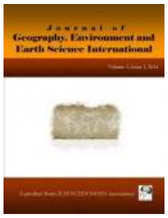

Journal of Geography, Environment and Earth Science International
8(2): 1-14, 2016; Article no.JGEESI.29937
ISSN: 2454-7352

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Evaluation of Hydrologic Response to Design Precipitations and Land Use/Land Cover Change in an Ungauged Tropical Rainforest Catchment, Southwest Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MOO designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AAK and OOO managed the literature searches, geospatial analyses of the study and author FOU supervised the field work. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2016/29937
Editor(s):
(1) Wen-Cheng Liu, Department of Civil and Disaster Prevention Engineering, National United University, Taiwan and Taiwan Typhoon and Flood Research Institute, National United University, Taipei, Taiwan.
Reviewers:
(1) Ahmed Melegy, National Research Centre- Dokki, Cairo, Egypt.
(2) Charles Onyutha, Muni University, Arua, Uganda.
Complete Peer review History: http://www.sciencedomain.org/review-history/16809

Original Research Article

Received 5th October 2016
Accepted 28th October 2016
Published 5th November 2016

ABSTRACT

This study evaluated Opa catchment's hydrologic response to design precipitations and land use/land cover change. The study involved hydrologic model building, which consisted of basin characteristics' extraction, meteorological model and control specifications. The basin characteristics were extracted using Hydrologic Engineering Centre-Geospatial Hydrologic Modelling System (HEC-GeoHMS) extension in ArcGIS 10.0. The meteorological parameters for

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the model were obtained by using a design rainfall after the frequency analysis of twenty one year annual maximum historical rainfall data based on Log-Pearson type III probability distribution. The 2, 5, 10, 25, 50, 100 and 200 years return periods were analyzed out of which 2, 25, 50 and 100 return periods were selected for flood discharge and volume simulation by the model. The model was calibrated and validated using known rainfall and discharge values in the catchment before it was transferred to the whole catchment. The model was evaluated using Nash-Sutcliffe efficiency (NSE) statistics and index of agreement. The study concluded that hydrologic response to design precipitation and land use/land cover is very significant (P<0.05) and that rainfall-runoff could be modelled for ungauged watersheds using available datasets coupled with GIS techniques in order to sustainably manage the watershed and mitigate flood disasters.

Keywords: Catchment; watershed; management; flood; precipitation.

1. INTRODUCTION

Hydrology is defined as the science that deals with the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with the environment, including their relation to living things [1-2]. Hydrological or hydrologic models have become an indispensable tool for studying hydrological processes, impacts of modern anthropogenic factors on hydrological systems and general water management in various catchments [3]. In the recent past, there has been a significant increase in the development of computer based hydrological models due to improved models and methodologies as well as the demand for improved tools to address the challenges of water resources management. Many of the developed models have their potential applications and are well documented [4-6]. The addition of Geographic Information System (GIS) technology further enhanced these capabilities and increased confidence in the accuracy of modelled watershed conditions, improved the efficiency of the modelling process and increased the estimation capability of hydrologic models [7].

Many rivers in Nigeria had been ungauged in the last three decades and this has impacted negatively on the livelihood of people who live in flood plains. The general lack of up-to-date streamflow data has made river basin management problematic especially in the area of flood risk management and the development of a real time flood warning system. Coupled with this is the impact of climate change in form of flooding which is becoming more pronounced in many catchments in Nigeria. According to Van Western and Hosfstee [8], mitigation of flood disaster can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of hazardous events in an area as well as the vulnerability of the people, buildings, infrastructures and economic activities in a potentially dangerous area. Unfortunately, [9-12] reported that this detailed knowledge is always lacking in most urban centres of the developing world especially Nigeria. Ishaya et al. [12] was of the opinion that one way to mitigate the effects of flooding is to ensure that all areas that are vulnerable are identified and adequate precautionary measures taken to ensure either or all of adequate preparedness, effective response, quick recovery and effective prevention. Before these could be done, information is required on important indices of flood risk identification which are elevation, slope orientation, proximity of built-up areas to drainages, network of drains, presence of buffers, extent of inundation, cultural practices as well as attitudes and perceptions in an integrated system. But many of these data are not available for many catchments in the country. However, flood modelling can be carried out using the characteristics of the watershed (topography, soil, landuse/landcover) as well as minimal climatic dataset. Hence, this study built an hydrologic model which was used to evaluate Opa catchment's hydrologic response to design precipitations and land use/land cover change in order to determine the volume of the runoff generated from design precipitation of different return periods. This was with a view to predicting flood vulnerability with respect to land use dynamics for effective tropical rainforest watershed management.

1.1 The Study Area

The study was conducted in Opa watershed, which is a sub-unit of Ogun Osun River Basin and located in the tropical rainforest of southwestern Nigeria. It is between latitude 7°26'56''N to 7°35'5''N and longitude 4°24'53''E

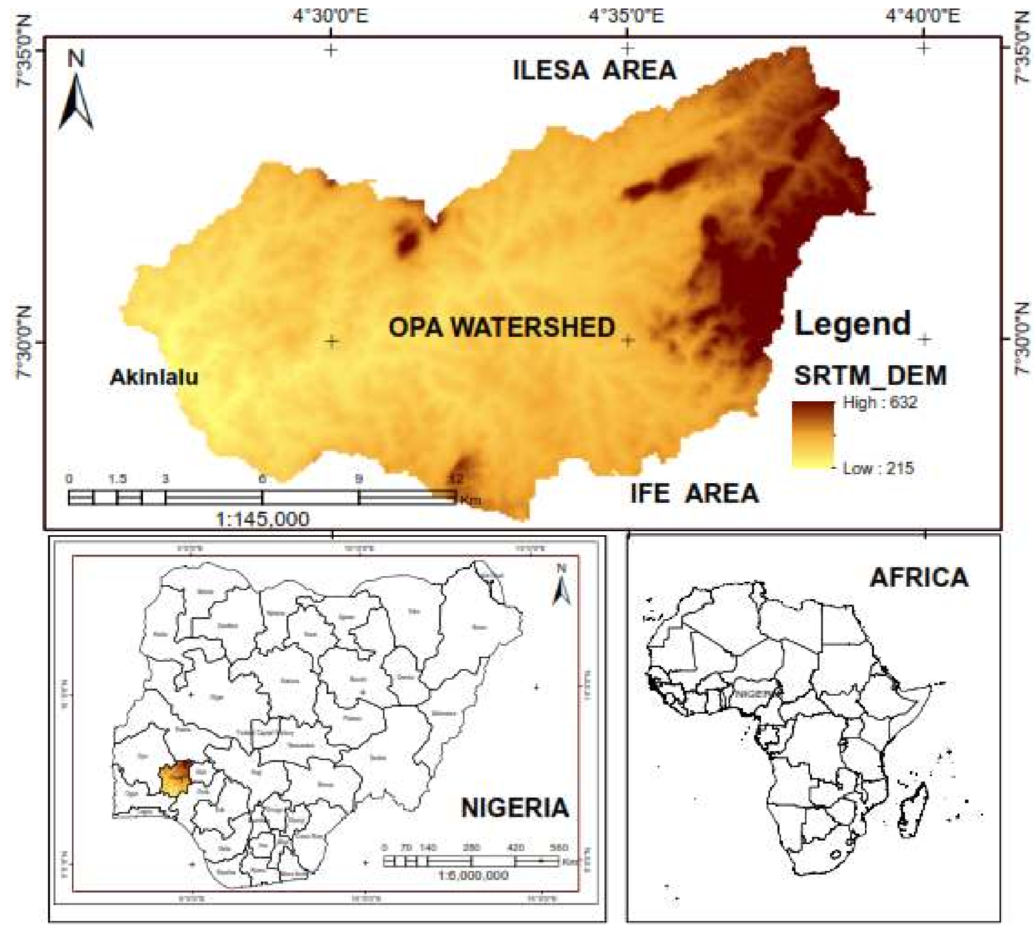

Fig. 1. The study area
(Source: author's field work)

to 4°39'13''E. It cut across the boundaries of four local governments – Atakunmosa West, Ife Central and Ife East and Ife North. The area is located in the cocoa belt of Nigeria. The climate of the study area belongs to the Moist Tropical Climates according to Köppen Global Climate Classification System [13]. They are known for their high temperatures year round and for their large amount of year round rain [14-15]. The geology of the area as reviewed by [16] includes granite gneiss and schist epidiorite. The soil of the catchment is Alfisols with Ferruginous Tropical overlay in most cases. The soil belongs to Egbeda and Iwo Asssociation and OxicTropudalf series by the USDA system and it was derived from granite and gneiss parent materials [17]. The natural or climax vegetation of the area is lowland tropical rainforest. However, the natural vegetation of the area has now been reduced to secondary forest or replaced by perennial and annual crops [18]. The main river in the catchment is Opa which has many tributaries such as Obudu, Esinmirin, Ominrin, Ogbe, Okun, and Mokuro. Fig. 1 shows the digital elevation model with the extent of the catchment.

2. MATERIALS AND METHODS

In carrying out this research, data collected, processed, analysed and presented include digital elevation model, satellite imageries, soil map, precipitation data as well as published and unpublished data. The hydrologic model used for rainfall-runoff simulation was built using basin characteristics component, meteorological component and control specification component before running the model.

2.1 Watershed Delineation and Extraction of Basin Characteristics

The basin characteristics required for hydrologic modelling of the study area were extracted from digital elevation model of the study area using Hydrologic Engineering Centre-Geospatial Hydrologic Modelling Extension (HEC-GeoHMS). Automated watershed and sub-watershed delineations were carried out following the procedure adopted by Orewole et al. [19] before extraction of physiographic characteristics. The basin characteristics extracted include: River Length, River Slope, Basin Slope, Longest Flow Path, Basin Centroid, Basin Centroidal Elevation, and Centroidal Longest Flow Path. Physiographic characteristics have been used for prediction of flow quantiles of ungauged catchments in several studies including [20-23] etc.

2.2 Hydrologic Modelling System (HMS) Inputs

Input parameters for the hydrologic modelling system (HMS) used were design precipitation data, Soil Conservation Service (SCS) Curve Number (CN) which was generated from GIS analysis of merging land use/land cover shape file and hydrologic soil group shape file. The NIGSAT 2007 satellite imagery (32 m resolution) obtained from Regional Centre for Training in Aerospace Surveys (RECTAS), Obafemi Awolowo University was resampled to 30m spatial resolution, subset to the boundary of the watershed and classified using supervised classification method of IDRISI Selva software. Four aggregated land use classes obtained in raster format were: Vegetated Area, Bare and Cultivated Land, Settlement and Water Body. The result was later vectorised using ArcGIS 10.0 for overlay analysis with soil shape file. To determine the rate of land use change in the study area and to model future scenario, the same procedure of supervised classification was used to classify the LANDSAT MSS imagery of 1977 and LANDSAT ETM of 1986.

2.3 Meteorological Component Preparation

Meteorological data required for Hydrologic Modelling System (HEC-HMS) model input are precipitation depths as a function of return period over the catchment. Since precipitation is related to runoff, it is important to analyze precipitation data in order to predict extreme occurrence for ungauged catchment as it is for this study area. The frequency of precipitation was determined assuming that the precipitation is a random variable and the mathematical theory of probability is applicable. Twenty-one years historic precipitation data of the catchment were analyzed to determine the frequency of 24 hour maximum precipitation as the record shorter than twenty years is not adequate [2]. The 2, 5, 10, 25, 50, 100 and 200 years return periods of the Annual Maximum series of precipitation of the catchment were calculated using Log-Pearson type III distribution. In this method, the variate (precipitation depth, P in this case) was first transformed into logarithmic form before analyzing the data. The values generated from the analysis were used as input precipitation values for 2 years, 25 years, 50 years and 100 years return period to simulate the runoff discharge and volume in the HMS.

2.4 HMS Processes Selection

During the HMS processes selection to obtain runoff volume and hydrograph, Soil Conservation Service (SCS) option was confirmed for Loss Method (getting excess rainfall from total rainfall) and Transform Method option was accepted (for converting excess rainfall to direct runoff) while Muskingum was confirmed for channel Route Method. The Soil Conservation Service (SCS) curve Number (CN) method estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

Where P_e = accumulated precipitation excess at time t; P = accumulated rainfall depth at time t; I_a = the initial abstraction (initial loss); and S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation. The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (CN) as:

$$S = \frac{25400}{CN} - 254 \tag{2}$$

The SCS transforms method transforms excess precipitation into direct runoff. In this method, 37.5% of the runoff volume occurs before the peak flow, and the lag time can be approximated by taking 60% of the time of concentration. The lag time is the length of time between the centroid of rainfall excess and the peak flow of the resulting hydrograph, whose values were computed using the CN Lag Time function in GeoHMS (24).

$$T_p = \frac{L^{0.8} * (S+1)^{0.7}}{1900 * Y^{0.5}} \tag{3}$$

Where, T_p =Basin lag time (hr), L= Hydraulic length of the watershed (ft), Y= Basin slope (%) and S = potential maximum retention

The Muskingum method in HMS was selected for streamflow routing in this study. The Muskingum method has different parameters K, X and number of sub-reaches (n) which need to be specified. Muskingum K is essentially travel time through the reach. Muskingum X is the weighting between inflow and outflow influence, it ranges from 0 to 0.5. The number of sub-reaches affects attenuation where one sub-reach gives more attenuation and increasing the number of sub reaches decreases the attenuation. Travel time T (hr) is approximately equal to L/3600V, where L = length of river (m), V = reach velocity (m/s). This method computes outflow from a reach using the following equations [24]:

$$Q_{OUT(1)} = (CA - CB) * Q_{IN(1)} + (1 - CA) * Q_{OUT(1)} + CB * Q_{IN(2)} \tag{4}$$

$$CA = \frac{2 * \Delta t}{2 * T * (1 - X) + \Delta t} \tag{5}$$

$$CB = \frac{\Delta t - 2 * T * X}{2 * T * (1 - X) + \Delta t} \tag{6}$$

Where: Q_{IN} = inflow of the routing reach in m^3/s, Q_{OUT} = outflow of the routing reach in m^3/s,
CA, CB = routing coefficients, Δt = computation time interval in hours, T = travel time through the reach in hours and X = Muskingum weighting factor (0 ≤ X ≤ 0.5).

2.5 Model Execution, Calibration and Validation

After the final task of establishing the model's time limits and cross checking all the data involved in the model, the model was executed. Calibration of the model was accomplished by using the urban sub-basins, in which a hydrograph was computed for an initial set of parameters and compared with the observed hydrograph at the Esinmirin-Ominrin confluence bridge along Mokuro Road (4.571017°E, 7.493549°N). The parameters were then adjusted on the basis of the comparison until a satisfactory fit was obtained. The storm event of July 20, 2012, which produced a basin average rainfall of 95 mm of rainfall over 7-hour duration, was used to calibrate the model and a similar event on September 29, which was 2 months later, was used for validation. When the parameters were considered acceptable, they were transferred over to the whole of Ife Catchment. The model evaluation statistics used was Nash-Sutcliffe efficiency (NSE). The Nash-Sutcliffe efficiency (NSE) is a normalized (dimensionless) statistic that determines the relative magnitude of the residual variance ("*noise*") compared to the measured data variance ("*information*") [25]. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation 7:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{o,i} - Q_{m,i})^2}{\sum_{i=1}^{n} (Q_{o,i} - \overline{Q}_o)^2} \tag{7}$$

Where Q_o is the observed flow, Q_m is the modelled flow, $\overline{Q}_o$ is the mean of observed flow, and *n* is the total number of observations. NSE ranges between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. In order to supplement the NSE, index of agreement [26], I_d was also used as presented in equation 8.

$$I_d = 1 - \frac{\sum_{i=1}^{n} \left| Q_{o,i} - Q_{m,i} \right|^{P_q}}{\sum_{i=1}^{n} \left(\left| Q_{m,i} - \overline{Q}_o \right| + \left| Q_{o,i} - \overline{Q}_o \right| \right)^{P_q}} \tag{8}$$

Where Q_o is the observed flow, Q_m is the modelled flow, $\overline{Q}_o$ is the mean of observed flow, and *n* is the total number of observations.

Onyutha (2016) observes that If the assessment of the model is with respect to high flows, values of P_q greater than 1 can be used. This study made use of $P_q = 1$ to obtain a balance between high flows and low flows as well as $P_q = 2$.

3. RESULTS AND DISCUSSION

3.1 Model Building Output

The delineation process resulted into a dendritic watershed with 17 sub-basins shown in Fig. 2. The figure also shows the physical representation of the watershed with river network, sub-basin shapes, centroids, longest flow paths and HMS model links. The extracted hydrologic characteristics of the watershed which are inputs in HMS model are shown in Tables 1 – 3. While Table 1 shows the sub-basin area, perimeter, longest flow length, upslope and downslope elevations, centroid elevation, river and basin slope, as well as the Gravelius' index, Tables 2 and 3 show model input parameters for simulating existing and future amount of precipitation abstraction and runoff due to land use changes/percentage imperviousness. The model input parameters include curve number, time of concentration, lag time, potential maximum retention and initial abstraction.

The preocessed curve number grid for the watershed is shown in Fig. 3 with curve number ranging between 71 and 87 showing that the watershed is not well-drained as such not flood-proof even in near-natural state.

Table 4 shows the result of rainfall frequency analysis using Log-Pearson Type III distribution for design precipitation for different return periods. Log-Pearson Type III distribution is an analytical method which is very reliable in predicting extreme precipitation frequency and is often used in disaster management. According to Onyutha and Willems [27-28], for return periods larger than the data record lengths, extrapolations of the hydrological design quantiles are characterized by uncertainty. It should therefore be noted that modeled design values for large return periods e.g. ≥50 years might be biased from the true population estimate.

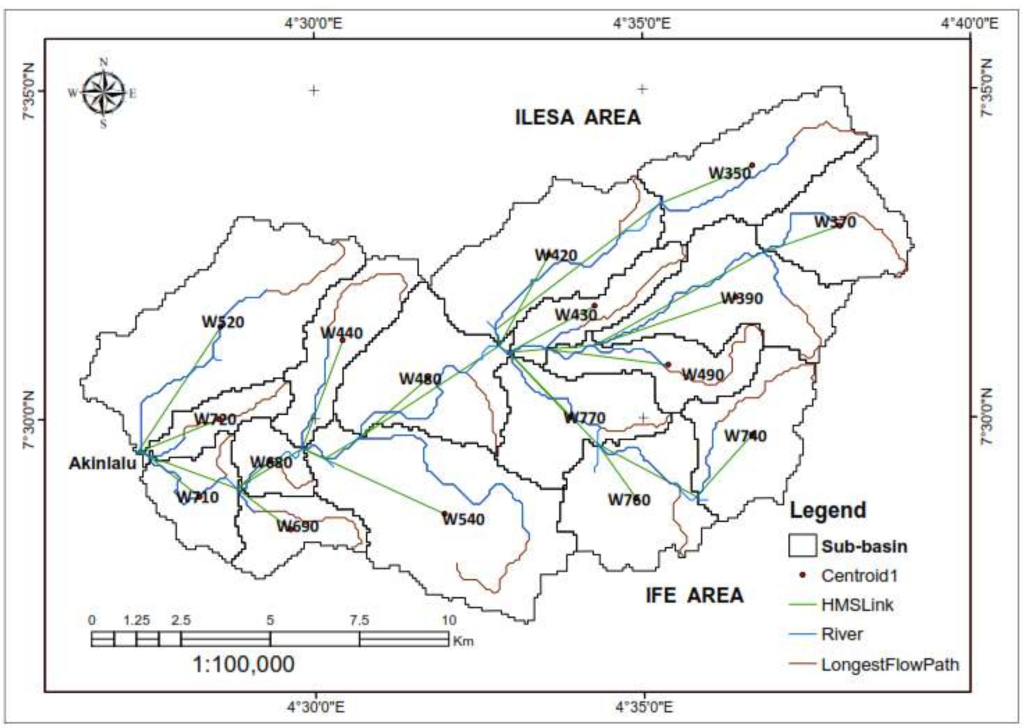

Fig. 2. Output of HEC-GeoHMS watershed processing showing 17 sub-basins with rivers, centroid HMS links and the longest flow paths

Table 1. Hydrologic characteristics of the watershed

Sub-basin ID	Sub-basin area (km^2)	Perimeter (km)	Longest flow length (m)	Elevation upslope (m)	Centroid elevation (m)	Elevation downslope (m)	River slope (%)	Basin slope (%)	Gravelius' index
W350	13.91	24.49	7.30	453.00	315.00	250.00	2.78	2.64	1.31
W370	10.03	18.96	6.30	424.00	355.00	302.00	1.94	4.43	1.20
W390	14.39	26.33	10.23	440.00	417.00	230.00	2.05	3.40	1.39
W420	16.75	24.30	7.50	303.00	236.00	219.00	1.12	1.44	1.19
W430	5.90	17.67	6.55	371.00	264.00	218.00	2.34	3.55	1.46
W440	8.87	20.44	7.52	383.00	248.00	212.00	2.28	1.88	1.37
W480	14.37	23.02	7.54	279.00	249.00	212.00	0.89	1.01	1.21
W490	7.80	20.80	8.48	421.00	275.00	226.00	2.30	3.56	1.49
W520	24.58	31.30	10.07	290.00	209.00	190.00	0.99	2.47	1.26
W540	25.50	30.20	13.17	351.00	262.00	212.00	1.06	3.07	1.20
W680	3.78	9.57	3.17	254.00	204.00	205.00	1.54	3.90	0.98
W690	5.80	15.28	4.87	279.00	253.00	205.00	1.52	2.22	1.27
W710	6.32	14.92	5.11	262.00	217.00	190.00	1.41	1.84	1.19
W720	4.22	14.91	5.24	265.00	214.00	190.00	1.43	1.71	1.45
W740	11.17	19.15	6.52	618.00	332.00	255.00	5.57	8.05	1.15
W760	12.81	20.26	5.27	305.00	268.00	235.00	1.33	2.00	1.13
W770	11.01	20.62	6.22	326.00	246.00	218.00	1.74	1.27	1.24

Table 2. Hydrologic modelling system (HMS) input parameters for the watershed (Present condition)

Sub-basin ID	Present SCS curve number (CN)	Present Impervio-usness (%)	Potential max retention *S* (mm)	Initial abstraction I_a (mm)	Lag time T_{lag} (hr)	Time of concentration T_c (hr)
W350	73.46	20	91.78	18.36	3.01	5.02
W370	76.25	0	79.12	15.82	1.91	3.18
W390	72.71	20	95.33	19.07	3.55	5.92
W420	79.43	30	65.77	13.15	3.49	5.82
W430	86.44	30	39.85	7.97	1.58	2.63
W440	79.90	5	63.88	12.78	3.02	5.03
W480	82.41	85	54.22	10.84	3.81	6.35
W490	81.91	30	56.10	11.22	2.27	3.78
W520	75.84	20	80.89	16.18	3.76	6.27
W540	85.93	85	41.58	8.32	3.03	5.04
W680	69.46	20	111.65	22.33	1.42	2.37
W690	71.91	0	99.21	19.84	2.48	4.13
W710	71.64	0	100.53	20.11	2.85	4.75
W720	74.01	5	89.19	17.84	2.83	4.71
W740	72.03	0	98.63	19.73	1.64	2.73
W760	81.07	30	59.29	11.86	2.12	3.54
W770	86.33	85	40.22	8.04	2.55	4.24

3.2 Model Calibration and Validation

The HMS model designed was callibrated using an urban sub-basin, in which a hydrograph was computed for an initial set of parameters and compared with the observed hydrograph at the Esinmirin-Ominrin confluence bridge, Ile-Ife (4.571017°E, 7.493549°N). The parameters (Muskingum's K and X values) were then adjusted on the basis of the comparison until a satisfactory fit was obtained. Selected storm events were used for validation after which the parameters were considered acceptable and were transferred over to the whole of Ife Catchment. Based on the Nash-Sutcliffe efficiency (NSE) model evaluation statistics [29], the value obtained was 0.9 for both flood discharge (Q) and flood volume (V). It means that the variance in the prediction of the model is very low, close to 1. It confirms the reliability of the statistics as the best objective function for reflecting the overall fit of a hydrograph [30]. Although Nash and Sutcliffe Efficiency [29] was used for the model performance evaluation, the mean squared error leads to oversensitivity of the aforementioned model performance metric to extreme values. Furthermore, according to Onyutha [31], caution must be taken to use multiple criteria for model performance for clarity of the insight about the influence of model selection on simulation or forecast results. Eventually, index of agreement [26] was also used to supplement the NSE. Similar value of 0.9 was obtained for both flood discharge (Q) and flood volume (V) using $P_q = 1$ and $P_q = 2$.

3.3 Hydrologic Response to Design Precipitation

The simulated runoff peak discharge for 2, 25, 50, and 100 year return periods based on existing and future scenarios are presented in Table 5. It was observed from the Table that higher runoff peak discharge occurred in the sub-basin with settlement, bare and cultivated areas,

Table 3. Hydrologic modelling system (HMS) input parameters for the watershed (Future condition)

Sub-basin ID	Future SCS curve number (CN) 2030	Future Impervio-usness (%) 2030	Potential Max retention *S* (mm)	Initial abstraction I_a (mm)	Lag Time T_{lag} (hr)	Time of concentration T_c (hr)
W350	79.90	30	63.90	18.36	2.49	4.15
W370	76.25	5	79.11	15.82	1.91	3.18
W390	79.43	30	65.78	19.07	2.92	4.86
W420	82.41	40	54.22	13.15	3.18	5.30
W430	86.44	30	39.85	7.97	1.58	2.63
W440	82.41	10	54.22	12.78	2.79	4.64
W480	85.93	90	41.59	10.84	3.38	5.63
W490	86.33	40	40.22	11.22	1.95	3.25
W520	81.91	30	56.10	16.18	3.12	5.20
W540	85.93	85	41.59	8.32	3.03	5.04
W680	79.90	30	63.90	22.33	1.05	1.75
W690	75.84	5	80.92	19.84	2.22	3.70
W710	71.64	5	100.55	20.11	2.85	4.75
W720	74.01	10	89.20	17.84	2.83	4.71
W740	81.07	0	59.31	19.73	1.26	2.09
W760	86.33	40	40.22	11.86	1.78	2.96
W770	86.33	90	40.22	8.04	2.55	4.24

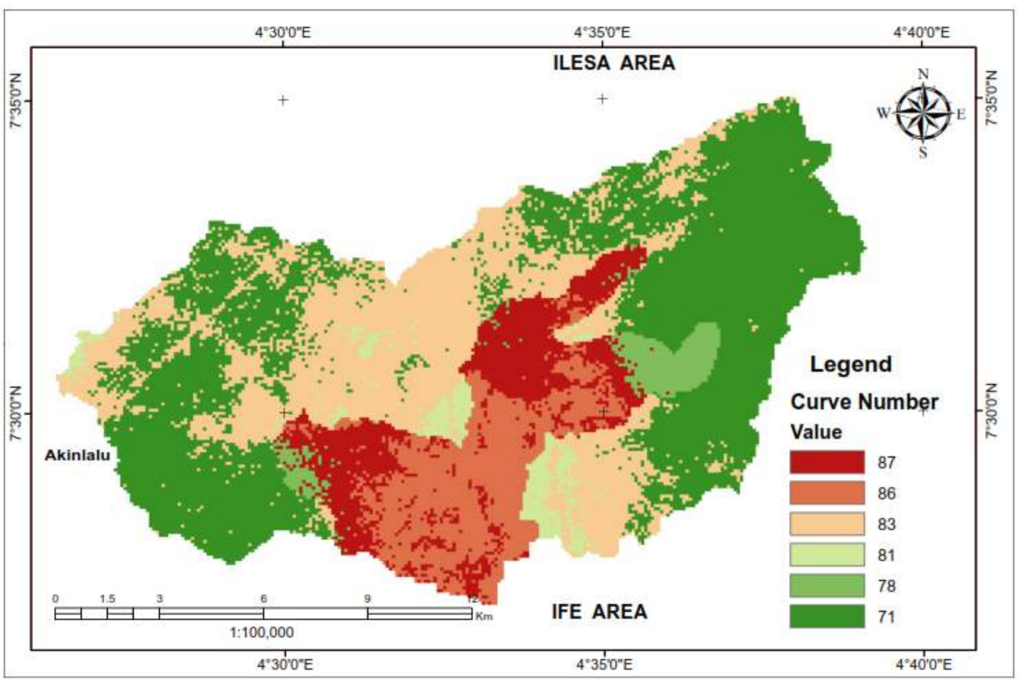

Fig. 3. SCS curve number grid

and water body (such as W540, W770, W760 and W480) as a result of low abstraction losses. The same observation was noted for the runoff volume generated as shown in Table 6. Meanwhile vegetated areas (such as W710 and W720) recorded low peak discharge and low runoff volume as a result of high abstraction losses through infiltration aided by dense vegetal cover. However, areas that are densely vegetated but have higher slope (such as W350, W370 and W390) exhibit low abstraction loss and high peak discharge and runoff volume. For the existing conditions in the watershed, the runoff peak discharge, Q_e and runoff Volume, V_e rise with increasing design precipitation in form of annual return period across the watershed. However along the watershed, the area of sub-basins determines the runoff discharge and volume. The smallest sub-basin (W720) with 4.22 Km^2 has the least discharge values of 6.7, 17.2, 20.8 and 24.9 m^3/s for the increasing annual return periods of 2, 25, 50 and 100 years as opposed to the sub-basin (540) which has an area coverage of 25.5 Km^2 for the same return periods as shown in Table 5. The peak volume in the watershed is enormous even with the existing conditions. It ranges between 106.7 x 10^3 m in the smallest sub-basin and 2 year return period to 4531.6 x 10^3 m in the largest sub-basin and 100 year return period. The hydrograph result of the 100-years return period simulation for the basin outlet channel, the outlet sub-basin and the closest reach to the outlet is shown in Fig. 4. Statistical Analysis of Variance (ANOVA) carried out on the results of runoff discharge and volume shows significant difference for varying precipitation amounts at confidence level ($P< 0.05$). The H_0 is that there is no significant difference in the runoff discharge or discharge volume of existing condition and future condition across the selected return period while the H_1 is that there is significant difference. The H_0 was discarded and H_0 was accepted after the ANOVA test.

Table 4. Designed annual maximum precipitation (in mm) in the catchment for different return periods using Log-Pearson Type III distributions

Return period (years)	Skew coefficient K(0.8451)	Precipitation depth *P* (mm)
2	-0.139	77
5	0.775	100
10	1.337	118
25	2.004	142
50	2.473	162
100	2.921	184
200	3.352	208

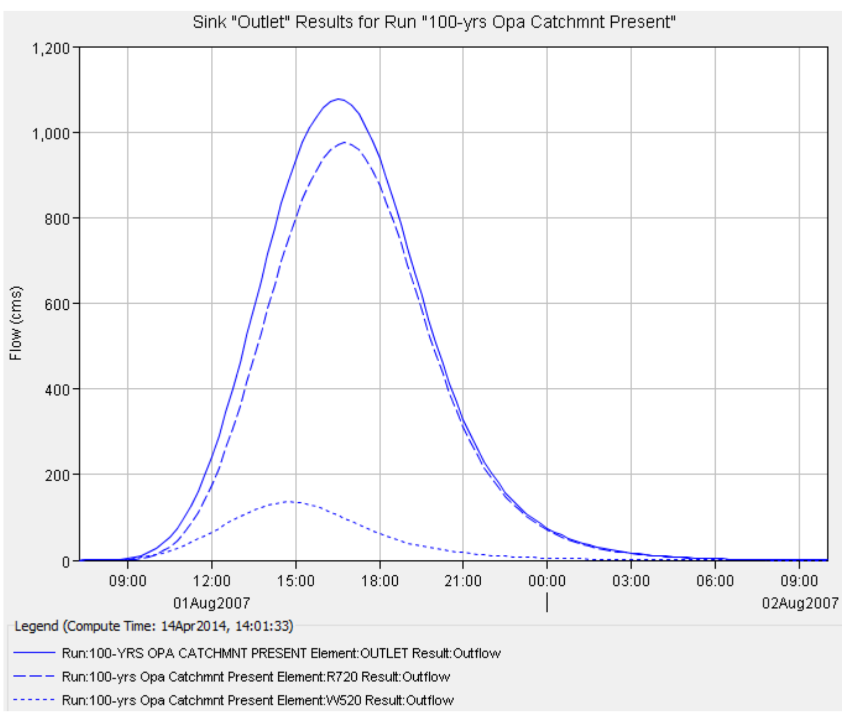

Fig. 4. Sink "Outlet" result for run*100 years Opa catchment basement

Table 5. Response of runoff peak discharge to design precipitation for different return periods and scenarios

Annual return period, T		T = 2 yrs			T = 25 yrs			T = 50 yrs			T = 100 yrs		
Sub-basin ID	**Area (Km^2)**	**Q_e (m^3/s)**	**Q_f (m^3/s)**	**Q_f - Q_e (m^3/s)**	**Q_e (m^3/s)**	**Q_f (m^3/s)**	**Q_f - Q_e (m^3/s)**	**Q_e (m^3/s)**	**Q_f (m^3/s)**	**Q_f - Q_e (m^3/s)**	**Q_e (m^3/s)**	**Q_f (m^3/s)**	**Q_f - Q_e (m^3/s)**
W350	13.91	25.5	38.5	13	59.2	75.6	16.4	71	88.8	17.8	84.1	103.3	19.2
W370	10.03	21.9	23.2	1.3	50.1	51.1	1	60.2	61.2	1	71.3	72.4	1.1
W390	14.39	22.7	35.5	12.8	55	72.5	17.5	66	85.4	19.4	78.4	99.6	21.2
W420	16.75	36.4	44.9	8.5	77.1	87.5	10.4	90.8	102	11.2	106	118.1	12.1
W430	5.9	24.5	24.5	0	39.5	39.5	0	45.7	45.7	0	52.6	52.6	0
W440	8.87	17.3	21.2	3.9	40.2	44.9	4.7	48	53	5	56.6	62	5.4
W480	14.37	44.4	49.8	5.4	79	85.5	6.5	90.6	97.8	7.2	103.3	111.3	8
W490	7.8	24.1	30.3	6.2	45.1	50.7	5.6	52.8	58.7	5.9	61.3	67.5	6.2
W520	24.58	41.1	61.6	20.5	96.6	124.5	27.9	115.5	145.9	30.4	136.6	169.6	33
W540	25.5	92.4	92.4	0	157.1	157.1	0	180	180	0	205.2	205.2	0
W680	3.78	9.6	16.3	6.7	19.5	24.7	5.2	23.4	28.9	5.5	27.8	33.4	5.6
W690	5.8	8.4	11.9	3.5	23.2	27.7	4.5	28.4	33.2	4.8	34.2	39.5	5.3
W710	6.32	8	8.9	0.9	23.3	24.1	0.8	28.6	29.4	0.8	34.5	35.4	0.9
W720	4.22	6.7	7.2	0.5	17.2	17.7		20.8	21.3	0.5	24.9	25.5	0.6
W740	11.17	21.7	38.5	16.8	53	68.4	15.4	64.4	80.6	16.2	77.1	94	16.9
W760	12.81	40.1	52.3	12.2	74.8	84.9	10.1	87.5	98.3	10.8	101.6	113	11.4
W770	11.01	44.1	44.9	0.8	72.2	72.9	0.7	82.7	83.4	0.7	94.3	94.9	0.6

T= Return Period; Q_e = Peak Discharge for existing landuse/landcover condition; Q_f = Peak Discharge for future landuse/landcover condition

Table 6. Simulated Runoff Volume in the catchment for different return periods

Annual return period, T		T = 2 yrs			T = 25 yrs			T = 50 yrs			T = 100 yrs		
Sub-basin ID	Area (Km^2)	V_e ($1000m^3$)	V_f ($1000m^3$)	V_f - V_e ($1000m^3$)	V_e ($1000m^3$)	V_f ($1000m^3$)	V_f - V_e ($1000m^3$)	V_e ($1000m^3$)	V_f ($1000m^3$)	V_f - V_e ($1000m^3$)	V_e ($1000m^3$)	V_f ($1000m^3$)	V_f - V_e ($1000m^3$)
W350	13.91	454	617.6	163.6	1184.8	1434.5	249.7	1425.9	1693.3	267.4	1698	1981.9	283.9
W370	10.03	257.4	282.4	25	777.9	810.2	32.3	951.3	984.9	33.6	1147.2	1182.1	34.9
W390	14.39	458.8	631.5	172.7	1205.8	1472.2	266.4	1453.2	1739	285.8	1732.8	2036.8	304
W420	16.75	735.1	859.3	124.2	1713.8	1884.1	170.3	2024.3	2203.4	179.1	2371	2558.1	187.1
W430	5.9	309	309	0	678	678	0	792.1	792.1	0	918.5	918.5	0
W440	8.87	295.3	347.7	52.4	791.6	866.8	75.2	952.2	1031.8	79.6	1132.3	1216	83.7
W480	14.37	998	1036.1	38.1	1934.5	1983	48.5	2218.5	2268.9	50.4	2531.7	2583.8	52.1
W490	7.8	364.1	433.3	69.2	832	925.2	93.2	979.1	1076.7	97.6	1142.7	1244.4	101.7
W520	24.58	864.6	1147.3	282.7	2203.9	2621.9	418	2640.4	3085.3	444.9	3131.1	3601.1	470
W540	25.5	1795.2	1795.2	0	3467.9	3467.9	0	3973.8	3973.8	0	4531.6	4531.6	0
W680	3.78	108.9	167.8	58.9	294.5	389.8	95.3	357.2	460.1	102.9	428.3	538.6	110.3
W690	5.8	116	160.2	44.2	391	463.1	72.1	485.6	563.7	78.1	593.5	677.3	83.8
W710	6.32	124.3	142	17.7	422.1	445.9	23.8	524.8	549.7	24.9	642	668	26
W720	4.22	106.7	117.8	11.1	319.6	334.3	14.7	391.2	406.6	15.4	472.3	488.3	16
W740	11.17	225	367.9	142.9	756	998.6	242.6	938.5	1202.1	263.6	1146.5	1430.1	283.6
W760	12.81	585.5	711.7	126.2	1347.4	1519.5	172.1	1587.6	1768.2	180.6	1855.2	2043.7	188.5
W770	11.01	776.4	794.7	18.3	1499.1	1520.5	21.4	1717.6	1739.6	22	1958.5	1981	22.5

T= Return Period; Q_e = Peak Discharge for existing landuse/landcover condition; Q_f = Peak Discharge for future landuse/landcover condition

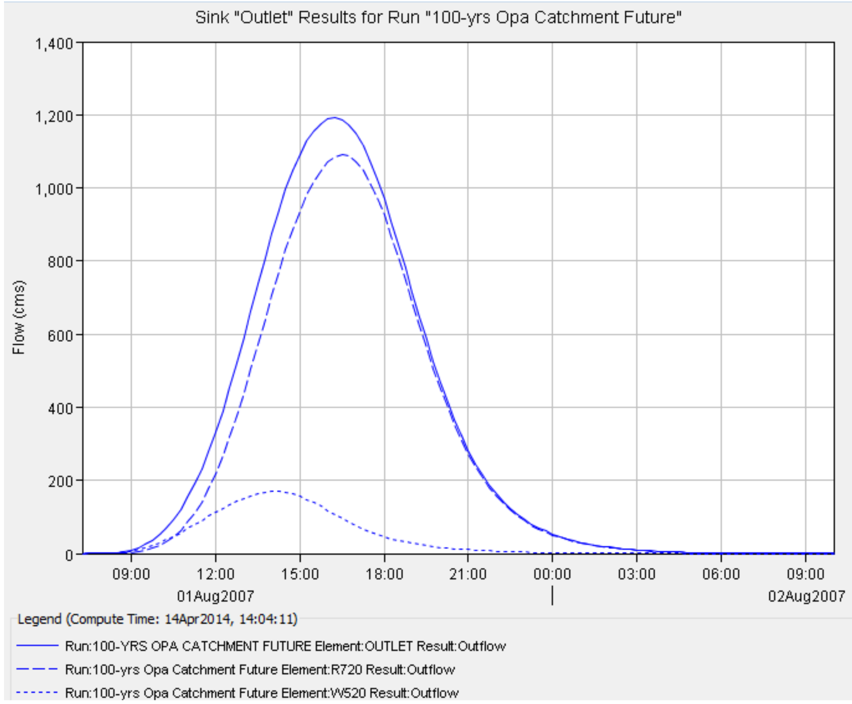

Fig. 5. Hydrograph of Opa catchment at the outlet junction for a design precipitation event having a return period 100 year for future conditions scenario

3.4 Hydrologic Response to Land Use/Land Cover Change

The simulated future scenario of runoff peak discharge for 2, 25, 50, and 100 year return periods when compared to the existing conditions showed some levels of increment which needed to be tested for significance. However, from Tables 5 and 6, the trend of the differences for runoff discharge, Q_f - Q_e and volume V_f - V_e across sub-basins and for different precipitation frequency levels, could be observed. A paired t-test statistics was carried out for the existing and future conditions at different precipitation frequency levels and result shows a highly significant difference in the means of sampled groups (P<0.05). The runoff flow at the watershed outlet for the future scenario in Fig. 5 shows an increase of 115.8 m^3/s over the existing condition scenario (Fig. 4) while the volume increment is 2248.6 6 x 10^3 m. It therefore means that the envisaged land use/land cover change will generate an enormous runoff in the watershed that requires appropriate preventive and adaptive measures before it leads to a serious disaster.

4. CONCLUSION

It can be concluded from this study that hydrologic modelling offers a cheaper and alternative method of studying ungauged watershed for sustainable management. The study also concluded that there is significant hydrologic response to varying precipitation frequency and land use/land cover change in the tropical rainforest catchment. Based on the findings from this study, it is recommended that: Stakeholders in watershed management should embrace hydrologic modelling systems for effective watershed management in other to mitigate flood or drought disasters and to define adaptive measures to climate change effects such as extreme precipitation. There is need to maintain adequate vegetation cover in areas where hydrological response to land use change critical in order to mitigate flood hazards. Urban development should be directed towards areas where flooding impacts will be minimal and at the same time restoration efforts should be directed towards areas that could reduce flood risk potential. There is need to implement policies that are designed to protect watersheds and develop sustainably.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/16809