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Morphologic alterations to Jakara channel due to urbanization

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ABSTRACT

This study assesses the impact of urbanization on the Jakara stream channel - a semi arid area that has received little attention. The proportion of the catchment under impervious cover was determined along the Jakara catchment using black and white air photographs taken in 1961and 1981 satellite imagery of 1987, 1995 and 2006. These were used together with land use maps, road maps and layout plans and ground truthing. Consistent and significant differences in the sites were demonstrated in bankfull width, depth, cross section and wetted perimeter. Channel density increased by 28.6% due to storm sewers, culverts and other runoff removal. About 99 percent of the Jakara channel banks in the urban reach and 30 percent n the semi urban reach are artificially reinforced to prevent channel widening by bank erosion. In addition, residential and commercial landowners filled the channel margins to increase property acreage. Physical channel structure has changed from a pool/riffle sequence to a uniform pattern. Results obtained here show that there are major alterations to the morphology of drainage systems. They need to be taken into account to better understand the hydrologic response of anthropogenic basins, and to improve the modeling, planning and design of sub-urban and urban areas. Finally, a series of advantages of this approach are also discussed.

Introduction

Urbanization of river basins has been associated with serious problems that dramatically degrade both the form and function of stream ecosystems that can be difficult to mitigate (Booth and Jackson 1997). These impacts have recently been referred to as Urban Stream Syndrome (Paul and Meyer 2001).

Studies of urbanization impacts on river systems in Nigeria have concentrated in the humid tropics of south west and south east (Jeje and Ikezeato, 2002, Ebisimeju, 1989ab, 91, Odemerho, 1984, 1991). There have been no such studies in the semi arid northern part that have different hydrological characteristics with perennial streams, and particular dynamics that may induce urbanization effects different from those in these regions and elsewhere, consequently urban-induced channel changes in places like Jakara catchment are largely matters of anecdotal information with serious gaps in both our knowledge and the data. This makes it difficult to establish proper understanding required to proffer suitable mitigation measures.

More significant is the fact that the quantification of changes to the structure of the drainage patterns caused by urbanization has not been developed in detail, and no formal methodologies are used to characterize urban basins from a morphological point of view. As a result few studies have been conducted to describe the morphology of drainage networks in urban areas, and the idea of relating the shape of the hydrologic response to the morphological characteristics of urban areas has been examined even less (Rodriguez *et al*., 2003, 2005).

The aim of this study is to assess the impact of urbanization on channel morphology of Jakara stream Kano, Nigeria; by comparing channel reaches under different levels of urbanization. This approach can give innovative tools to evaluate the impacts of urbanization, and, to better characterize the response of urban basins to such disturbances.

Study Area

The study is on the Jakara River catchment which is located between latitude 12^o 25 to 12^o 40 N and longitude 8^o 35 to 8^o 45E.It traverses the ancient city of Kano. The present climate of the study area is the tropical wet-end-dry type which is characterized by a wet season that lasts between June and September during which about 800mm of rain occur. Temperature is high throughout the year however, climate changes have occurred ending about 10,000 years BC (Grove and Warren, 1968). During the arid phases desertic conditions are believed to have prevailed. On the other hand humid conditions wetter than the current tropical wet climate prevailed during the fluvial phases.

The study basin is located on the Basement Complex, and within the area where a wind drift material (a silty wind-blown deposit of the last arid phase) has concealed the pre-arid regolith and its associated ferruginous soils on the upland plain and old alluvial deposits on the river terraces. The silty surface cover impedes infiltration because initial splashes create puddles which block the tiny pores. However, the material on the channel beds is very sandy (at least 60% medium to coarse sand), porous and seasonally mobile.

Urbanization along the Jakara channel is not uniform. The main concentration of urban surface is at the upper course where the catchment is 100% under impervious cover. The middle course is a transition area experiencing very rapid change from rural to urban with the urban surfaces covering about 33%. The lower course is generally rural, with urban areas covering less than 3% of the catchment. A detailed study of land cover along the Jakara catchment was conducted using black and white air photographs taken in 1961and 1981. These were used together with land use maps, road maps and layout plans to determine the extent of urban land use from 1961 to 1981 along the catchment.

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Up to 1961, the amount of urban structures on the Jakara catchment is minimal and this is a period of low urbanization with less than 5% urbanization of the watershed. In addition, urban structures were not impervious (houses were made of up mud and most of the roads were laterite covered) and well outside the channel. A substantial part of the catchment is used for agriculture and grazing only. The amount of urban development within the Jakara watershed increased substantially from 1987, the period of high urbanization. When expressed as percentage of the total catchment area, the amount of the amount of urbanized land increased from 4% in 1961 to 27.95% in 1987. Figs. 3, 4 and 5, were produced with data from Landsat imagery interpretation followed by intensive field verification show land use changes along the Jakara catchment for the years 1987, 1995 and 2006. The main concentration of urban/impervious surface is at the upper course where the catchment is 100% under impervious cover. The middle course is a transition area experiencing very rapid change from rural to urban with the impervious surfaces covering about 13%. The lower course is generally rural, with impervious areas covering only about 3% of the catchment.

Fig. 3 Land use along the Jakara catchment Kano metropolis, 1987

Fig. 4 Land use along the Jakara catchment Kano metropolis, 1995

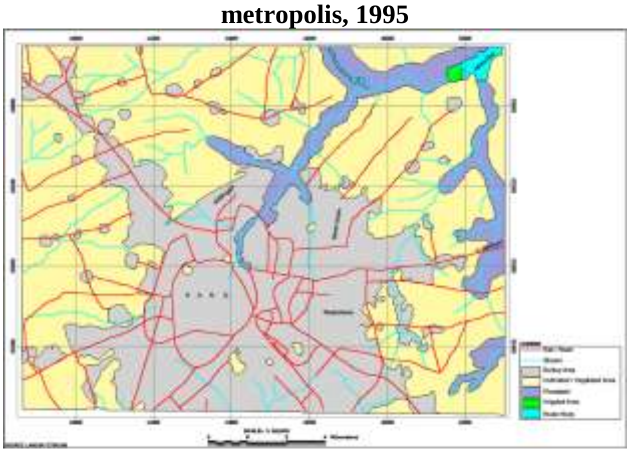

Fig. 5 Land use along the Jakara catchment Kano metropolis, 2006

Analysis of types of impervious cover in the Jakara channel (Table 1) revealed that rooftops alone constitute the major impervious surface in the urban and semi urban sites of the Jakara catchment as opposed to the cases reported in Europe and North America, where the transport component exceeds the rooftop component in terms of total impervious area created. For example, transport-related imperviousness comprised 63 to 70% of total impervious cover at the site in 11 residential, multifamily and commercial areas where it had actually been measured (City of Olympia, 1994b). This phenomenon reflects the ascendancy of the automobile in both culture and landscape in the Europe and North America. Furthermore, in Europe and North America, zoning has strongly emphasized and regulated the first component (rooftops) and largely neglected the transport component. While the rooftop component is largely fixed in zoning, the transport component is not. This is not the case in the Jakara catchment where rooftops are the dominant impervious cover and where the road component had not changed in 40 years (Table 1).

Table 1 Proportion of Impervious Cover in the Sampled Reaches of Jakara channel

characteristics	Rural reach	Semi urban reach	Urban reach
Total area(m^2)	17.5	15.0	17
% Roads	0.01	0.30	0.80
% Flood plain	5.20	6.10	NIL
% Buildings	2.60	28.0	99.0
% Cultivated area	80.0	5.60	NIL
% Irrigated area	11.0	9.00	NIL
% Water body	0.30	0.60	0.20
% Total impervious area	2.61	28.3	99.8

Source: Land use Map of Kano Metropolis, 2000, Land sat Imagery of Kano 1987, 1995, 2006 and Field work, 2008

Methodology

The impact of urbanization on the Jakara channel was studied by comparing sections of the channel under varying intensities of urbanization.

Site and reach selection

Based upon the degree of urbanization, Jakara stream was divided into three sites with different levels of urbanization

a) An upper watershed dominated by urbanization (Fagge/Airport road/Nomansland)

b) A middle section that is under going urbanization exurban/semi urban (Gama kwari)

c) A lower watershed that is primarily rural (Dosara/Yadakunya)

The sites were selected after a field reconnaissance to establish that they conform to convention as demonstrated by Neller, (1988), May *et al*., (1997). Efforts were made to best represent the end members of the range. The percentage of impervious land was treated as an estimator of the percentage of land experiencing urbanization.

Having determined the three sites along the Jakara channel, two reaches were selected from each of the three sites for detailed study. Fig.2 shows the location of the six sample reaches along the Jakara channel.

The sample reaches were determined after a field reconnaissance to assess the overall character and the diversity of the channel morphology. Distortions especially points where a tributary or sewer joins the channel were avoided (Turner *et al*.,; Klauda *et al*., 1998, Booth and Jackson,1997, Vannote *et* *al.*, 1980, Hynes 1975). The selected reaches were transacted to measure the morphological variables.

Fig.2 Sampled reaches along the Jakara channel

The following channel morphological variables were measured in the profiles at each of the six selected reaches:

Channel full dimension parameters: Cross section; Width; Depth; Wetted perimeter; Land use and Slope.

Channel Planform dimension parameters: Meander length; Meander width; Sinuosity and Number of threads (single or multiple)

Channel morphology was measured using tape, level rod and hand leveler to acquire detailed bankful cross-sectional data. Impervious area was estimated from airport photographs, land use maps, roadmaps, layout plans and land Landsat imagery and road map of Kano metropolis. The percent area under urban development (impervious cover) for each site was calculated by summing the area of homes, streets and other structures and multiplied by average size of the development as determined by map inspection. These were truthed by fieldwork.

Results and discussion

Table 2 shows the morphological characteristics of full channel dimension of the six sampled reaches. The mean channel width is 12.73m with standard deviation of 3.78 and coefficient variation of 29.8 percent and a range of 10.8. The mean cross-sectional area is 24.54m^2 with standard deviation of 17.37, coefficient of variation of 70.8 percent and a range of 6.59. The mean depth is 1.71m, standard deviation of 0.81 and coefficient of variation of 47.4 percent and a range of 2.11.The mean wetted perimeter is 18.43m, standard deviation 2.69, coefficient of variation 14.6 percent and a range of 6.59. The statistics show a high degree of variation in the channel dimension considering that it is a 3rd order stream; this is reflected in the high variation between standard deviation and mean value and the range. However, all the variables of full channel dimension show that the urban reach is larger than the semi-urban and rural reach.

Table 2 Channel Full Dimension Variables

Chanel reach	Width (m)	Depth (m)	Cross section m^2	Welted parameters m)
I	18.80	2.81	52.83	16.01
II	16.70	2.53	42.25	14.97
II1	10.75	1.80	19.35	17.11
1V	12.11	1.62	19.62	18.97
V	8.10	0.79	6.34	20.90
VI	9.90	0.69	6.83	22.60
Mean	12.73	1.71	24.54	18.43
Stand Deviation	3.79	0.81	17.37	2.69
Range	10.0	2.11	46.49	6.59
Coeff of variation	0.298	0.474	0.708	0.146

Source: Fieldwork, 2008

The observed variation between the reaches can be explained by the fact that increased impervious surface in a catchment associated with urbanization causes increased surface runoff (Hollis, 1975), leading to increased channel erosion (Trimble, 1997).The higher flow events of urban streams are capable of performing more "effective work" in moving sediment than they had done before (Wolman, 1964). Thus, response of urban channels is to increase their cross sectional area to accommodate the higher flows. This is done by streambed down cutting or stream bank widening, or a combination of both. Consequently, urban stream channels often enlarge their cross-sectional areas by a factor of 2 to 5, depending on the degree of impervious cover in the watershed and the age of development (May *et al.*, 1997; Avolio, 2003; Othitis *et al.*, 2004; Brierley and Fryirs, 2005; among others). On the other hand, the relatively smaller channel size observed in the rural and reaches could be due to low flow peak discharges brought about by high infiltration. Plate 1 shows a typical section of the widening urban channel with bank susceptible to erosion and collapse. Rural channel reduction could be also due to fluvial deposit that results in infilling by deposition of sediments from the urban reach and the abandonment of the former summit by running water.

Plate 1 Bank susceptible to erosion and collapse in the Rural Reach of Jakara channel

Data in Table 3 indicate that width/ depth ratios are higher in the urban reach compared to the semi-urban and rural reach. In the urban reach, the width of the meander belt is lower than that of semi urban (5.95m vs. 11.75m), whereas, rural reach has a wider average width of the meander belt than semi urban and urban reaches (34.55m).

Table 3 Comparison of Reach Planform Dimension Variables

Channel characteristics	Urban Reach	Semi-Urban Reach	Rural Reach
Meander length (m) (mean)	5.95	11.75	34.5
Meander width (m) (mean)	2.95	8.57	4.5
Slope	2.05^0	1.8^0	1.05^0
Sinuosity	1.07	1.21	1.56
Width/depth ratio(mean)	12.30	6.70	6.65

Source: Field work, 2008

An analysis of the width dimension for rural semi urban and urban reaches illustrates the magnitude and characteristics of these modifications. The width function corresponds to the number of links in the network at a flow distance from the outlet (Rodríguez-Iturbe and Rinaldo, 1997). It is an important morphological characteristic since it gives a good idea of the hydrologic response. In the urban reach, all the transport elements that form the flow paths are considered as links, including gutters, pipes and a natural channel that drains the urban area. Smith *et al.* (2002) used named the drainage network obtained for the natural catchment as the "equivalent natural network".

Observation also, revealed that the channel pattern changed from the natural pool and riffles in the rural reach to braided to quasi-meandering in the urban and semi urban reaches with considerable entrenchment, which ranged from 0.8 to 2.9m. Mean sinuosity ranged from 1.07m in the urban, 1.21 semi urban and 1.56 in the rural reach. Reduced sinuosity in urban reach of the Jakara results from straightening in an effort to protect property from stream bank erosion and flooding as seen in Plate 2.

Plate 2 Straightened section in the urban reach of Jakara channel

Another impact of urbanization on basin morphometry observed was alteration of drainage density, which is a measure of stream length per catchment area (km/km^2). Natural channel densities decrease dramatically in urban catchments as small streams are filled in, paved over, or placed in culverts (Dunne & Leopold 1978, Meyer & Wallace 2001). However, artificial channels (including road culverts) may actually increase overall drainage densities, leading to greater internal links or nodes that contribute to increased flood velocity (Graf 1977, Meyer & Wallace 2001). Results from this study are consistent with these observations as the drainage density estimated from maps and aerial photographs has decreased by 18% along the channel, but by more than 79% in the urban reach and 43% in the semi urban reach as the channel has been paved over during urban development, but field assessment show that storm water drains have increased drainage densities by 28.6% overall but by as much as 88% in the urban reach and 51% in the semi urban reach.

Observations in the semi-urban reach shows that the beginning of a widening process is evident with channel segments abandoned by the active channel and lateral bars beginning to stabilize. Widening of the channel by the coalescing of previously distinct vegetated bars are also evident. The channel begins to divide into a number of incised sub-channels (Plate 3). Urban reach on the other hand show a characteristic form that results from increased flow intensities. The stream bed is generally uniform, wide or incised to accommodate the increased discharge from the watershed.

Plate 3 Threaded section of urban reach of the Jakara channel

The indices of bank stability are roughly equal across all six reaches, and all classify as "unstable" under Fitzpatrick *et al.*, (1998) scheme expect where the channel are modified by concrete. The mean angles of the banks of the semi urban were higher than the rural reach (2.15 vs 1.05). Mean channel gradients are generally very low reflecting the local topography.. The urban and semi urban reaches in this study have been channelized or incised at the crossing site and such channel alterations have led to incision that disconnects the stream from its floodplain, and this instability migrates through the whole system. The scour that the culverts and bridges cause only compounds channel incision and degradation problems. Previous studies have shown that bridges have caused increased cross-sectional areas by two times or more up to 85 m downstream of a crossing (Gregory and Brookes, 1983).However, these instances of increased bank erosion and sediment movement are related to the type of structure at the crossing.

Conclusions

The impact of urbanization on stream channels have been well studied in perennial systems and the results are widely accepted, and demonstrate that increases of urban areas within a watershed lead to increases in stream channel size (depth and/or width). The present investigation attempted to expand this understanding into ephemeral and intermittent stream channels in semi-arid environment. The focus of this study was to relate level of urbanization in watershed to observed changes in the morphology of the stream channel. The study sites selected were intentionally small since stream channels draining smaller watershed areas are most sensitive to changes in impervious cover. Results of this study indicate that urbanization in the Jakara watershed has caused impacts similar to those described in other studies (Ebisimeju, 1989a, b, 1991; Odemerho,1992; Trimble,1997; Booth and Jackson, 1997; Jeje and Ikeazeato, 2002). Morphological variables in all three sites were measured. All the variables of full channel dimension show that the urban reach is larger than the semi-urban and rural reach. These changes generally accord with the conceptual model outlined by Wolman (1967), where a phase response is characterizes by erosion from increased runoff to produce channel enlargement. The observed variation in channel morphology due to urbanization has serious implication in watershed management. However, because this is a relatively small data set, generalizations made from the current data will have to be confirmed with a more extensive inventory of stream channel form in the study area.

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