IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 8, Issue 4 Ver. II (Apr. 2014), PP 40-45
www.iosrjournals.org

Impact of Urbanization on Channel Morphology: Some Comments

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Abstract: *This paper evaluates the dominant concepts that characterize stream channels in urban environments and the basis of the explanation which is predicated on the argument that larger flows beget larger channels. The paper uses observation of the Jakara stream channel in Kano metropolis, Nigeria which indicates that although urbanization has a variety of effects on stream channel morphology, other factors such as nature, age and historical evolution in urban development as well as natural factors such as climate, physiography, geology, vegetation and soils are significant in explaining the observed channel in urban areas. The paper therefore argues that many of the relationships advocated between channel form and urbanization probably are the results of combination of many temporal or geomorphic factors or of local conditions and that the relationship between channel morphology and urbanization observed in Jakara channel did not isolate the process or processes that are responsible for the pattern or a trend for all reaches of the channel. The paper recommends that in view of the significance of urban channels to aesthetics and the stream ecosystem a framework for understanding the dynamics requires continuous research especially in semi arid areas that have few empirical studies.*

Key Words: *channel morphology, runoff, riparian vegetation, bank erosion, channel reach*

I. Introduction

Streams in urban setting are significant features of landscape not only because of the aesthetics, but the fact that their degradation due to urbanization has led to serious consequences such as flooding, loss of life and property and disruptions of the entire stream ecosystem with enormous consequences to aquatic life and biodiversity. The seriousness of the impact of urbanization in urban channels dubbed as urban syndrome (Paul and Meyer, 2001), has prompted many studies which demonstrated that urbanization of a catchment result in irreversible consequences, that produce delirious change on runoff characteristics; channel morphology; hydraulic geometry and to the stream ecosystem (Wolman 1967; Leopold 1968; Hammer 1972; Hollis, 1975; Klein, 1979; Booth 1991; Schueler 1994; Ridd, 1995; Booth and Jackson 1997; Paul and Meyer 2001; May *et al.*, 2002; Jeje and Ikezeato, 2002; Hession *et al*. 2003, , Roesner and Bledsoe, 2003; Nabegu, 2010).

However, the complexity of urban land uses that constitute urban areas and the varying responses reported creates serious challenges for understanding the mechanisms by which urban impacts change channel structure and function (Booth *et al.*, 2004). Yet, understanding the temporal and spatial pattern of change in urban channels and recognizing where along the adjustment process a particular system may lie is important. Such understanding can help to developing appropriate management schemes for changing urban rivers. Furthermore, variations within channels mean that different strategies may be required for different channel segments to handle spatially distributed response mechanisms (Chin and Gregory, 2005), as well as decision making as to appropriate restoration plan, even if the magnitude of change cannot be predicted precisely (Neller, 1989, Watershed Protection Techniques, 2000). This paper overview the main concept developed to characterize the impact of urbanization on stream channels and based on empirical observations of Jakara channels comment on the major weakness of the postulations.

II. Conceptual Basis Of The Urban Stream Channel Phenomena

Conceptually urbanization has three major effects on urban stream ecosystem. First, the creation of impermeable surfaces inhibits infiltration so that storm rainfall appears as runoff. Thus, small floods may be intensified by as much as ten times by urbanization (Smith, 2005). Secondly, urbanization of watershed causes channelization which further degrades the ability of a channel to contain a flood (Hill, 2000). Thirdly, streets and roads are serviced by a network of surface drains and sewers which deliver water more rapidly to the local channel. This has the effect of reducing the lag time between initial rainfall and the onset of flooding. Additionally, the channel is often constricted by bridge supports or riverside structures, thus reducing the carrying capacity of the stream. This increases the frequency with which high flows overtop the riverbanks (Smith, 2005). These factors, in combination, create conditions that are conducive to channel instability—widening (erosion) and deepening (degradation) in most reaches and debris and sediment accumulation (aggradation) in others as illustrated by Gibbons and Arnold, (1966) in Figure1.

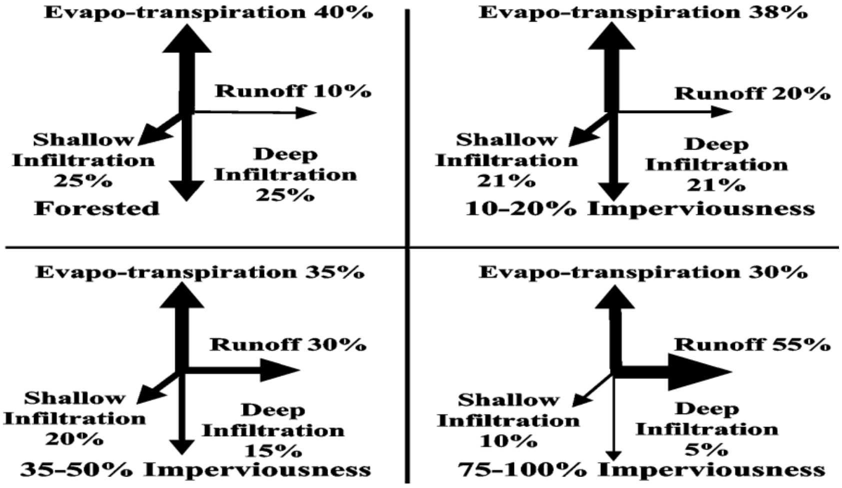

Fig. 1 Changes in hydrologic flows with increasing impervious surface cover in urbanizing catchments (After Arnold and Gibbons 1996).

Chin (2006) also presented a conceptual model in Figure, 2 that illustrate the general phases of urbanization with associated channel process changes, channel conditions, and morphological adjustments where the effects and variables that impact the river system were described: sediment production/yield (S); imperviousness (I); hydrological (H); morphological (M); and physical and biological degradation (D). The sediment production curve, based on Wolman (1967), is the foundation of Chin's model, characterized by increased sediment due to active construction, which can cause net aggradations and channel-size reduction initially. Following active construction, sediment production decreases (Wolman 1967; Wolman and Schick 1967), inducing net channel erosion and enlargement as well as morphological change. An increase in imperviousness causes hydrological effects, changes in channel morphology, and biological degradation in streams (Chin 2006).

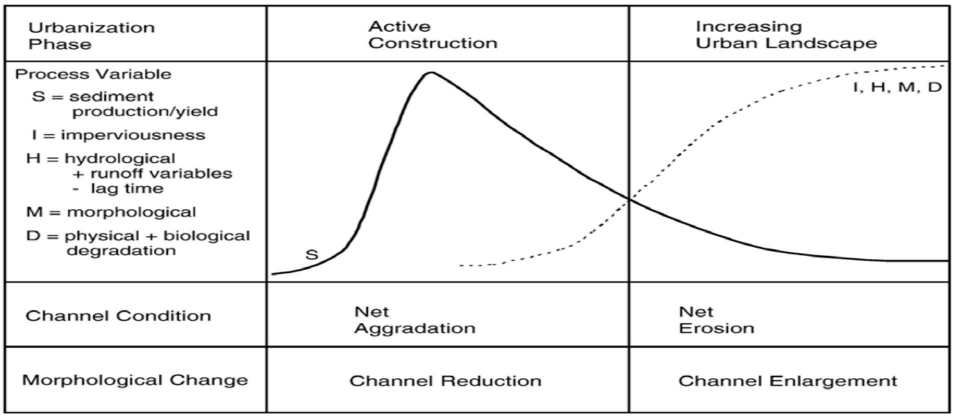

Figure 2 Phases of Urbanization with associated Channel Process changes, Channel conditions, and Morphological Adjustments (After Chin, 2006)

III. The Case Of Jakara Channel

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. 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 (Olofin, 1991). 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 catchment is located on the Basement Complex, and within the area where a wind drift material has concealed the pre-arid regolith and its associated ferruginous soils on the upland plain and old alluvial deposits on the river terraces.

IV. Methodology

Impervious area was estimated from air photographs, land use maps, roadmaps, layout plans and land Landsat imagery of Kano metropolis and was used as surrogate to estimate the extent of urbanization in the Jakara catchment. The percent area under urban development 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. Based upon the degree of urbanization, Jakara stream was divided into three reaches with different levels of urbanization (a) upper watershed dominated by urbanization (b) middle section that is undergoing urbanization exurban/semi urban and (c) lower watershed that is primarily rural. The reaches were selected after a field reconnaissance to establish that they conform to convention as demonstrated by Neller, (1988) and May *et al*., (1997).

Having determined the three reaches along the Jakara channel, two sites were selected from each of the reaches for detailed study. The sample sites 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.,* 1991; Klauda *et al.,* 1998, Booth and Jackson, 1997, Vannote *et al.,* 1980). The selected sites were transacted to measure the morphological variables.

Urbanisation In The Jakara Channel

The main concentration of urban/impervious surface is at the upper course where the catchments is 100% under impervious cover. The middle course is a transition area with the impervious surfaces covering about 13%. The lower course is generally rural, with impervious areas covering only about 3% of the catchments.

Measured Morphological Variables In The Jakara Channel

The full channel dimension of the six sampled sites, indicated a mean channel width of 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.

More significant is the fact that the Jakara channel enlargement variables measured showed a capacity ratio of 2.36, width ratio 1.94, depth ratio 2.25 and enlargement ratio of 7.21. These ratios indicate much larger increase compared with what has been reported elsewhere where, typical channel enlargement ratios range from 1.0–4.0 (Gregory, 1987a). Data from humid tropical areas of Nigeria in Ekulu river show a capacity ratio of 0.79, (Jeje and Ikeazota, 2002), Elemi River show a capacity ratio of 0.81, (Ebisemiju, 1989) and the Ikpoba River has a capacity ratio of 1.2 (Odemerho, 1992). The variation observed between the Jakara channel and others necessitates the following comment as to the possible causes and direction of inquiry.

Complexity of The Stream Channel Environment

The main explanations of the dimensions of channels in an urban stream network have been larger flows beget larger channels. Consequently, a prediction of channel change based on the magnitude of anticipated hydrologic change has been accepted as the end result (Booth 1991). However, field observations in Jakara channel suggests that the location of the measurement could impact the results as where the measurement is located in a "transport" reach, where water and sediment are passed downstream with little channel adjustment, or a "response" reach, where channel form readily adjusts to changing conditions will all produce different results. Similar observations were made by Merritts et.al, (2006). Also even within the same reach of the Jakara channel dimensions vary with local channel gradient and the pattern of gradient changes across the channel network. These complex variables are hardly incorporated in most of the reported studies, which agrees with the observation of Montgomery and Buffington, (1997).

Nature Of Urbanization

The nature of urbanization in Jakara catchment as mapped in the study assumed that the nature of impervious cover that signifies urban land use over the catchment is similar and that locations in similar land use are also similar in essentially all other respects such as vegetation, watershed size and slope, soils, and hydrology which is rarely the case (Wolman 1967; Wolman and Schick 1967; Leopold 1973).Observation in the Jakara channel shows that even at reach-level channel morphology is influenced by local slope and confinement occasioned by human modification of the channel. Similar to the observation was made by Montgomery & MacDonald (2002).

Also urbanization in the Jakara channel is not the same as in Europe or North America. For example, transport-related imperviousness comprised 63 to 70% of total impervious cover in 11 residential, multifamily and commercial areas where it had actually been measured (City of Olympia, 1994). 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.

V. Complexity Of History

Observation of the Jakara channel shows that, widening in the urban reach of Jakara channel indicate that natural geomorphic recovery processes are incomplete and impeded by artificial bank stabilization. Field surveys of urban reach in Jakara identified segments in various stages of adjustment where some reaches were adjusting to urbanization but others were affected to such an extent that adjustment was no longer possible as in (Plate 1 and 2). However, in other location in the urban reach with no modification the lack of bank-stabilizing as seen in (Plate 3) may partially explain why these channels typically have wide, shallow, low sinuosity geometries. The result is a highly varied, transient channel forms that are a reflection of several factors rather than an equilibrium state. This is supported by the argument that the responsiveness to change depend on the local geomorphic and network context, such as the location within the catchment (Roberts, 1989; Montgomery and Buffington, 1997), mobility of channel materials (Chin, 1998), and the geologic and vegetation characteristics that influence erosive resistance (Henshaw and Booth, 2000).

Plate 1 modified Jakara channel reaches

Plate 2 Jakara channel without modification

VI. Difficulty In Separating The Causative "Process"

The association of channel widening with urbanization in Jakara channel did not clearly provide the process or processes that are responsible for driving the widening, and understanding if the widening is a transient, or if it represents a trend for all reaches of the channel. As expounded elsewhere by Merritts *et al*. (2006) we do not know if the observed channel widening is simply a natural response driving the channels back towards a pre-colonization form. Furthermore, although urbanization of catchment influences channel enlargement as shown in the Jakara channel, there is no basis of establishing a predictive relationship between a given level of impervious cover and the resulting increase in channel area. Similar observation was reported by (Schueler, 2000).

Climatic Influence

It has been shown by many studies that streams in semiarid climates such as the Jakara are most vulnerable to morphologic adjustment because of the prevalence of channels that actively transport bedload sediment and lack of stabilizing vegetation. Several researchers suggest the above reasons for the likely increase in channel sizes in such areas. Regional variations related to hydro climatic effects have been proffered notably by Ebisemiju, 1(989a,b), Jeje and Ikeazeato (2002) in the humid tropics of Nigeria and southeast Asia by Douglas, (1974, 1985b) and in Israel by Laronne and Shulker, (2002).

In the Jakara channel, the low rainfall in the area typical of semi arid regions results in weathering processes dominated by mechanical rather than chemical means. Clay production is thus inhibited and silt-sized fractions are predominant in the soils. The lack of bank-stabilizing clay in a semi-arid region ephemeral stream channels may partially explain why these channels typically have wide, shallow, with low sinuosity geometries. The sparseness of vegetation along the channel bank can also contribute to larger channel widening tendencies since vegetation along the bank of the channel has been known to stabilize the channel and restrict bank collapse and erosion as was also observed by among others, Reid and Frostick, (1997) , Merritt and Wohl, (2003).

The large channel observed in this study may also be due in part to several localized factors. Roof tops have been shown to be important medium in conveying runoff speedily to channel enhancing erosion and channel enlargement. This added to absence of lawns, intense modification of the channel, sand mining on the channel, weak soil and intense rainfall events are likely causal factors of the observed widening. Furthermore, it is pertinent to bear in mind also, that the ultimate base level for fluvial processes in the study area is the mean water level of Lake Chad which at 282m above sea level is only 150m lower than the bed elevation of the channels in the study area. Hence, the capacity of the channels to evacuate the floods generated does not match the rate of generation, leading to channel widening to accommodate the floor water. The storm channel is, therefore, a natural response to the combination of the prevailing environmental factors in the study area (Olofin, 1989b). It has also been argued that response to land use or environmental change varies for different channel types. Alluvial channels like that of Jakara, in particular, exhibit a wide variety of potential responses. Changes in channel roughness due to alteration of channel sinuosity and bed forms which are pervasive in this area can also explain the large capacity ratio in this area.

VII. Conclusion

Studies on urbanization effects on urban stream channels suggest several areas where gaps in understanding should be addressed by future work. These opportunities include understanding the variability in responses within and between physiographic provinces in the evaluating the combined impacts of land-use and climate change; understanding how pre-urbanization land-use history affects stream response; developing a clearer understanding of the complex interactions between catchment and in-stream processes in urban systems. Such studies would benefit from interdisciplinary approaches that involve hydrologists, soil scientists, geochemists, engineers, planners, ecologists, economists, social scientists, and others hydrology and ecosystem response.

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