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Channel and Morphological Response of Two Watersheds to Urbanization in Benin City, Edo State, Nigeria

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ABSTRACT Two rivers (Ikpoba and Ogba) studied in Benin City show that stream channel alters due to change in stream flow regime brought about by the conversion of the natural cover to different land uses as a result of urbanization. Stream channels draining areas subjected to impervious land uses tend to develop relatively large stream channel bank full cross-sectional areas than those draining areas under pervious land uses. The primary effect is induced velocity by way of increased discharge. Consequently, and as a secondary effect, there is a tendency for channel enlargement.

INTRODUCTION

There is a growing interest in the effects of urbanization on hydrological cycles as well as on stream morphology and dynamics (Anderson, 1970). In other words, progressive change in land use and vegetation accompanied by increase in impervious surfaces will result in such phenomena as increase in runoff ratio, the amount of peak discharge and the rate of stream flow. Closely linked with this is the draw down effect of the ground water level. The focus of this paper is the examination of the response of channels to increase in peak flow brought about by urbanization.

Previous studies have shown that progressive urbanization of a drainage basin can result in changing channel morphology and hydraulic geometry of stream channels (Troxell and Leopold, 1971; Hammer, 1972; Knox, 1977; Knight, 1979; Morisawa and Vemure, 1976; Morisawa and Laflurem 1979; Ebisemiju, 1989). Disturbed watershed will respond by both morphologic and hydraulic variables alterations (Simon, 1992, Simon and Hupp, 1992; Oyegun, 1984, 1994; Church 1992; Pizzuto, 1994; Elliot and Gyetvai, 1999).

Notwithstanding the growing literature on the effect of urbanization on stream channel morphology, none of these investigations have examined the implications of these increased flows on channel size and hydraulic geometry response in detail particularly in Nigeria (Odemerho, 1980). Again, despite the importance of these results, there still remains a great shortage in quantitative data on the effects of urbanization on stream system (Miller et. al, 1971). The present study is aimed at analyzing the impact of urban development on the studied watersheds and to use the results thereof as guiding principles for watershed management.

STUDY AREA AND METHODOLOGY

The study was conducted in both the Ikpoba and Ogba River basins, Benin City, Edo State, Nigeria. The Ikpoba basin drains approximately 520.3km^2 (Aziegbe, 2003) while the Ogba basin drains approximately 340.1km^2(Fig.1a-d). Both catchments' areas are underlain by deeply weathered sedimentary rock that is often referred to as the Benin formation (Ogunkule et. al, 1980). The topography is undulating with a relative relief of 12 meters (Odemerho, 1992). Rainfall distribution is fairly uniform and the climate is tropical moist. Tropical rainforest, which has now been removed by farming and urbanization, is the natural vegetation of the watersheds (Odemerho, 1992). Today the rainforest is nothing more than a gallery of riparian forest bordering stream channels and valleys. The rest of the catchment's areas remain a mosaic of farmlands, fallow bushes at various stages of maturity, and urban uses. Benin City is an ancient city dating back to the 12th century, although modernization and rapid urbanization began in the late 60s (Onokerhoraye, 1977). Ever since, the built up area of the city has increased some 15 folds (Ozo and Ikhuoria, 1983). However, rapid urbanization has been going on without commensurate basic runoff disposal facilities (Omuta, 1987). During storms, large quantities of runoffs flow freely into these rivers.

These large inputs of sediments and runoffs are responsible for channel enlargement experienced within the urban reaches of these rivers.

Stream response to urbanization was studied adopting the inferred method, which involved the comparison of stream section in basins under different land use stages. Two major rivers were investigated. They are the Ikpoba and the Ogba river watersheds with approximate areas of 520.3km^2 and 340.1km^2. The studied channels are headwater tributaries of these major rivers. Channel morphology was measured using tape, level rod and hand leveler to acquire detailed bankful cross-sectional data. Velocity measurements were made using a horizontal axis-ott type current meter mounted on a wading rod. At times, velocity was estimated using float method especially when the water becomes too shallow and velocity too low to adopt the conventional discharge measurements. Flood discharge measurements were made by estimating discharge from a gauge on a bridge abutment at which detailed cross section has been made. Land use data was obtained from aerial photographs of scale 1:40,000 stereoscopically. These were truthed by fieldwork.

Impervious area was determined from a land use map of scale 1:15,000 and large-scale aerial photographs of scale 1:6000. From a relatively similar development, the number of homes were counted and multiplied by average floor size for the development as determined by map inspection. In the case of irregularly shaped or inconsistently sized homes or other structures, the areas were accumulated by outlining them on a tracing paper and measuring their total area. The percent area made impervious for each zoning areas was calculated by summing the area of homes, streets, parking lots and other structures and dividing through by the area of the zoning category as arrived at by planimetering. The basins were transacted. Two variables as related to landuse and topographic parameters were measured for each transect. Each parameter was considered as mean for land in the transact. Land in each transect was divided into 10 categories and land made impervious was the major concern. Impervious land implies roads, houses, commercial buildings, sewers and airport runways and developed lands. Lands under cultivation as well as wooded lands represented non-impervious surfaces. Topographic and drainage parameter for each transect include average land-shape, slope of flow path from the transect to stream and channel slope profile.

RESULT AND DISCUSSION

It was found that stream basins in the impervious areas display larger stream baneful cross-sectional areas as compared to those under the non-impervious areas (Table 1).

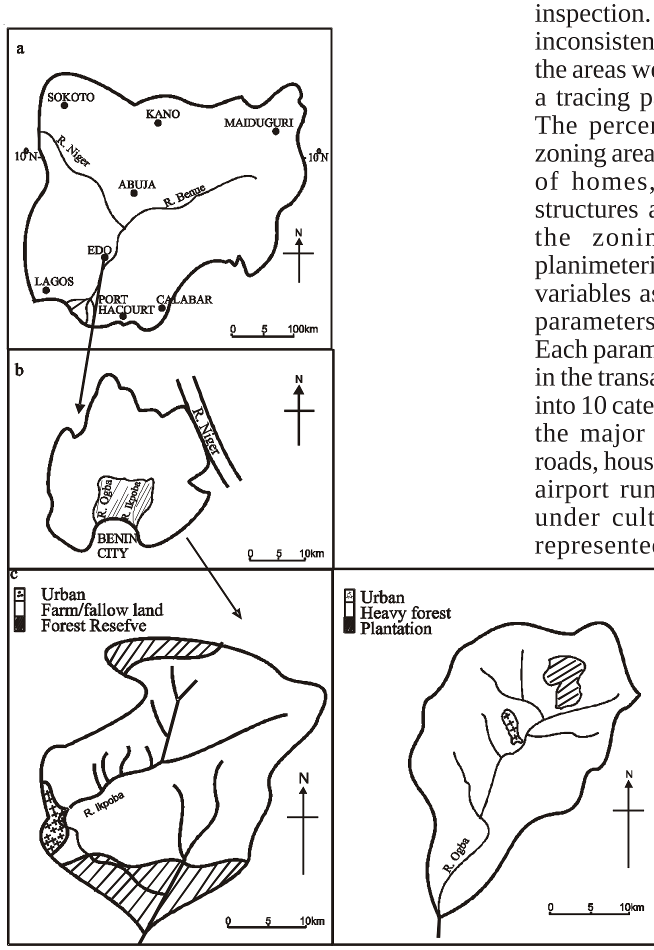

Fig. 1. Ikposa and Ogba river basins, Benin City, Edo state, Nigeria

Table 1: Stream variations in relations to landuse

Basin Surface Landuse	*Average Bank full stream Cross-sectional*		*x for impervious and non-impervious*	
	Ikpoba	*Ogba*	*Ikpba*	*Ogba*
Impervious				
Road	6.32	3.01		
Commercial Building	7.32	3.04	$6.54km^2$	$5.50km^2$
Houses	10.05	6.33		
Airport run-way	4.21	12.04		
Sewers	4.46	8.33		
Non-Impervious				
Cultivate land	2.23	3.12		
Undeveloped land	1.03	1.00	$3.46km^2$	$4.50km^2$
Wooded land	1.00	1.01		

Source: Fieldwork 2004

Channel size tends to vary within each land use category depending on whether impervious or non-impervious surface. However, the average channel size for basins under impervious and non-impervious landuse is $6.54m^2$ and $4.26m^2$. But channels within the vicinity of impervious land uses have a mean channel size of $8.56m^2$. Hammer (1972) and Dune and Leopold (1978) showed that channel size is best expressed as a function of watershed size. Figures 2 and 3 is a plot showing stream channel cross-sectional area as a function of drainage area under impervious and non-impervious land uses. This shows that the cross-sectional areas for channels draining pervious areas lie above the mean line representing unaltered natural basins. Channels draining impervious areas lie below the mean line. The scatter-plot reveals that channels under non-impervious catchments are similar to one another whereas the points scatter displayed among points representing impervious and non-impervious basins reflect the disturbance introduced into the fluvial system by human land uses.

Some level of relationship expressed between channels size and basin area for the two categories of basins are shown as:

$$C = 0.885Di^{0.54} \quad (1)$$

and

$$C = 1.56Di^{0.46} \quad (2)$$

Where C is bankfull channel cross-sectional area and Di and Dii being impervious and non-impervious drainage basins. The exponents in equations 1 and 2 confirm that stream channel cross-section increases by the basins dominant landuse, which in this study, are impervious and non-impervious. Stream channel tends to increase farther in basins under impervious landuse than basin under non-impervious as shown by the exponent's values of 0.54 and 0.46. By proposing an assumption of uniform climate and relief conditions, stream channel size could be explained within the context of hydrological implications. In other words, relatively large channel size of streams draining impervious basins could be due to increased peak discharges. On the other hand, the relatively smaller channel size of streams draining fallow basins could be due to low flow peak discharges brought about by high infiltration capacity. Studies by Fox (1976), Morisawa and Vemuri (1976), Hammer (1972, 1973), Kowal (1970), Odemerho (1984,1992) and Aziegbe (2003) support this finding.

At-a-Station Hydraulic Geometry Under Pervious and Impervious Landuses

When a stream is affected by a change in discharge or sediment delivery of sufficient magnitude, it usually enters a period of instability. During this period, changes in system morphology occur which restore stability as the system adjusts to a new steady state condition (Pickup, 1975). Since Leopold and Maddock's (1953) contribution on hydraulic geometry, it has become a common practice to organize a mass of hydraulic data from a drainage basin as plots of channel flow parameters against different discharges. Continuity equations show that with increasing discharge, width, depth and mean velocity increased according to simple power functions.

$$W = aQ^b, D = cQ^f, V = kQ^m$$

Where: Q is discharge; W, D and V are width, depths and velocity respectively. The values a, c, and k are intercepts of the regression lines and the exponents b, f, and m, are the slopes of the regression lines when the hydraulic parameters are plotted logarithmically.

In order that too much discrepancy did not set in to alter the result of this study, basins similarity in terms of relief, gradient and other physical characteristics were selected for use in the analysis. This decision helps to ensure that the hydraulic exponential values reflect the dominant landuse in the basins, which make stream channel changes comparable (Table 2).

A unit regression analysis was performed to

Table 2: Geographic characteristics of stream basins studied

	Ikpoba	*Ogba*
Altitude (max. in m)	12m	12m
Slope (m) (x)	5^0	3^0
Size (km^2)	520.3km^2	340.1km^2
Area made Impervious (%)	54.4%	38.3%
Area non-Impervious (%)	54.6%	61.7%

Source: Fieldwork, 2004

determine the at-a-station relation of stream width, depth and velocity to changes in stream discharges associated with dominant land uses in the basins. The variables were first transformed to logrimathic units in order to yield linear relationships and increase the precision of correlation and regression analysis. This is in conformity with studies done elsewhere (Leopold, et al. 1964) in which it was shown that many geomorphic and hydrologic variables show logarithmic relationships. For the 4 stations monitored for data purposes for this study, the rates of change revealed in exponential values varies within and among basins.

The second form of adjustment represents stream stations where urban development has long ceased in its immediate upstream stations. As shown in Table 3,and Figures 2 and 3, three stations displayed the **m>f>b** pattern while one (the Ikpoba downstream station), displayed the **f>m>b** pattern.

Table 3: At a station hydraulic geometry

Watershed Names	*W = aQb*	*D = cQf*	*V = kQm*
	Hydraulic geometry		
	b	*f*	*M*
Ikpoba upstream	0.06	0.45	0.53
Ikpoba downstream	0.07	0.5	0.4
Ogba upstream	0.05	0.44	0.50
Ogba downstream	0.08	0.43	0.48

Source: Statistical Analysis

DOWNSTREAM HYDRAULIC VARIABLES

The Term ‘downstream’ does not necessarily refer to actual downstream changes along a single channel. In studies of downstream hydraulic geometry, the emphasis is on regional relationships between points on channels located in topologic space (Gippel, 1985). However it represents the co-variations of hydraulic geometry

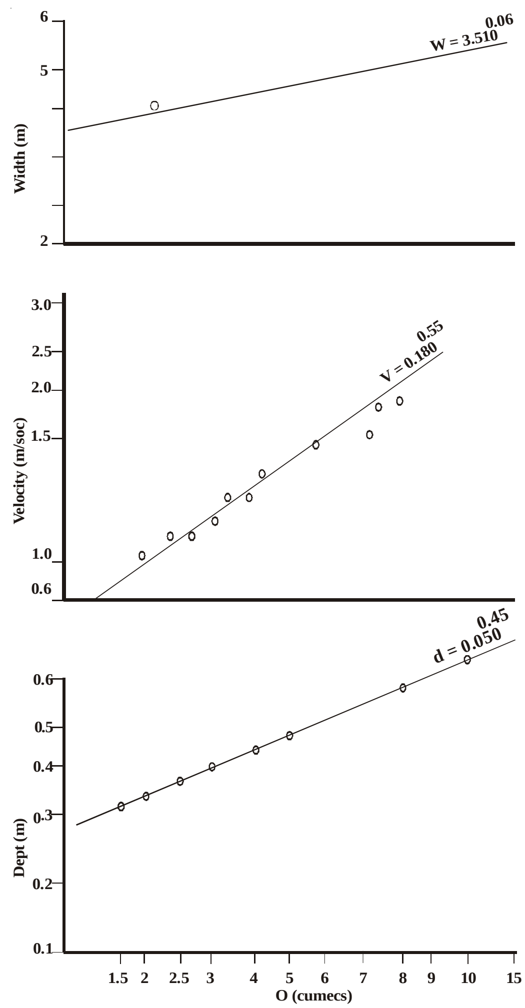

Fig. 2. Width, depth and velocity adjustment to discharge at Ikpoba

parameters when discharge is increased in downstream direction from a reference point. As with the at-a-station plots, the downstream measurements were taken in each individual watershed on the same day, assuming that approximately the same flow frequency is thus represented at each transect.

While the Ikpoba River accommodates increasing discharge downstream by adjusting the width (large b-exponent), the Ogba River tends to increase the flow velocity (large m-exponent) downstream. For both rivers, the hydraulic exponents reveal a considerable enlargement of their channels downstream.

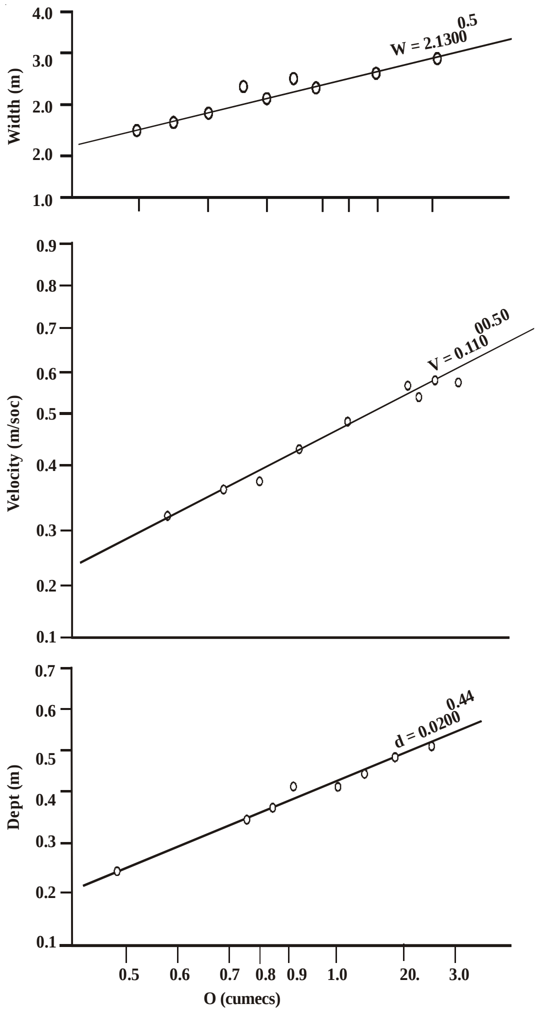

Fig. 3. Width, depth and velocity adjustment to discharge at Ogba

Although the variations in their width (b-exponents) are small, the changes are significant.

DISCUSSION

The study indicates that urbanization in the watersheds studied has brought about pronounced changes in stream flow regimen, with consequent impacts on both immediate stream channel response to stream flows and long term morphological character. Channel enlargement appears to be directly related to increased flood magnitudes, but channel enlargement does not keep pace with increasing flood magnitudes in a 1:1 manner. This presupposes that increased flood flows are partially accommodated by increased over bank flow or increases in peak flow velocities which may represent an intermediate step in the long term equilibrium adjustment of a stream to changing hydrologic regimen, with consequent impacts on both immediate stream channel response to stream flows and long term morphological character. Channel enlargement appears to be directly related to increased flood magnitudes, but channel enlargement does not keep pace with increasing flood magnitudes in a one-to-one manner.

The rates of change for all the stations as revealed by the exponents have the general form $m>f>b$. This is an indication that with changing discharge, velocity increases at the highest rate while width increase at the lowest rate. The second trend of adjustment found in this study is of the form $f>m>b$ as in Ikpoba downstream. The first form of adjustment is associated with stream stations whose immediate upstream areas are under rapid urban development. A geomorphic threshold appears operational in the relationship of impervious areas versus channel adjustment ratio or ratio of mean flood, such that above a certain impervious cover or degree of development, a radical increase in the effects of flood magnitudes and channel enlargement results. This finding is in agreement with that of Laflure (1978). Schum (1968) and Lewis (1968) noted in their studies that the effect of channel slope, nature of channel material, bed load, the local lithology, flow regime and amount of water flowing within the channel also contribute to the values of the exponents. In this study, channel shape as depicted in the measuring locations shows that lithology, to some extent, are similar in all the stream sections studied such that the exponents could fairly be related to the differing flow regimes associated with basin surface landuse phases.

Lewis (1966) points out that low flow hydraulic geometry relations are different from those obtained at moderate to high flows. He states further that channel irregularity results in marked break-of slopes in hydraulic geometry relationships. He concluded that there is one set of relations up to bank-full state, where width increases rapidly with relationships at bank-full and above, where width increases slowly with large increase in depth. Laflure (1978) notes that this type of relationship is due to the particular cross-section form. Studies by Lewis (1966) and as Richards (1976) indicate that a variety of likely relationships are possible, depending on the channel configuration. Thus, keeping the parameters that are likely to affect the hydraulic exponents as indicated by Lewis (1966) and Richards (1976), all flow measurement was taken at low flows and single bank-side angle. Morisawa and Laflure (1979) and Odemerho (1984) hold the same assumption in order to relate the exponent values to the various stages of urbanization in their studies. The variations noted in the exponents in this study therefore relates to the differences in flow regime associated with the different landuse stages of the basins.

CONCLUSION

Studies in urbanization watersheds, stream channel in Benin City is demonstrated to be consistently larger for basin under impervious land uses than those under non-impervious land uses. The foremost effect of urbanization is increased runoff. The streams adjust to this increased storm flow by first increasing its velocity and later enlarging its channel to accommodate the discharge, and eventually decreasing over bank folding and velocity. These changes, which are in a state of flux, will continue until a new equilibrium state is reached. But should changes continue in the basins, the equilibrium state becomes unattainable unless urbanization ceased.

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