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USE OF LIMITED HYDROLOGICAL DATA AND MATHEMATICAL PARAMETERS FOR CATCHMENT REGIONALIZATION: A CASE STUDY OF THE OSUN DRAINAGE BASIN, NIGERIA

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ABSTRACT: *A protocol is proposed for the regionalization and subdivision of catchments based on hydrometric parameters. Such catchment regionalization may assist the development of appropriate catchment management strategies and policies. As a case study, the trends of variations in daily stage and discharge of seven gauging stations located in the 9,900 km² Osun Drainage Basin (South West Nigeria) were investigated. Linear regression models for all stations show the expected strong positive association of stage and discharge. The estimated daily changes explain only 1.44% of variations in stage, 0.25% variation in discharge and 99.5% in stage-discharge for station 5, 5.5% variation in stage, 0.7% variation in discharge and 99.7% in stage-discharge at station 25, and 10% variation in stage, 8.9% variation in discharge and 100% in stage-discharge at station 27. For the other studied stations,* R^2 *estimated from daily stage and daily discharge give widely varying patterns.* R^2 *estimated from daily stage and daily discharge is non-significant, but is significant for the daily stage-discharge relationship. The derived daily-stage and daily-discharge equations for the seven stations and their corresponding coefficients of determination can be used to classify the basin into three distinct zones. These are Zone I (coefficient of determination within the range of 0-6% for the daily-stage and daily-discharge), Zone II (coefficient of determination within the range of 7-10.5% for the daily-stage and daily-discharge), and Zone III (coefficient of determination within the range of 11-22% for the daily-stage and daily-discharge). The exponents of the stage-discharge equation can also be used for spatial classification. Zone A exponent is in the range of 1.3-1.7, Zone B exponent is in the range 2.2-2.3 and Zone C exponent is in the range 4.0-4.7. These can be combined to produce three hydrometric regions. It is proposed this regionalization protocol could be used as an initial step in dividing complex catchment systems into more homogeneous subunits, to assist subsequent catchment management and planning. The hydrometric regionalization protocol is now being evaluated on the Osun and other drainage basins in Nigeria.*

Keyword: *Derivation, Gauged and Ungauged Rivers, Drainage Basin, Power Equations*

INTRODUCTION

A proper understanding of the flow regime of rivers is essential for channel design and especially the estimation of flood discharges such structures could tolerate (Awokola and Martins, 2001). Solutions to such problems are necessary in any engineering activity connected with streams in which flow rates are stochastic in nature. Effective flood protection and erosion control schemes are among the challenges of hydraulic engineering, in which the inter-relationships between stream flow mechanics, dynamics and hydrology must be carefully studied and interpreted.

In Nigeria and other developing countries, there are problems of data inadequacy- frequent data gaps and non- existence of data at development sites - and these issues create serious design and project management problems (Sonuga, 1990). The most challenging situation exists when no flow records are available anywhere in the catchment. There are also other categories of ungauged catchment: (i) sites on a river where some tributaries are gauged, and (ii) sites on a river, which are gauged at one or more different locations upstream or downstream. In many aspects, even a site which has only several years of record must be evaluated as if it were an ungauged catchment, because the information usually requires augmentation. Even when models are constructed, they will require additional site-specific parameters to be defined for each application site (Beven, 2000; Awokola, 2001).

The derivation of relationships between hydrological variables is of great importance for the transfer of information from the few-gauged rivers to the many other rivers with hydrologically-similar catchments for which no stream flow data exist. We need an approach to ascertain the actual changes in hydrological response of a particular catchment within a drainage basin, which can reveal land transformations and interactions that occurred in the past. The 'region of influence' (ROI) approach adopted by Burn (1990) is limited to measures which do not rely on actual flow data. Regionalization or regional typification has been extensively analysed (Hosking *et al.,* 1985; Lettenmaier *et al.,* 1987; Chowdhury *et al.,* 1991; Hosking and Wallis, 1997). This approach entails inducing knowledge of the regional hydrological structure of the study territory on regional structure identified in a sample of gauged basins.

The aim of this study is to assess and evaluate the hydrologic response of seven gauging stations (catchment areas) in the Osun Basin of South West Nigeria that had one-year (1982) of complete hydrological record. Data analysis enabled the initial development of a regionalization protocol, based on analytically-determined hydrometric parameters. The results will hopefully be useful for engineers, conservationists and planners at gauged and ungauged sites and it will reveal the threshold of flood discharges required for the economic design of hydraulic structures and economic feasibility analysis of water resources management and environmental impact assessment of projects. In a previous study, Elkaduwa and Sakthivadivel (1998) observed that adverse environmental impacts were directly related to changes in flow regimes and that rapid runoff was responsible for high soil erosion rates, loss of land productivity and more frequent flash floods. The high rate of sediment supply due to accelerated erosion caused degradation of stream channels, increasing the likelihood of flash floods, deposition of coarse material and silting of irrigation canals.

THE STUDYAREA

The Osun River Basin occupies 9,900 km^2 and is located approximately between latitudes $6^0$30'N-$8^0$20'N and longitudes 4^0E-$5^0$10'E (Figures 1a and 1b). The Osun River - a major drainage system in South West Nigeria- rises in the Oke-Mesi ridge ~5 km north of Effon-Alaye and flows through Itawure, before flowing first westward through Osogbo and Ede and then southward to enter Lagos Lagoon. The main tributaries are the Oba and Erinle. The basin's climate is strongly influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), a quasi-stationary boundary zone that separates the sub- tropical continental air mass over the Sahara and the equatorial maritime air mass over the Atlantic Ocean.

The ITCZ moves northwards beyond the basin at the peak of the rainy season in June and July, and southwards to the coast, in the middle of the dry season in December and January. Data obtained from stations in the basin show that February and March are the hottest months in the year. The mean daily maximum temperature for February is 31.4 ^{o}C in the south and as high as 34.6^{o}C in the north. The main feature of the rainfall pattern is its seasonal distribution. The rainy season begins earlier in the south, usually commencing in March, and continues until late October or early November.

Cretaceous sedimentary rocks are present in the southern section of the Osun Basin. The remaining sections are composed of crystalline rocks of the Basement complexes, which belong to the older Intrusive Series (Jones *et al*, 1964).

MATERIALSAND METHODS

There are 16 stream gauging stations in the Osun River Basin and 17 such stations in the Ona RivBasin and its tributaries Ibu and Omi (Tahal Consultants, 1982). The seven stations used in this study are shown in Fig.1a. They are monitored by Oyo and Osun State Water Corporations. Rating tables are available for all gauging stations (Table 1). Some 2,555 daily stage data for the seven stations were subjected to statistical analysis. All stage information was used with the available rating tables for each station to derive the rating equations in Table 2. The derived equations were used to predict discharge values for the range of daily stage available and the monthly maximum discharge for each station was calculated using the maximum stage and appropriate derived equation. The trend in daily stage and stream flow were analysed using the conventional techniques of linear regression models.

Table 1: List of Gauging Stations, Rivers and Locations

Rivers	Location	Gauging Station Number
Osun	Asejire	5
Osun	Iwo-Railway Station	25
Osun	Ede	27
Oba	Awe/Ife-Odan	35
Oba	Oyo/Ogbomosho	39
Osun	Ilase	52
Osun	Esa-Odo	64

RESULTS AND DISCUSSION

The power equations derived for stations 5, 25, 35 and 52 and the second-degree polynomial equations derived for stations 27 and 35 gave a perfect fit. Stations 39 and 64 showed good and perfect fit for the power and polynomial equations within the limits or range shown in Table 2. Analysis of Station 35 data showed that both power and polynomial equations gave a perfect fit, with coefficients of determination of $r^2 = 0.9988$ and 0.9995, respectively. Further investigations of physical and hydro-topographical parameters of the basin are required to ascertain the basis for the differences in the mathematical results between the stations. The trends of variations in daily stage and discharge are shown graphically in Figures 2-5; while the summary of the derived relations are reported in Table 3. The linear regression models for the entire stations show an increasing trend of both stage and discharge (Table 3). The coefficients of determination (R^2)

Table 2. The Derived Rating Equations for each Station

Stations	Derived Rating Equations (m^3/s)	Type of Equation	Remark
5	$Q_5 = 17.36H^{2.27}$	Power	Perfect Fit
25	$Q_{25} = 8.23H^{3.99}$	Power	Perfect Fit
27	$Q_{27} = 0.24H^{4.73}$	Power	Poor Fit
	$Q_{27} = 10.06H^2 + 15.67H - 62.39$ **($r^2 = 0.996$, $r = 0.998$), n = 2,555**	2nd Degree Polynomial	Perfect Fit
35	$Q_{35} = 7.44H^{1.59}$	Power	Perfect Fit
	$Q_{35} = 2.47H^2 + 8.02 - 2.78$ **($r^2 = 0.999$, $r = 0.9995$), n = 2,555**	2nd Degree Polynomial	Perfect Fit
39	$Q_{39} = 4.96H^{1.68}$	Power	Good Fit (Range 0.03-3.15 m)
	$Q_{39} = 6.87H^2 - 11.11H + 5.71$ **($r^2 = 0.993$, $r = 0.9965$), n = 2,555**	2nd Degree Polynomial	Good Fit (Range 2.01m and above)
52	$Q_{52} = 2.56H^{2.24}$	Power	Perfect Fit
64	$Q_{64} = 6.25H^{1.25}$	Power	Good Fit (Range 0.03-2.4 m)
	$Q_{64} = 3.14H^2 - 0.14H - 0.96$ **($r^2 = 0.9989$, $r = 0.999$), n =2,555**	2nd Degree Polynomial	Perfect Fit

All r coefficients significant at P<0.001.
Source: Awokola (2003).

Table 3. The Daily-Stage, Daily-Discharge and Stage-discharge Equations

Station	Stage-Discharge	Equation	Coefficient of Determination (R^2) %	Zone
5	Stage (m)	$H^5 = 0.0005x + 0.3866$	1.44	I
	Discharge (m^3/s)	$Q^5 = 0.0111x + 5.5639$	0.25	I
	Stage-Discharge (m^3/s)	$Q^5 = 17.36H^{2.27}$	99.5	
25	Stage (m)	$H^{25} = 0.0012x + 1.0459$	5.51	I
	Discharge (m^3/s)	$Q^{25} = 0.101x + 37.657$	0.66	I
	Stage-Discharge (m^3/s)	$Q^{25} = 8.23\ H^{3.99}$	99.7	
27	Stage (m)	$H^{27} = 0.0016x + 2.4032$	10.05	II
	Discharge (m^3/s)	$Q^{27} = 0.1107x + 34.783$	8.89	II
	Stage-Discharge (m^3/s)	$Q^{27} = 0.24\ H^{4.73}$	100	
35	Stage (m)	$H^{35} = 0.0029x + 0.0843$	19.3	III
	Discharge (m^3/s)	$Q^{35} = 0.0349x - 2.2518$	17.1	III
	Stage-Discharge (m^3/s)	$Q^{35} = 7.44\ H^{1.59}$	100	
39	Stage (m)	$H^{39} = 0.0012x + 0.7247$	3.57	I
	Discharge (m^3/s)	$Q^{39} = 0.0094x + 3.9889$	2.64	I
	Stage-Discharge (m^3/s)	$Q^{39} = 4.96\ H^{1.68}$	96.7	
52	Stage (m)	$H^{52} = 0.0033x + 0.8655$	21.05	III
	Discharge (m^3/s)	$Q^{52} = 0.0369x + 1.6053$	14.67	III
	Stage-Discharge (m^3/s)	$Q^{52} = 2.56\ H^{2.24}$	99.9	
64	Stage (m)	$H^{64} = 0.0034x + 0.7541$	18.97	III
	Discharge (m^3/s)	$Q^{64} = 0.0332x + 0.838$	15.03	III
	Stage-Discharge (m^3/s)	$Q^{64} = 6.25\ H^{1.25}$	92.28	

estimated from daily stage and daily discharges are not significant, but are significant for the daily stage-discharge relationships.

The derived daily-stage and daily-discharge equations for the seven stations and their corresponding coefficients of determinations have been used to subdivide the basin into three distinct zones, based on the proposal of Solin (2005) that selected sets of gauged basins should represent the whole population of basins. These are Zone I (coefficient of determination within the range 0-6% for the daily-stage and daily-discharge), Zone II (coefficient of determination within the range 7-10.5% for the daily-stage and daily-discharge), and Zone III (coefficient of determination within the range 11-22% for the daily-stage and daily-discharge) (Table 4). The exponents of the stage discharge equation have been used as the basis of an additional classification system. Zone A exponent is in the range 1.3-1.7, Zone B exponent is in the range 2.2-2.3 and Zone C exponent is in the range of 4.0-4.7 (Table 4). The two methods of zoning were combined, as shown in Table 5, to produce a unitary zoning system. Thus, Zone A_u includes stations 35, 39 and 64; Zone B_u includes stations 5 and 52 and Zone C_u includes stations 25 and 27. The derived unitary zoning of hydrometrically-similar catchments within the Osun River Basin is presented in Figure 6.

Table 4: Classification of the Basin into Zones

Zone	Station number	Criteria
I	5,25 & 39	R^2: range 0-6%
II	27	R^2: range 7-10.5%
II	35,52 & 64	R^2: range 11-22%
A	35,39 & 64	Exponent: range 1.3-1.7
B	5 & 52	Exponent: range 2.2-2.3
C	25 & 27	Exponent: range 4.0-4.7

Table 5: Combination of the two derived zones

Station No.	Zone	Zone	Joint Zones	Groupings	Unitary Zone
5	I	B	IB	IB, IIIB	
				5, 52	B_u
25	I	C	IC	IC, IIC	
				25, 27	C_u
27	II	C	IIC		
35	III	A	IIIA	IIIA, IA, IIIA	
				35, 39, 64	A_u
39	I	A	IA		
52	III	B	IIIB		
64	III	A	IIIA		

It is proposed that this regionalization protocol could be used as an initial step in dividing complex catchment systems into more homogeneous subunits, to assist subsequent catchment management and planning. The regionalization protocol is now being evaluated on the Osun and other drainage basins in Nigeria.

CONCLUSIONS

The derived daily-stage and daily-discharge equations for the seven stations and their corresponding coefficient of determinations were used to classify the Osun basin into three distinct hydrometric zones. These were Zone I (coefficient of determination within the range 0-6% for the daily-stage and daily-discharge), Zone II (coefficient of determination within the range 7-10.5% for the daily-stage and daily-discharge) and Zone III (coefficient of determination within the range 11-22% for the daily-stage and daily-discharge). The exponents of the stage-discharge equation were used for another classification, Zone A exponent in the range 1.3-1.7, Zone B exponent in the range 2.2-2.3 and Zone C exponent in the range 4.0-4.7. The combination of the two zoning methods resulted into three distinct unitary zones: A_u for stations 35, 39 and 64; B_u for stations 5 and 52, and Zone C_u is for stations 25 and 27. These results can be used for preliminary selection of hydrometrically-similar catchments within the Osun basin. Further investigations of basin hydrometric parameters are required to ascertain the basis for the difference in the mathematical results for the stations. An optimized hydrometric regionalization protocol could provide a useful tool for catchment evaluation and management in Nigeria and beyond.

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