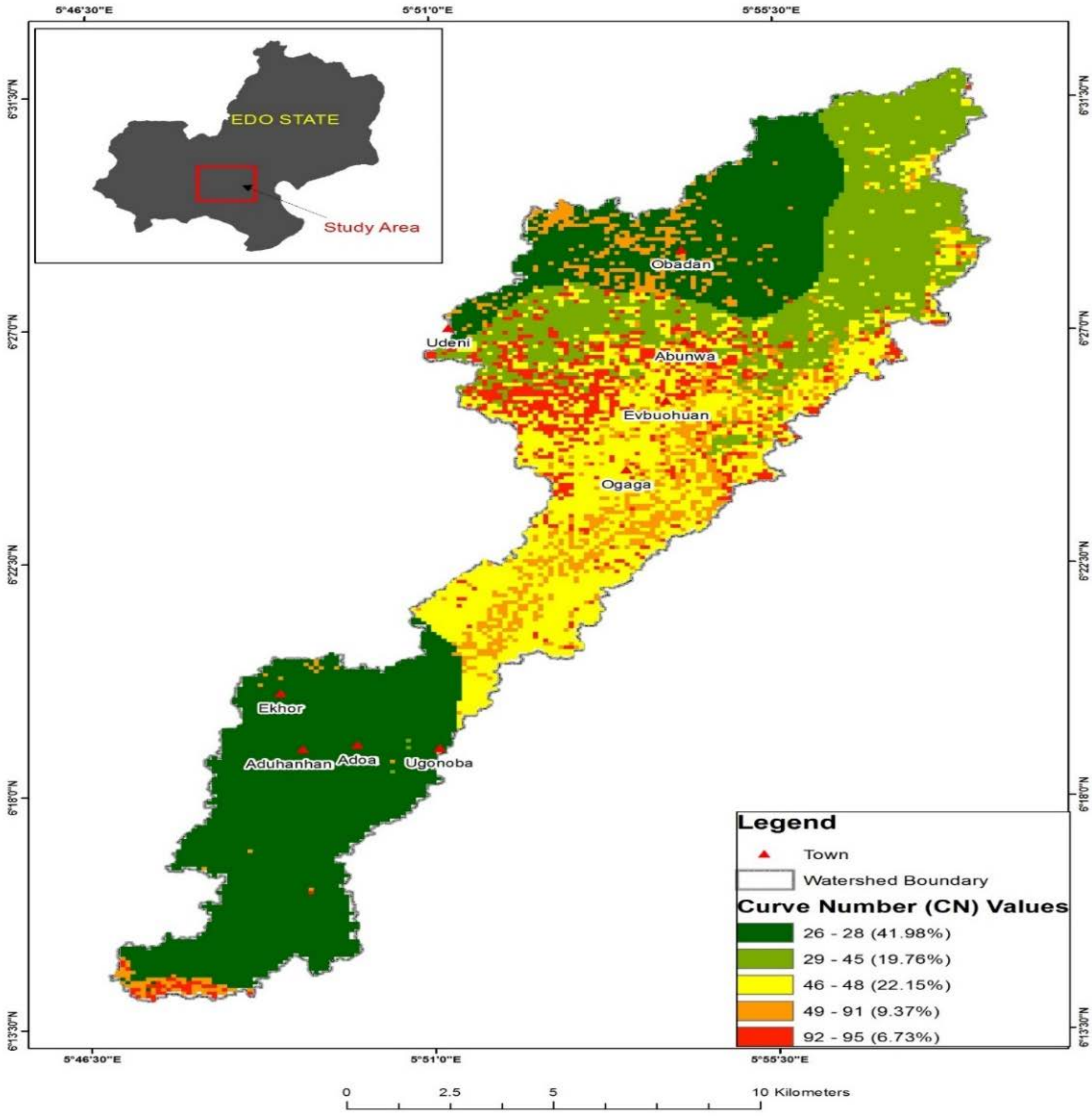

Figure 2. Curve number distribution for Okhuwan River Basin.

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

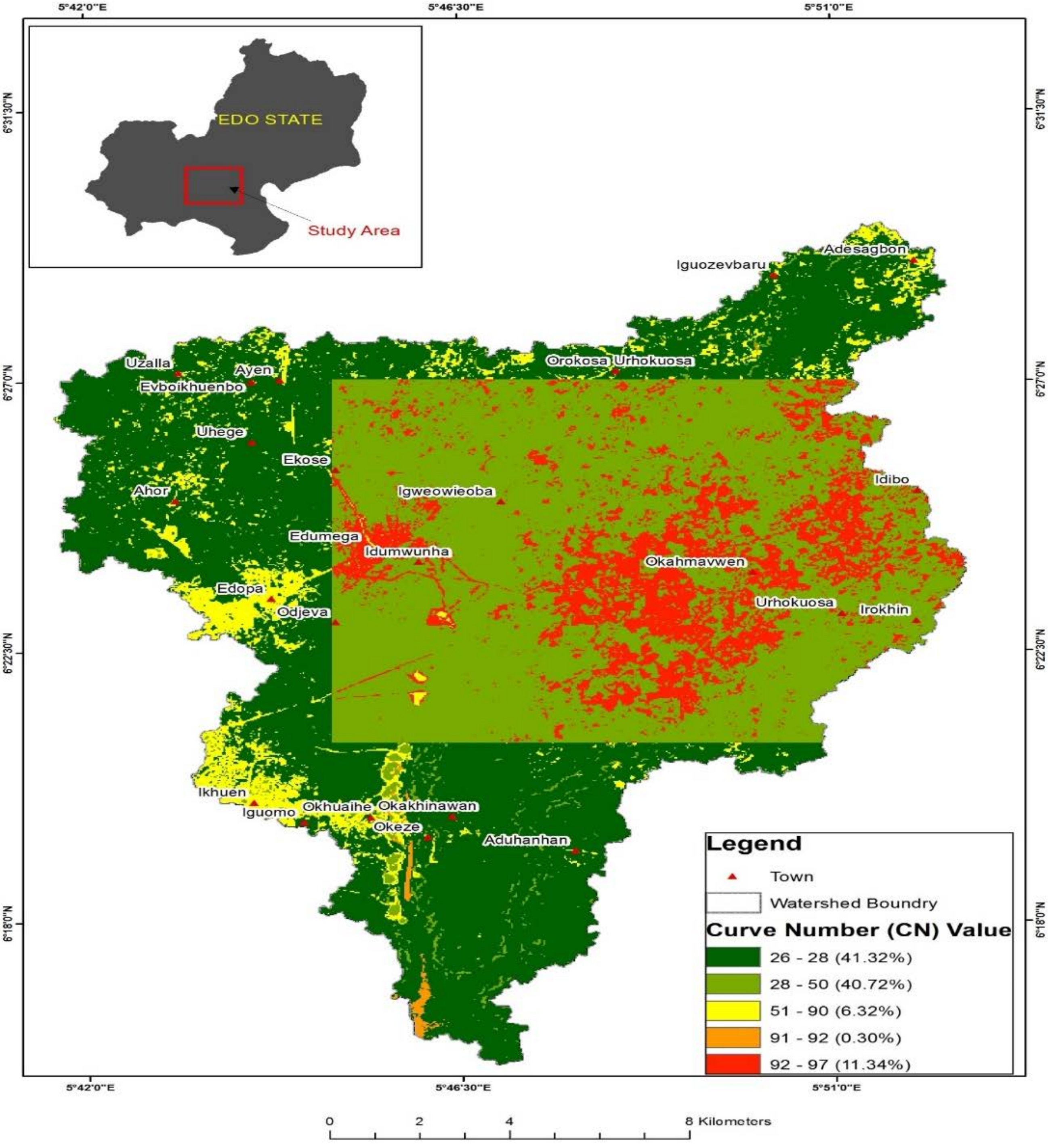

Figure 3. Curve Number distribution for Ohkaihe River Basin.

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

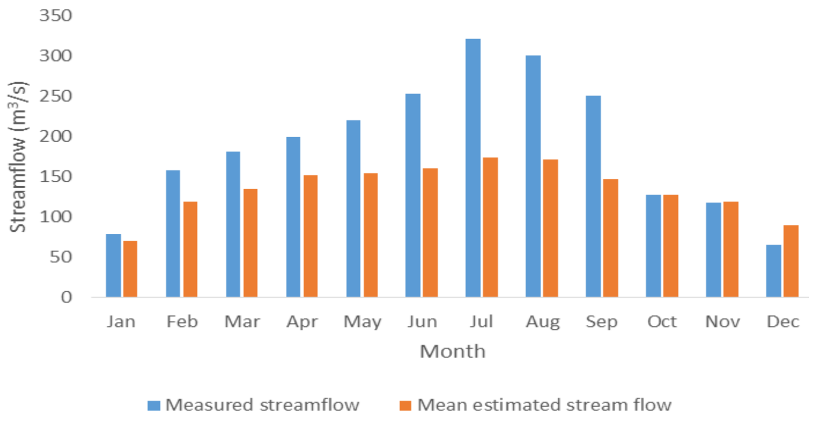

Figure 4. Mean seasonal comparison of estimated and measured streamflow in Okhuwan basin (9 points across river basin).

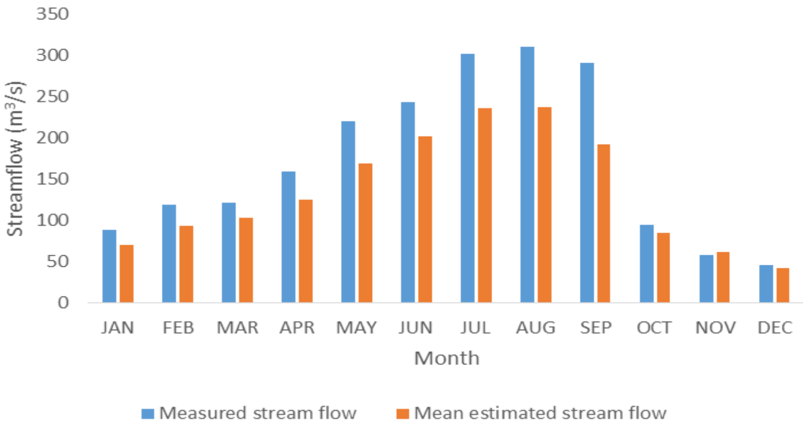

Figure 5. Mean seasonal comparison of estimated and measured streamflow in Okhaihe basin (8 points across river basin).

central and western parts of Okhuwan catchment, and the central and eastern part of Ohkaihe 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 decrease in lag time.

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 revealed 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) and237.3 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	126.9293337	119.5655722	7.363761585	0.648722576
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	321.825	155.1381103	165.9811172	-10.84300687	-0.955232358
Aug	300.8233333	153.7525448	159.0373283	-5.284783508	-0.465571615
Sept	251.57	130.7311387	142.7526803	-12.02154154	-1.059057291
Oct	128.0666667	118.5275765	101.918727	16.60884956	1.463183666
Nov	118.2433333	92.15021168	98.67083462	-6.520622941	-0.574444903
Dec	65.95333333	76.12450699	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	77.15513203	-6.37028858	-0.602715429
Feb	118.88	93.45571229	98.14911165	-4.693399358	-0.444059036
March	121.44	102.9504214	99.94984166	3.000579699	0.283895409
April	159.354	125.8491147	126.6189344	-0.769819765	-0.072835358
May	220.544	169.5802915	169.6606021	-0.080310614	-0.00759847
June	243.3116667	201.8637189	185.6756101	16.18810879	1.531613962
July	301.825	236.6248772	226.8344833	9.790393978	0.926303641
Aug	310.8233333	237.2717251	233.1640023	4.107722743	0.38864611
Sept	291.57	193.0025509	219.6210121	-26.61846115	-2.518466318
Oct	95.47333333	84.92461121	81.68462452	3.23998669	0.306546547
Nov	58.24333333	62.09263575	55.49666429	6.59597146	0.624068081
Dec	45.95333333	42.46126954	46.85175343	-4.390483889	-0.415399137

Lowest stream flows were recorded in January for estimated (70.2 m^3/s) and in December with streamflow amounts of 65.9 m^3/s Okhuwan basin. In Okhaihe basins, the lowest streamflow volume was recorded in December, 45.9 m^3/s (measured) and 42.5 m^3/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

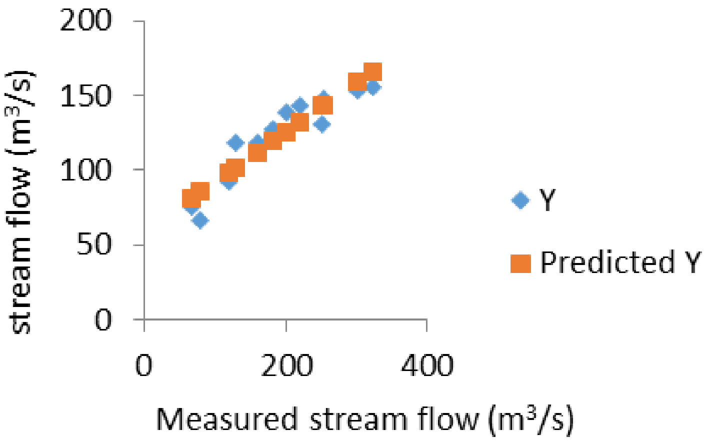

Figure 6. Line fit plot for seasonal measured and mean estimated streamflow (9 points) in Okhuwan Basin.

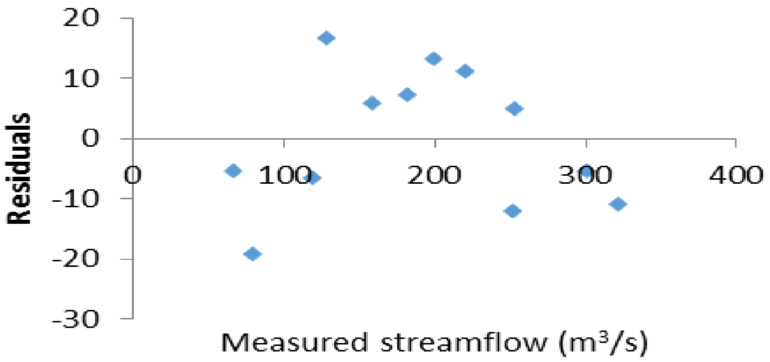

Figure 7. Residual plot of seasonal measured and mean estimated streamflow (nine points) in Okhuwan Basin.

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

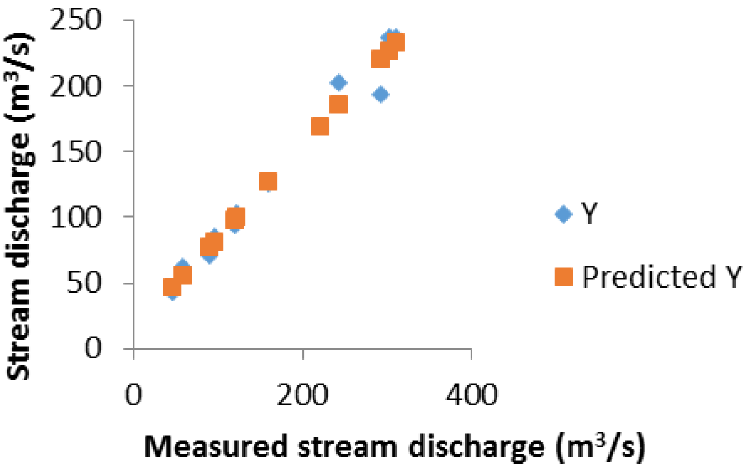

Figure 8. Line fit plot for seasonal measured and mean estimated streamflow in Okhaihe basin (8 points across river basin).

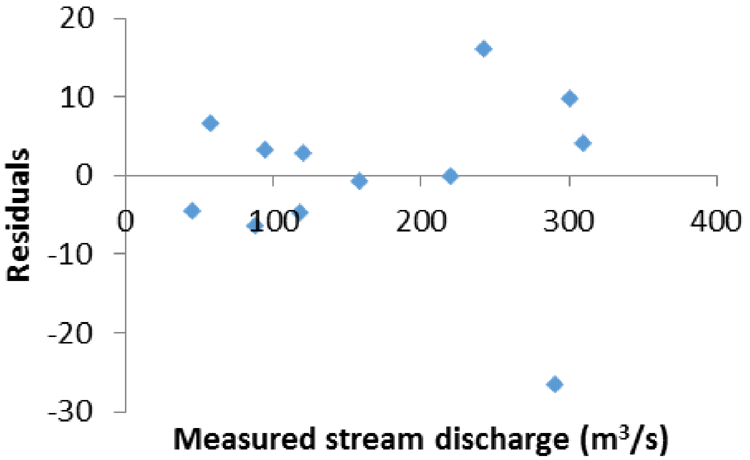

Figure 9. Residual plot of seasonal measured and mean estimated streamflow (9 points) in in Okhaihe.

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
Ekhor	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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	Measured	189.9	24.027	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
Okhuaihe/ 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.

Uhege	Measured	171.4	28.2	97.7	9542.4	264.9	46.0	310.8	2056.5
	Estimated	131.6	19.8	68.8	4729.4	206.8	35.3	242.1	1579.5
Ayen	Measured	171.4	28.2	97.7	9542.4	264.9	46.0	310.8	2056.5
	Estimated	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	R^2	Adjusted R	Standard Error	AVOVA *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	.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 Okhaihe Basin.

Name of town	R	R^2	Adjusted R	Standard Error	AVOVA *F*	Significant *F*
Okhuaihe/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

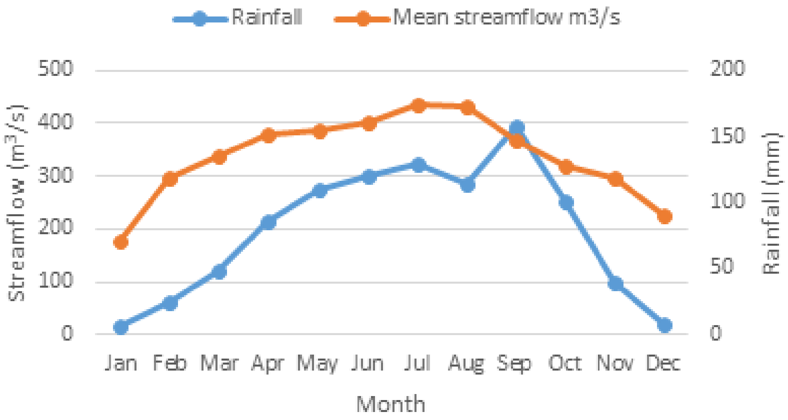

Figure 10. Graphical seasonal patterns of rainfall and estimated discharge in Okhuwan Basin.

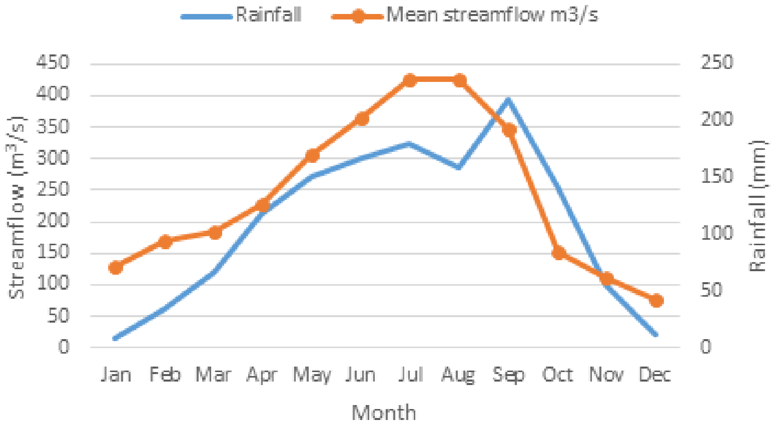

Figure 11. Graphical seasonal patterns of rainfall and estimated discharge in Okhaihe Basin.

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
Rain fall	1.00										
MS	0.84	1.00									
Point 1	0.58	0.77	1.00								
Point 2	0.77	0.88	0.92	1.00							
Point 3	0.83	0.86	0.89	0.98	1.00						
Point 4	0.76	0.86	0.92	0.96	0.95	1.00					
Point 5	0.83	0.94	0.74	0.91	0.88	0.86	1.00				
Point 6	0.89	0.86	0.67	0.88	0.90	0.80	0.92	1.00			
Point 7	0.85	0.90	0.60	0.77	0.79	0.74	0.87	0.81	1.00		
Point 8	0.62	0.79	0.89	0.90	0.88	0.90	0.81	0.75	0.74	1.00	
Point 9	0.94	0.94	0.71	0.86	0.87	0.84	0.91	0.86	0.89	0.68	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	Locations of estimated streamflow (m^3/s)							
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
Rain fall	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.

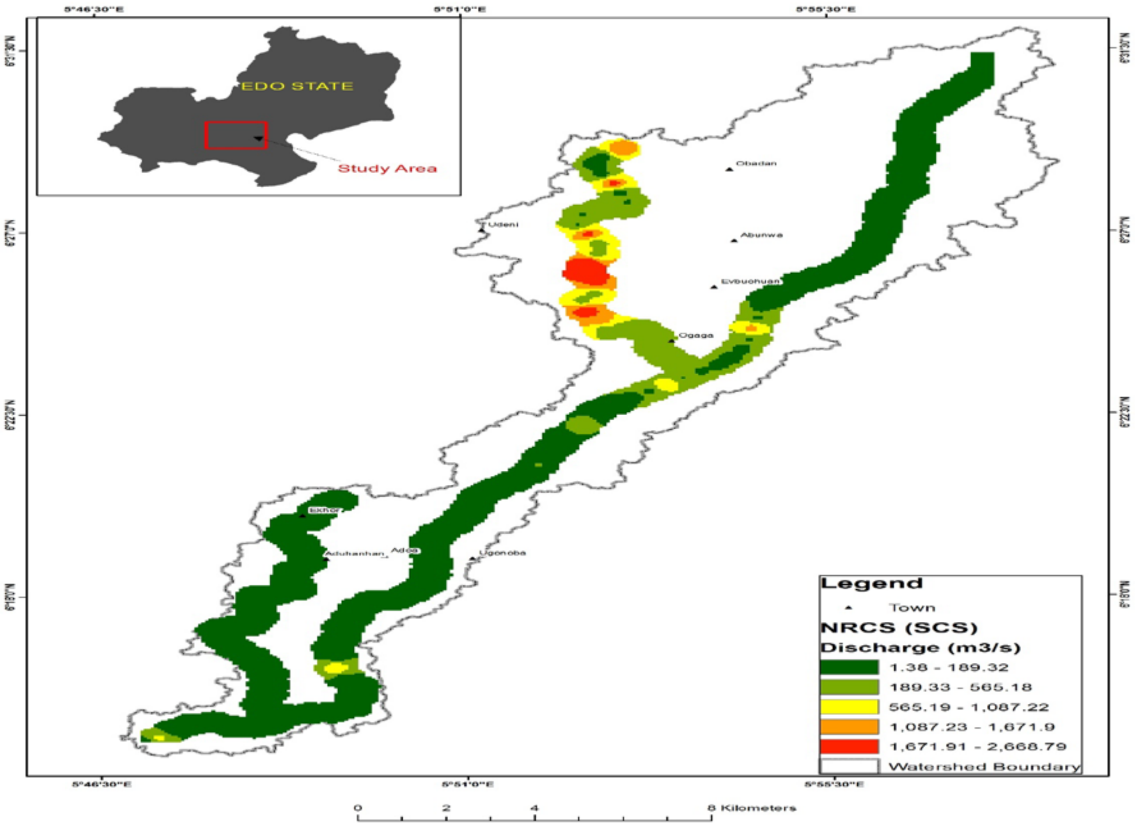

Figure 12. Spatial distribution of estimated discharge in Okhuwan Catchment.

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

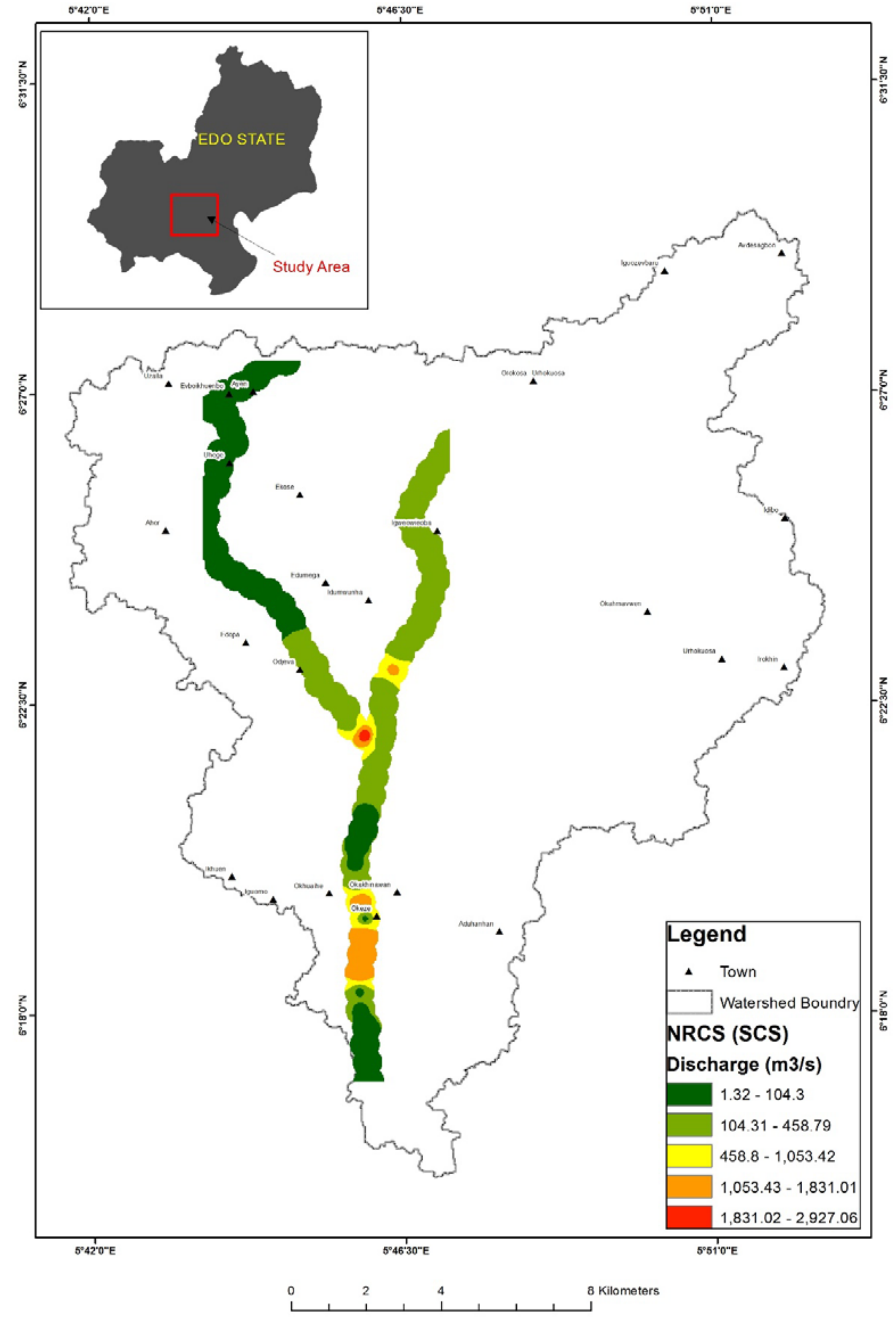

Figure 13. Map showing spatial distribution of estimated discharge in Okhuaihe Catchment.

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 projected 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 Okhaihe 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.

Atedhor 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.

Ayoade JO (1988). Tropical hydrology and water resources. Macmillan.

Aziegbe FI (2006). Channel and morphological response of two watersheds to urbanization in Benin City, Edo State, Nigeria. Journal of Human Ecology 20(3):177-182.

Banasik K, Krajewski A, Sikorska A, Hejduk 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.

Braca 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, Dadan-Garba 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 scrubs on 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.journaljsrr.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 subtropics: 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/10.1007/s40003-020-00475-2

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, Osiatuma 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, Izinyon OC (2021). Exponent determination in a poorly gauged basin system in Nigeria based on flow characteristics investigation 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 VAN (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: 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. Civil Engineering 10(6):362.

Kite G (2001). Modelling the Mekong: hydrological simulation for environmental impact studies. Journal of Hydrology 253(4):1-13.

Maghsood FF, Moradi HM, Bavani AR (2019). Climate change impact on flood frequency and source area in northern Iran under CMIP5 scenarios. Water (Switzerland) 11:273. https://doi.org/10.3390/w11020273.

Martens DA (2002). Relationship between plant phenolic acids released during soil mineralization and aggregate stabilization. Soil Science Society of America Journal 66(6):1857-1867.

Merem EC, Twumasi Y, Wesley J, Isokpehi P, Shenge M, Fageir S, Crisler M, Romorno C, Hines A, Hirse G (2017). Analyzing water management issues using GIS: the case of Nigeria. Geosciences 7:20-46.

Mishra AK, Coulibaly P (2009). Developments in hydrometric network design: A review. Reviews of Geophysics 47(2).

Mishra SK, Geetha K, Rastogi AK, Pandey RP(2005). Long-term hydrologic simulation using storage and source area concepts. Hydrological Processes: An International Journal 19(14):2845-2861.

Mishra SK, Singh VP, Sansalone JJ,Aravamuthan V (2003). A modified SCS-CN method: characterization and testing. Water Resources Management 17(1):37-68.

Morice CP, Kennedy JJ, Rayner NA, Jones PD (2012). Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set. Journal of Geophysical Research P 117.

Nadal-Romero E, Regüés D, Martí-Bono C, Serrano-Muela P (2007). Badland dynamics in the Central Pyrenees: temporal and spatial patterns of weathering processes. The Journal of the British Geomorphological Research Group 32(6):888-904.

Ngene BU, Nwafor CO, Bamigboye GO, Ogbiye AS, Ogundare JO, Akpan VE (2021). Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach. Heliyon 7:55-59.

Novella NS, Thiaw WM (2016). A seasonal rainfall performance probability tool for famine early warning systems. Journal of Applied Meteorology and Climatology 55(12):2575-2586.

Nruthya K, Srinivasa VV (2015). Evaluating Methods to Predict Streamflow at Ungauged Sites using Regional Flow Duration Curves: A Case Study. International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015). Aquatic Procedia 4:641-648.

Nwankwoala HO (2014). Problems and options of integrated water resources management in Nigeria: administrative constraints and policy strategies. International Letters of Natural Sciences 14:12-25.

Odemerho FO (1992). Limited downstream response of stream channel size to urbanization in a humid tropical basin. The Professional Geographer 44(3):332-339.

Ogunkule AO, Omoti U, Ataga DO, Esiche A (1980). Field Tours. Presented at the 8th Annual Conference of the national Soil Correlation Committee and the Soil Science Society of Nigeria, Bebin City, Nigeria.

Oguntoke O, Aboderin OJ, Bankole AM (2009). Association of water-borne diseases morbidity pattern and water quality in parts of Ibadan City, Nigeria. Tanzania Journal of Health Research 11(4):189-195

Oguntoyinbo JS (1982). Climate II and III: Precipitation and Radiation. Niger. Maps Lond. Hodder Stoughton.

Pradhan NR, Byrd AR, Ogden FL, Hendrick JM (2012). SEBAL evapotranspiration estimates for the improvement of distributed hydrological model runoff and soil moisture predictions 352:435-439

Raji MIO, Ibrahim YKE (2011). Prevalence of waterborne infections in Northwest Nigeria: A retrospective study. Journal of Public Health and Epidemiology 3(8):382-385.

Raji P, Uma E, Shyla J (2011). Rainfall-Runoff Analysis of a compacted area. Agricultural Engineering International: CIGR Journal 13(1).

Rantz SE (1982). Measurement and computation of streamflow. US Department of the Interior, Geological Survey

Razavi T, Coulibaly P (2013). Streamflow Prediction in Ungauged Basins: Review of Regionalization Methods. Journal of hydrologic Engineering 18(8):958-975.

Sahu RK, Mishra SK, Eldho TI (2012). Improved storm duration and antecedent moisture condition coupled SCS-CN concept-based model. Journal of Hydrologic Engineering 17(11):1173-1179.

Schwab GO, Feeveet RK, Barnes KK, Edminster TW (1971). Elementary soil and water engineering, 2nd ed. John Wiley and Sons.

SCS (2004). National Engineering Handbook Section 4: Hydrology, Chapter 4. Soil Conservation Service, Washington DC: USDA.

Simons DB, Richardson EV (1962). The effect of bed roughness on depth-discharge relations in alluvial channels, U.S. Geological Survey Water-Supply Paper 1498-E.

Singh PK, Mishra SK, Berndtsson R, Jain MK, Pandey RP (2015). Development of a modified SMA based MSCS-CN model for runoff estimation. Water Resources Management 29:4111-4127. https://doi.org/10.1007/ s11269-015-1048-1

Sivapalan M, Takeuchi K, Franks SW, Gupta VK, Karambiri H, Lakshmi V, Liang X, Mcdonnell JJ, Mendiondo EM, O'connell PE, Oki T, Pomeroy W, Schertzer D, Uhlenbrook S, Zehe E (2003). "IAHS decade on predictions in ungauged basins (PUB), 2003-2012: Shaping an exciting future for the hydrological sciences." Hydrological Sciences Journal 48(6):857-880.

Soulis KX, Valiantzas JD (2013).Identification of the SCS-CN parameter spatial distribution using rainfall-runoff data in heterogeneous watersheds. Water Resources Management 27(6)1737-1749.

Soulis KX, Valiantzas JD, Dercas N, Londra PA (2009). Analysis of the runoff generation mechanism for the investigation of the SCS-CN method applicability to a partial area experimental watershed. Hydrology and Earth System Sciences Discussions 6(1).

Taiwo AM, Olujimi OO, Bamgbose O, Arowolo TA (2012). Surface Water Quality Monitoring in Nigeria: Situational Analysis and Future Management Strategy, Water Quality Monitoring and Assessment, Dr. Voudouris (Ed.). InTech

Tirkey AS, Pandey AC, Nathawat MS (2014). Use of high-resolution satellite data, GIS and NRCS-CN technique for the estimation of rainfall-induced run-off in small catchment of Jharkhand India. Geocarto International 29(7):778-791.

Verma S, Verma RK, Mishra SK, Singh A, Jayaraj GK (2017). A revisit of NRCS-CN inspired models coupled with RS and GIS for runoff estimation. Hydrological Sciences Journal 62(12):1891-1930.

Wang G, Hapuarachchi P, Ishidaira H, Kiem AS, Takeuchi K (2009). Estimation of soil erosion and sediment yield during individual rainstorms at catchment scale. Water Resources Management 23(8):1447-1465.

Wang Q, Zhao G, Liu Y, Zhang P, Chai J (2016). Effects of vegetation types on yield of surface runoff and sediment, loss of nitrogen and phosphorus along loess slope land. Transactions of the Chinese Society of Agricultural Engineering 32(14):195-201.

Xiao PQ, Yao WY, Shen ZZ, Yang CX (2009). Study on runoff and infiltration process and hydraulic parameters characteristics with grass coverage. Journal of Soil and Water Conservation 23(4):50-53.

Young AR (2006). Streamflow simulation within UK ungauged catchments using a daily rainfall-runoff model. Journal of Hydrology 320(2):155-172.

Zhao W, Fu BJ, Chen L, Zhang Q, Zhang Y (2004). Effects of land-use pattern change on rainfall-runoff and runoff-sediment relations: a case study in Zichang watershed of the Loess Plateau of China. Journal of Environmental Sciences 16(3):436-442.