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Historical rainfall-runoff modeling of river Ogunpa, Ibadan, Nigeria

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Abstract

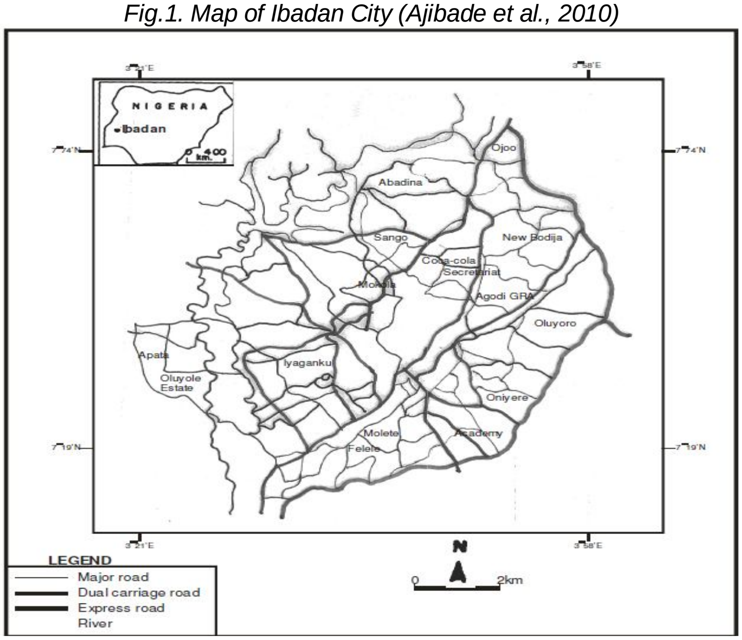
Flooding in major cities like the city of Ibadan, the largest urban centre south of the Sahara, Africa, is a common phenomena. Flooding occurred in several areas of the city each time when Ogunpa River overflowed its banks. Flood damage mitigation measures were necessitated by increased runoff due to rapid urbanization of the catchment area coupled with inadequate runoff data along the river course. Ogunpa River gained its national and international notoriety when many lives and properties worth billions of Naira were lost in the floods of 1960, 1963, 1978, 1980 and 2011. This study was conducted at Queen Elizabeth gauging station to develop an historical rainfall-runoff model for River Ogunpa. The model developed was a linear regression approach considering the effects of previous and current rainfall on the flow of the effluent streams. Average daily net rainfall data and average daily rainfall were regressed against average daily runoff data. Using linear regression method Net rainfall values (R') and rainfall values (R) were regressed against the corresponding discharge (Q) arrived at correlation coefficients of 0.66975 and 0.71191989 respectively. Utilizing 101 years of rainfall records for Ibadan City, runoff data for Ogunpa River were derived. This data could serve as a veritable hydrologic input in the design of embankment flood mitigation structures for River Ogunpa. It is recommended that to find a lasting solution to the menacing frequent flooding more runoff gauging stations be provided along the river course of Ogunpa River within Ibadan metropolis.

Keywords: Rainfall run-off model, River Ogunpa, Nigeria

Introduction

Ibadan city, Nigeria, a large city in Africa, lies within longitudes $3^{0}45'$ and $4^{0}05'$ East and latitudes $7^{0}10'$ and $7^{0}30'$ North (Adegbola, 2006). The city of Ibadan has a population of slightly over five million, spread over an area of about 400km^2.The city is naturally drained by four rivers with many tributaries viz: Ona River in the North and West; Ogbere River towards the East; Ogunpa River flowing through the city and Kudeti River in the Central part of the metropolis. The maps of Ibadan Metropolis and drainage basins are presented in Fig.1. & 2.

Fig.1. Map of Ibadan City (Ajibade et al., 2010)



There are four major streams in the Ogunpa River basin with pereinial flow, *viz*: Ogunpa, Labelabe, Gege and Kudeti. Ogunpa River has a catchment area of about 54.02km^2, with a length of 12.76km. It originates at Asi/Bodija Area and flows through the city towards the Lagos Ibadan Expressway. Ogunpa River, from its source to Queen Elizabeth Road gauging-station, has a catchment area and length of about 17.89km^2 and 4.23km, respectively. Ogunpa basin rises in the north-east section of the city near Agodi and Bodija, and eventually flows southwards passing through Oyo State Secretariat to Ogunpa Lake. A dam built across the Ogunpa created the lake for storage purposes to augment water supply. Almost fifty percent of the Ogunpa basin north of the confluence with the Kudeti is tributary to the Ogunpa Lake. Downstream of the Lake, the Ogunpa flows southwards through the western part of the inner core and past the south-eastern end of the Gbagi Market, a business district. From this point, the Ogunpa flows generally southwards through an area subjected to very intensive development at Oke-Foko, Oke-Ado, Molete and Isale-Ijebu and Bode. South of Ibuko Market, the Ogunpa is joined by the Kudeti stream which emanates from Oke-Irefin area of the metropolis, and both flow towards the Lagos Ibadan Expressway. The Labelabe stream originates from the north end of the Golf Course and flows southwards through Onireke and Ekotedo before crossing the Ibadan-Oyo Road. From Ibadan-Oyo Road, it flows through the northern boundary of

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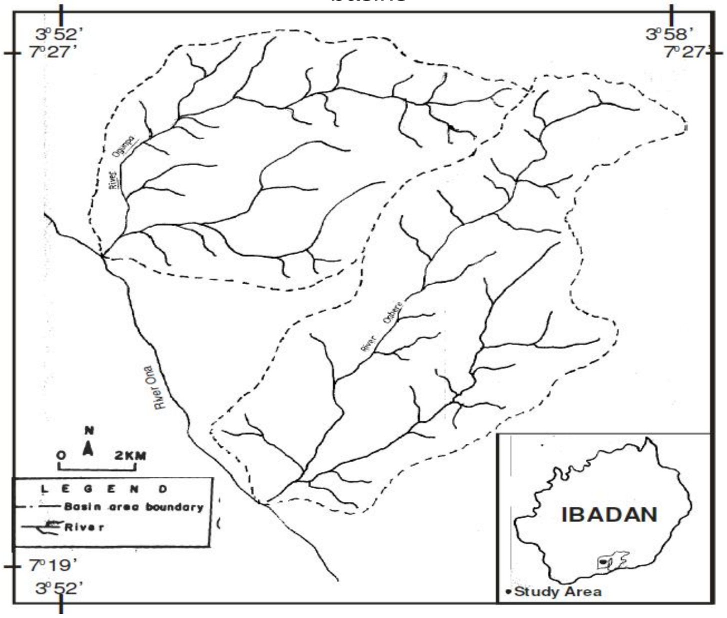
Fig.2. Rivers Ogunpa and Ogbere drainage basins



the Dugbe Market and the Gbagi Business District, before joining the Ogunpa stream at Oke-Padi. The Gege stream rises on the west side and flows south-westerly through Oke-Foko and Isale Osi, before crossing the Amunigun Road at Gege.

Flooding occurred in several areas of the city each time Ogunpa River overflowed its banks. Flood damage mitigation measures were necessitated by increased runoff due to rapid urbanization of the catchment and inadequate runoff data along the river course. The flooding of 1960, 1963, 1978, 1980 and 2011, where many lives and properties worth billions of Naira were lost, gave Ogunpa River its national and international notoriety. The flooding of August, 1980, tagged: ''omiyale'', was the worst for Ibadan City. Some researchers have worked on the Ogunpa River catchment in the past few years. Maku (2002) worked on the environmental impacts on soil and water of River Ogunpa in Ibadan. The study was aimed at establishing the levels of nutrient salts, heavy metals and PH values of soil and water of Ogunpa River. Job (2000) worked on flood and flood control using River Ogunpa as a case study. Oyegun, (1980) worked on predicting channel morphology from sediment yield discharge and urbanization of upper Ogunpa river. Morohunfola (1986), also carried out hydraulic routing of River Ogunpa.

Worldwide extensive work has been done by many authors in the area of application of numerical modeling techniques to runoff problems. Linsley *et al*. (1975) used the coaxial graphical correlation method past a gauging station to forecast volumes of runoff and the hydrograph. Thomas and Friering (1962) developed a model to generate monthly stream flows, used n-years of flow record grouped into twelve records, one for each month, and twelve linear regression equations. Special problems were encountered with application of this method to ephemeral streams. Sittner et al (1969) adopted Antecedent Precipitation Index (API-model) for continuous synthesis of the runoff hydrograph. The API-model is aimed at predicting flow individual catchment during periods when the flow consists of groundwater discharge and small amounts of direct runoff. The direct runoff consists of channel precipitation, surface runoff and subsurface runoff, and is computed from precipitation data by the use of API-model type of rainfall-runoff relationship and unit hydrograph. The HYBSCH Model was developed in the Technical University of Dresden (Miegei, 1988) and was found to be most appropriate for the Central Highlands of Ethiopia by Taffa (1989). Originally referred to as the hybrid model, the Linear Perturbation Model (LPM) was suggested by Nash and Barsi (1983) for rainfall-runoff modelling. The potential of LPM for daily rainfall-runoff modelling on large catchments was demonstrated. Kothyari et al (1993) however showed that LPM is more accurate for monthly simulation than for daily runoff simulation, particularly from medium sized catchments. According to Raghunath (1991), runoff can be estimated for sites where stream flow records are not available, by multiple regression techniques using the drainage basin and climatic characteristics as independent variables. The regression constant and coefficient are calculated using stream flow data from gauged streams. By expressing the variables in common logarithms, the equation could be transformed to the linear form as:

$\text{Log } Q = a + b_1 \log X_1 + b_2 \log X_2 + \ldots + b_n \log X_n$ (1)

where Q is the annual or monthly peak flow or runoff volume with any assigned probability

Duration; a, is the regression constant

x, is an independent variable characteristics of a drainage basin, or its climatic factor.

Boughton (1993) presented a hydrograph-based model for estimating water yield of ungauged catchments. Chapman (1999) researched on comparison of algorithms for stream flow recession and baseflow separation.

Methodology

The governing equation for the rainfall-runoff modeling were derived by using linear regression methods as outlined by Tokun (1998), whereby average monthly rainfall was regressed against average monthly runoff *viz*:

$Q_n = A_n R_n + C$ (2)

where, Q_n is the estimated runoff in month, n; R_n is rainfall in month, n; An is the regression coefficient and C is the regression constant. For good correlation, average monthly net rainfall was regressed against average runoff, and equation 2 becomes:

$Q_n = A_n R^1{}_n + C$ (3)

where $R^1{}_n$ = Net Rainfall = Rainfall, R_n - Evapotranspiration, ET_n

Equations 2 and 3 indicates that runoff, Q_n is a function of the previous rainfall, R_n. An improved lumped parameter rainfall-runoff relationship was allowed using an established procedure, thus:

$Q_n = A_nR_n + A_{n-1}R_n + A_{n-2}R_{n-2} + A_{n-k}R_{n-k}$ (4)

where R_n is the net or effective rainfall values in months n, n-1, n-2, …n-k; A_n, A_{n-1}, ….A_{n-k}.

A_{n-k} is the regression coefficient to be evaluated by multiple regression analysis for each of the 12 months, and C, is the regression constant.Equation 9 is the governing equation for the historical rainfall-runoff modeling of Ogunpa River at Queen Elizabeth Gauging Station.

Seven years available daily gauge height records were collected from Ogun-Oshun River Basin Development Authority (OORBDA), Abeokuta. Queen Elizabeth Gauging Station was set up, and measurements of gauge heights were recorded continuously for three weeks to calibrate the available seven year records.

The stream gauge heights were converted to actual flow using the relationship:

$Q = AV$ or $Q = b\,d\,V$ (5)

where; Q is the discharge (stream flow) in m^3/s

A is the cross-sectional area of the box section in m^2.

b is the width of box section in m.

d is the depth or height of the box section water level (gauge height) in m.

V is the mean velocity of flow in m/s.

The mean velocity of flow (V) was determined by velocity measurements, using surface floats. The time (t) taken by the float to travel a known distance (L) was measured and the surface velocity was calculated. This was repeated several times per day to arrive at the mean velocity of each float across the culvert section.

Rating curve equations were generated from the observed water level and flow records using linear regression method by regressing the gauge height against the discharge. This method resulted into correlation coefficient (r) of 0.781086, regression constant (a) of -0.306901652 and regression coefficient (b) of 1.676734198.

Hence the resulting linear equation:

$Q = -0.306901652 + 1.676734198H$ (6)

was used to convert all the seven years daily gauge height records collected from Ogun Oshun River Basin Development Authority (OORBDA), Abeokuta to river flows.

Seven years daily flow records according to Shaw (2005), seemed to be too short for planning purposes. Rainfall/runoff model was therefore derived for Ogunpa River at Queen Elizabeth road gauging station. Net rainfall values (R') and rainfall values (R) were regressed against the corresponding discharge (Q) using linear regression method to arrive at correlation coefficient of 0.66975 and 0.71191989 respectively. Since the rainfall correlation coefficient was higher than that of the Net rainfall, this was adopted to obtain the rainfall/runoff model equation of:

$Q = 0.180119541 + 0.015018344R$ (7)

The value, Q is the generated flow in m^3/s; 0.180119541 is the regression constant; 0.015018344 is the regression coefficient and R is the average daily rainfall in mm.

The available one hundred and one (101) years average daily rainfall data for the city of Ibadan were substituted into Equation 7 to arrive at one hundred and one year's generated flow for Ogunpa River at Queen Elizabeth Road Gauging station. By implication, for every rainfall data available for the hydrologic zone, runoff data can be estimated using the rainfall-runoff modeling relationship derived in Equation 7.

Results and discussion

The rating curve derived for the purpose of converting gauge readings to stream flow records are as shown in Fig.3. The seven years observed and estimated flow records from OORBDA are presented in Fig. 4.

One hundred and one (101) years observed rainfall data (1905 to 2006) from the Department of

Fig.3. Rating curve for Ogunpa river at Queen-Elizabeth road gauging station

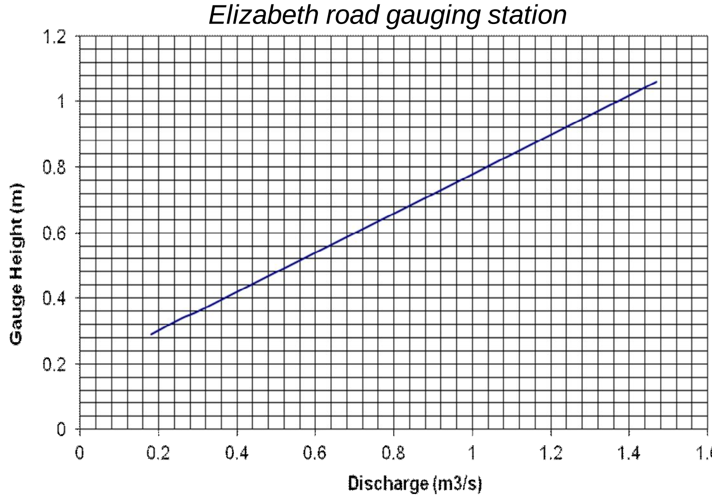
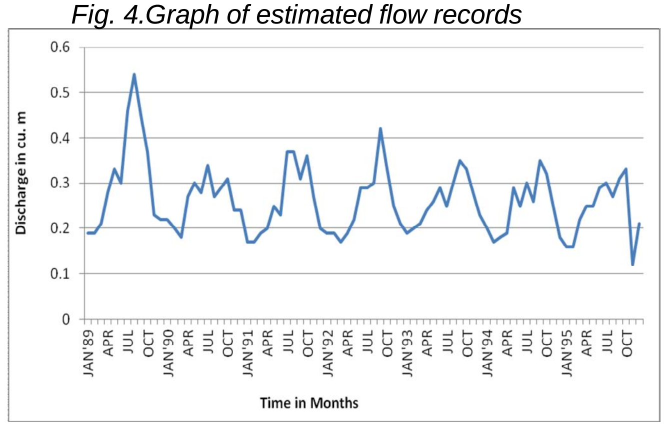


Fig. 4.Graph of estimated flow records



Meteorological Service, Old Airport, Ibadan, compiled by Akintola (1986), together with seven years gauge height records obtained from Ogun-Oshun River Basin Development Authority (OORBDA), Abeokuta, were used to compute 101-years flow records for Ogunpa River at Queen Elizabeth Road Gauging Station, using the relationship in Equation 7.

It was thus observed that the maximum average daily peak rainfall of 19.52mm occurred in the month of August, 1980 and its corresponding generated streamflow value was 0.473278m^3/s. This floodwater was responsible for the catastrophic flooding of the city of Ibadan where several lives and properties worth billions of Naira were lost.

Conclusions and recommendation

The following conclusions are drawn from the study:

(i) A flow rating curve has been established for the purpose of obtaining discharge from gauge height records of discharge in River Ogunpa at Queen Elizabeth Road.

(ii) One hundred and one years (1905-2006) measured rainfall data compiled by Akintola (1986) was used to derive runoff data of the same length, using a rainfall-runoff modeling approach.

(iii) The peak rainfall and runoff values occurred in August, 1980, and was responsible for the catastrophic flooding of Ibadan City.

(iv) In addition to other factors, which include inadequate channel cross-section and rapid urbanization, the August, 1980 Ogunpa River flooding was aggravated by the indiscriminate dumping of refuse and encroachment of the river course by buildings.

(v) Rainfall and runoff data are very crucial in design of flood mitigation structures on the Ogunpa River.

It is recommended that permanent flow recording stations should be installed along the Ogunpa River channel to assist in quantifying reasonably discharge floodwater for the purpose of control.

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