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Assesment of River Channel Alteration Due to Urbanization in Maiduguri, Norhteast, Nigeria

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Abstract

Rapidly change in the population of Maiduguri has brought tremendous change in the land use and land cover patterns of the Ngadda river basins. Increasing urbanization in the basin is followed by a variety of serious impacts on the conditions of the river system. Alteration in the hydrology and geomorphology of the streams are the most detrimental effects identified due to urbanization. This paper reviews the various ways of stream alterations due to urbanization, methods to assess these effects and the existing research gaps in the field of study. The changing river basins provide opportunity for the river watersheds management planners, and engineers to study the system - response relationship between urbanization and river basin. This may help for further research and better river basin management.

***Key Words**: Urbanization, Channel, Alteration, Stream.*

Introduction

The physical development of the urban areas normally occurs due to movement of people from rural to urban areas, which ultimately leads to the urbanization. Urban watersheds across the world are suffering from pressures of human such as urbanization, industrialization and population growth resulting into river basin changes. Any natural system like river basin is elegant in its own way. Urbanization affects stream ecosystems in a number of ways. For example, increased flooding and pollution, lower dry-weather flows, changes to the stream substrate and riparian vegetation, and channel widening are common results of urbanization which can lead to degradation of the stream habitat and a loss of diversity in the aquatic community. The greater volumes of storm runoff, higher peak flows, and more rapidly rising flows associated with urbanization have been recognized for many decades (e.g., Leopold 1968), largely because they can result in flooding of properties. The increased 'flashiness' of flows in urban catchments means that the frequency of flood events over a particular size increases as more water is conveyed directly to the stream channel.

One ubiquitous feature of urban stream syndrome is alteration of the river channel morphology and stability (Booth, 1990; Bledsoe, 2001; Russell *et al.*, 2020). Generally speaking, rivers will adjust their shapes in response to natural fluctuations in sediment supply and flow regime (Schumm et al., 1984), and the rate of this response is frequently accelerated by watershed urbanization. One problem is related to the increased imperviousness of the watershed, when natural ground surfaces are replaced by roads, sidewalks, buildings, and parking lots. Increased imperviousness interrupts the natural infiltration processes that gradually route rainwater downward into the subsurface, and the eventual recharge of the downstream river channel (Booth, 1990; Bledsoe and Watson, 2001; Morisawa and Laflure, 1979; Booth and Reinelt, 1994; Vietz, *et al.*, 2014) thereby disrupting the natural hydrological processes that route water and material downstream. More issues can arise from installation of drainage pipe networks that often lead to rainwater being collected over a much larger area, thereby increasing the extent of the area delivering flows to downstream channels (Vietz *et al.*, 2014; Utz *et al.*, 2016). Collectively, these practices can result in much more storm water runoff_ being instantaneously delivered to the channel head, and this increases the energy of the flow regime to a point that exceeds the rivers natural transport capacity.

Channels respond to such energy perturbations by first incising into the channel bed by erosion (Booth, 1990; Wohl, 2018; Dunne and Leopold, 1978), which is intensified by the coarsening of bed materials (Hawley and Bledsoe, 2016). Because incision leads to a deeper channel, the banks steepen and become unstable and more prone to erosion through bank failures (Leopold and

Wolman, 1964), thereby widening the channel and increasing sedimentation (Arnold *et al.,* 1982). Continued erosion leads to further incision as coarse particles are transported downstream. This cyclic process of incision and widening will continue until the channel reaches a new balance, or equilibrium, to accommodate the increased flows received from the urbanized watershed (Roberts, 1989). In extreme cases, a channel may incise many meters below the original level of their beds (Booth and Henshaw, 2001; Julian and Torres, 2006). This general view of channel adjustment in response to watershed urbanization has been well documented (Leopold et al., 2005; Hawley and Bledsoe, 2013), however, the space and time scales associated with their response has been poorly constrained (Grant et al., 2003; Bunte and Gravel, 2004; Shelley, 2007). One reason for this knowledge gap arises from the highly varied nature of bed material types and sizes between study sites (Utz *et al.,* 2016), as well as the presence or absence of storm water management infrastructure or exposed bedrock (Hawley and Bledsoe, 2016). Moreover, our present understanding of channel "re-equilibration" due to watershed urbanization is largely limited to studies of non-cohesive, alluvial systems (Driscoll *et al*, 2010), and less is known about erosional processes in cohesive channels (Edison *et al.,* 2010) let alone their morpho-dynamic response to human activities.

In this study, we investigate the channel morphological alteration of River Ngadda; an urban stream channel that has undergone substantial morphological alteration in response to century-scale watershed urbanization. Scientific research on this river system is limited to three studies (Nyanganji, 1994; Abdullahi et al., 2015; Jimme, 2014; Jimme *et al.,* 2016), and not even one has quantitatively assessed the channel alteration in response to urbanization. Specifically, Nyanganji, J.K. (1994) examined the Morphology and Hydrography of the Ngadda catchment and the Bama Beach Ridge (BBR); Jimme, M.A. (2014) examined the spatial pattern and socio-economic effects of urban flash floods and inundation on River Ngadda Channel. The rationale behind carrying out this study is to quantitatively assess the River Ngadda channel's alteration in response to watershed urbanization. Here, we use satellite imagery data, field observations, and GIS to assess longitudinal and cross-channel profiles. This work is very important because it provides additional insights into the effects of urbanization on fluvial geomorphology and can aid in the management and restoration efforts for the Ngadda River.

Aim and Objectives

The aim of this study is to assess alterations of channel due to urbanization along the Ngadda River in Maiduguri Metropolis. The specific objectives of the study include to:

1). Examine the various human activities along the river channel.

2). Assess how urbanization altered the stream channel of River Ngadda.

Research Question

1).What are the various types of human activities along river Ngadda channel?

2).Does urbanization altered the stream channel in Ngadda River?

Materials and Methods

Study Area

Maiduguri is located between latitudes 11 42N and 12 00 N and longitudes 12.54 and 13 14 E (Haruna 2010). Maiduguri covered an area of 543km2. The city is bounded in the north by Jere LGA, in the west, south and south-west by Konduga LGA, in the north-west by Mafa LGA. Maiduguri has mean annual maximum temperature of 34.8 with mean temperature ranging between 30 and 40 C. The months of March and April are usually the hottest months, while November and January are the cold and dry periods of harmattan. The city receives rainfall from June to September. However in rainy years, the city records rainfall earlier than June and later than September. Being a nodal city, trading is the major occupation of the inhabitants with few agrarian practices. The city is situated in a plain area. One of the problems confronting the geography of Maiduguri urban is the non-availability of a standard boundary of the urban. Therefore, in this study, the urban is defined to be the areas between latitudes 11˚ 27′ 30″ N and 11˚ 33′30″N and longitudes 13˚ 2′ 30″E and 13˚ 9′10″E (Fig. 1).

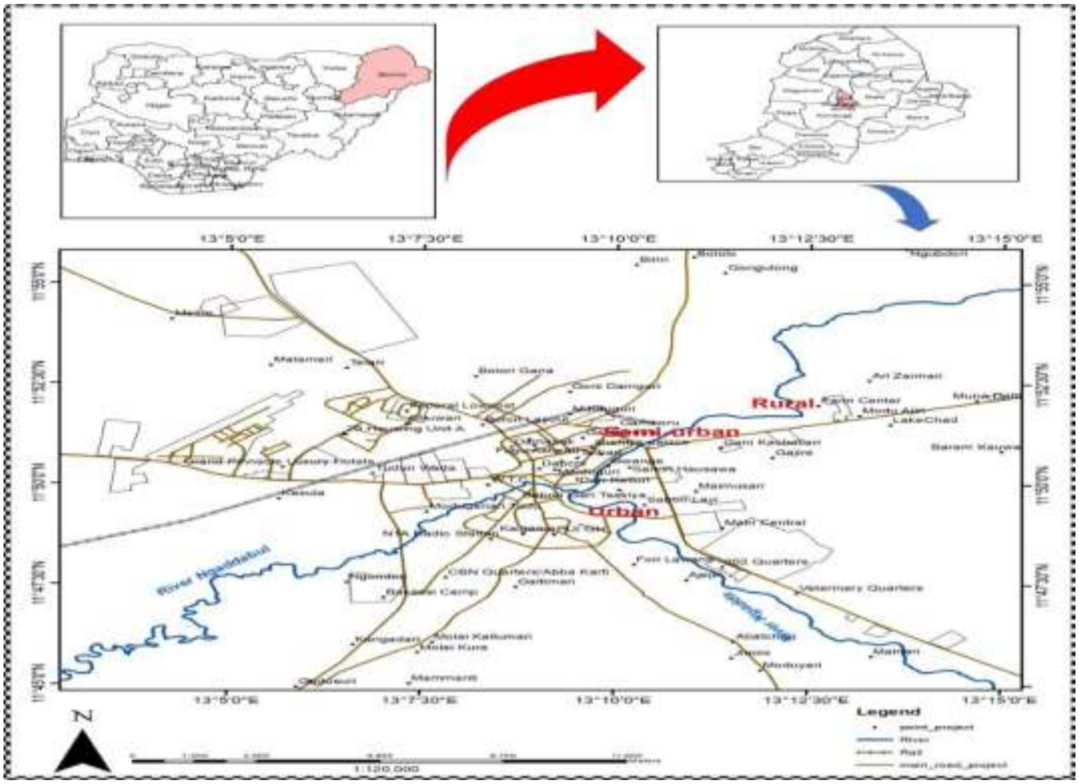

Figure 1: Maiduguri showing the study Area

Methods

There are a variety of field measurements that can be used to assess and describe channel morphology characteristics. The purpose of this study was to determine whether urbanization was altering stream channel in the Ngadda River. To achieve that purpose, measurement criteria were selected that was characterized the channel morphology of river, provide information for statistical analysis and allow comparison between the three segments and with other similar studies.

The channel dimension (length, width, depth and cross sectional area) of each reach was measured using Total Station (TS) with angular and linear accuracy of 2 seconds and ±2mm + 2ppm (see Ibitoye, 2012). With the hard copies of Google Earth imageries, the entire area routing runoff into the channel (catchment area) was identified physically in the field and delineated along the catchment or drainage divide. Infill developments (developments after the imageries have been captured) such as buildings, drainages, roads and impervious surface were also identified in the field. The Google Earth imageries were geo-referenced with the values of well dispersed and well distributed Ground Control Points (GCPs) that are identifiable on the imageries using

AutoCAD Land Development version 2007. All features of interest (buildings, drainages, roads and impervious surfaces) were later digitized on screen and their values estimated using geo-statistical tool of the software.

Results and Discussion

Direct modification of stream channels

This is common in urban systems. These direct alterations of channel morphology often are the most damaging changes urban streams experience. Typical channel alterations in urban streams include: channelization (i.e., channel straightening) and channel hardening or armoring (e.g., lining channels and banks with concrete and riprap) as observed in the urban and semi urban segments of Ngadda River. Building of drains along urban streets and concrete channels is a deliberate attempt to control surface runoff but the improper handling of the projects often influenced stream channel alteration at the receiving locations. Many of the channels and drains constructions are at times abandoned or terminated half way before reaching the natural drainage channels. Some drains were constructed without any consideration for the slope pattern of the road and amount of runoff to be generated, thus providing avenue for the runoff to overflow the drains during heavy rainfalls. Drainages were not even provided along some roads or provided and not serve the purpose of conducting runoff due to blockage and as a result, uncontrolled runoff flows along the roads/streets and unpaved drains and thus lead to development of incipient gullies around the channel which further exacerbate the alteration processes. These factors coupled with unconsolidated nature of soil beneath the concrete channel made it possible for the runoff to severely cut deeper and faster into the earth surface at the termination points.

Results from the descriptive analysis along the three segments of the Ngadda River indicates a highly urbanized watershed with greater than 90% impervious surface cover in urban reach (Figure 1). The semi-urban watershed, is a transition from forested rural area to develop urban haven impervious surface area of 29.8%. The rural watershed is generally most rural with impervious surface area of 2.81% respectively. This result also revealed that rooftops make up a significant percentage of the impervious surfaces within an urban area as compared to studies elsewhere, for instance in North America and Europe where road components dominate impervious cover (City of Olympia, 1994b). The amount of impervious cover i.e., percent of the watershed under urban

influence is a major factor in explaining channel response to urbanization. This is due to fact that, overland flow dynamics caused by increases in impervious surface, subsurface storm water routing typically delivers excess storm water directly into surface water systems during high flow events, further increasing peak discharge in streams and rivers during storm events (Walsh et al., 2005).
When the hydrologic characteristics and sediment supply of a fluvial system are disrupted by urbanization, the channel geomorphology of the system adjusts to accommodate these changes (Leopold, 1964). This interpretation is consistent with earlier studies elsewhere that have shown runoff increases 200% - 500% where impervious cover exceeds 10% of the watershed (Paul and Meyer, 2001, Arnold and Gibbons, 1996). This study indicates more than 70% imperviousness, which suggest that Ngadda channel in urbanized watershed tend to alter the stream channel in response to changes in flow frequency, hence the enlargement of their channel at higher rate than channel in the semi-urban and rural reaches.

Variability between the Channel Segments

Results of the longitudinal profile indicates that channel cross sectional area, width, wetted perimeter and width/depth ratio in the urban segment are larger than the semi-urban and rural reaches. The high degree of variation is an indication that the reach dimension varies from urban watershed to rural watershed, which means, urban reach is larger than the semi-urban reach and rural reach respectively. These variability are can help in determining the type of change that occurred in each reach bordered by impervious cover in urban and agricultural fields in semi urban and rural that rarely adjoin these data indicate significant variation for changes among the reaches. The channels showed both channel widening and channel deepening when compared with reference reaches. The significant increase of active channel width in the urban reach in response to urbanization is consistent with studies from other regions (e.g., Wolman 1967, Wolman and Schick 1967, Hammer 1972, Jacobson and Coleman 1986, Booth 1990, Trimble 1997, Galster *et al.* 2008).
The amount of channel widening however is greater than the amount of deepening and rate of channel widening increases in the downstream direction. The downstream hydraulic geometry describes the rate of increase in width, depth and cross sectional area in the downstream direction to accommodate the downstream increase in bankfull discharge. The amount of change shown by the result illustrates the transformational change the channels went through during the major urbanization phase on the Ngadda catchment. This corroborates the studies of Abdullahi et al, (2015) and Nyanganji (1994, 2011)

on the Ngadda basin. This rapid increase in watershed urbanization of Maiduguri had a profound impact on the hydrology of the river system and increased the demand for storm water management to route rainwater away from the downtown district. A network of storm water drainages were constructed around the channel and this culminated in a network of artificial drainage pipes that routed rainwater runoff directly to the Ngadda River channel. The immediate impact of this effort was a sharp increase in the flow discharge at the channel head, as more water rushed into the channel at a much faster rate. This suggests that stream systems can eventually adjust to the urban hydrologic regime and find a new dynamic balance between water and sediment input. The urban landscape, dominated by impervious surfaces, will lead to greater stream discharge than was present during the pre-urban phase, and this allows channels to lower their slope because gravity is no longer needed to create energy for the stream system. The hydrologic regime experienced by the channel is closely tied to the level of urbanization and impervious area in the watershed, particularly where the underlying geologic substrate does not have a large infiltration capacity, as is the case with the degree of urbanization of the Ngadda urban study sites.

Channel Enlargement Variables

Analysis of the enlargement parameters depicts a trend in enlargement of river Ngadda channel. The finding shows Ngadda channel with a capacity ratio of 1.21, width ratio 2.14, depth ratio 0.63 and enlargement ratio of 1.15. This result corroborates studies reported elsewhere where, typical channel enlargement ratios ranges from 1.0–4.0 (Gregory, 1987a). The semi-arid climatic conditions, particularly in Nigeria show trend in enlarged river channel. For example, Jakara channel data indicates a capacity ratio of 2.65and enlargement ratio of 7.21. Although, data from semi-arid generally contradicts what has been reported from the humid tropical areas of the country which shows reduction in channel capacity ratio. For instance, data 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) respectively. Consequently, urban stream channels often enlarge their cross sectional areas by a factor of 2 to 5, depending on the extent of urbanization in the watershed and the age of the development (May *et al.*, 2002; Avolio, 2003; Brierley and Fryirs, 2005 among others).

One of the observations during the field survey is the extent of human influence on the river through the direct and indirect effects of urbanization. The direct increase in impervious cover creates indirect increases in both the amount of water reaching the channel during rainfall events and the peak flow rates associated with rainfall. To accommodate this increase in peak flow events, the channel width and wetted perimeter have increased, as this study documented at the six surveyed cross-sections. Human perturbation of the urban drainage such as causeways, bridges, roads and buildings limited the flow capacity of the channel and floodplain. One important factor affecting the energy balance in the channel is constriction and modification of the river course, so that the flood water flow is different from the normal pattern of overbank flow and sluggishness over the floodplain. In this case, under flood conditions the alluvial plain performed the function of a high-velocity flow channel in a semi-confined environment as observed in some part of the urban reach.

A disturbance to one part of the fluvial system can change upstream or downstream through the network and shrink or become large in the process, yielding complex cumulative responses. The stream channel can be perturbed by some activities that occurred at various places elsewhere at various times in the fluvial system. The consequence of urbanization process is the tendency that transforms natural channel through various activities of bank erosion protection and control as well as flood mitigation. This corroborates Coles et al. (2004) who demonstrated that the streams are systematically narrower and deeper with increasing urban intensity.

Trends in Downstream Direction

Univariate regression analysis with dependent variables such as (bankfull width, mean bankfull depth, bankfull area, and wetted perimeter) shows increase in the downstream direction. Also residuals from the univariate regression were calculated to see what additional trends could be attributed to urbanization. These residuals refer to the difference between the estimated and actual values calculated from the regression equation. The results of Mann-Whitney nonparametric statistical test performed on these residuals three reaches demonstrated the p values reported from this test are greater than 0.05 for bankfull width, mean bankfull depth, bankfull area, and wetted perimeter. Thus, after accounting for the effects of higher percent of urbanization from the reaches by analyzing regression residuals, the unexplained changes is not significantly related to results of urbanization.

Conclusion and Recommendations

This study established that the development of urban Maiduguri has greatly altered the channel morphologies of River Ngadda channel that are experiencing different stages of urbanization (urban, semi-urban and rural segments), except where channelization directly altered the fluvial system. Findings also revealed the entrenched nature of the Ngadda River channel between the perturbed urban reach and unmodified rural reach. The statistical analysis revealed that urbanization does not explain any morphological changes in the downstream direction for rapidly urbanizing portions of the watershed. Some unexplained variation remains among the three reaches in terms of downstream trends in mean bankfull depth, bankfull width, bankfull area and wetted perimeter.

This natural variability is not explained by the changing degree of urbanization. Because urbanization does not explain the natural variability among the reaches, hence, the need for further research is advocated on understanding the variability in responses within and between physiographic provinces in the evaluating the combined impacts of land-use change. The government should embark on establishment of shelter belts that will encourage infiltration in urban areas and to reduce rapid flows into the existing river channel. Due to the lack of waste collection and management systems, urban wastes are disposed particularly in streams, gutters and culverts. Hence, the need for waste collection and disposal; maintenance and widening of waterways to ready them for the water loads in the rainy season; and the encouragement of communal action in sanitation and clean-up campaigns.

REFERENCES

Abdullahi, J. J. O .Odihi, and B. B. Wanah (2014) Assessment of the Impact of Human Activities along the River Ngadda Channel, Maiduguri, Borno State, Nigeria. Journal of Geography, Environment and Earth Science International, 2(4): 207-217, 2015; Article no.JGEESI.2015.019

Arnold, C.L.; Boison, P.J.; Patton, P.C. Sawmill Brook (1982) An example of rapid geomorphic change related to urbanization. J. Geol. **1982**, 90, 155–166.

Avolio, C.M., (2003). Local impacts of road crossings on Puget Lowland Creeks: M.S. Thesis, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA, 119 pp.

Booth, D.B.; Henshaw, P.C. (2001) Rates of channel erosion in small urban streams. In Geomorphic Processes and Riverine Habitat; American Geophysical Union: Washington, DC, USA, 2001; Volume 2, pp. 17–38.

Booth, D.; Reinelt, L.E. Consequences of urbanization on aquatic systems—measured effects, degradation thresholds, and corrective strategies. In Proceedings of the Watershed '93: A National Conference on Watershed Management, Alexandria, VA, USA, 21–24 March 1994; pp. 545–550.

Booth, D.B. (1990) Stream-channel incision following drainage-basin urbanization 1. J. Am. Water Resour. Assoc. **1990**, 26, 407–417.

Bledsoe, B.P. (2001) Watson, C.C. E_ects of urbanization on channel instability 1. J. Am. Water Resour. Assoc. **2001**, 37, 255–270.

Brierley, Gary J. and Kirstie A. Fryirs. (2005) .Geomorphology and River Management: Applications of the River Styles Framework. Oxford, UK: Blackwell Publishing

Bunte, K. Gravel (2004) mitigation and augmentation below hydroelectric dams: A geomorphological perspective. In Report to the Stream Systems Technology Center; USDA Forest Service Rocky Mountain Research Station: Fort Collins, CO, USA, 2004.

Dunne, T.; Leopold, L.B. (1987) Water in Environmental Planning; Macmillan: New York, NY, USA.

Driscoll, M.O.; Clinton, S.; Jefferson, A.; Manda, A.; McMillan, S. (2010) Urbanization effects on watershed hydrology and in-stream processes in the Southern United States. Water **2010**, 2, 605–648.

Edison, G.W.; Sawyer, C.B.; Hichcock, D.R.; Calabria, J.; Putman, B.; Chanse, V.; Post, C.J.; (2010) Hallstrom, J.O.; White, D.L.; Esswein, S.T.; et al. Sand River headwaters green infrastructure project, City of Aiken, South Carolina: A collaborative team approach to implementing green infrastructure practices. In Proceedings of the 2010 South Carolina Water Resources Conference, Columbia, SC, USA, 13–14 October 2010.

Galster, J. C., Pazzaglia, F. J., and Germanoski, D., (2008), Measuring the impact of urbanization on channel widths using historic aerial photographs and modern surveys, Journal of the American Water Resources Association, Vol. 44, No. 4, pp. 948-960.

Grant, G.E.; Schmidt, J.C.; Lewis, S.L. (2003) A geological framework for interpreting downstream effects of dams on rivers. In A Peculiar River, American Geophysical Union,Water Science Application; O'Conner, J.E., Grant, G.E., Eds.; American Geophysical Union: Washington, DC, USA, 2003; Volume 7, pp. 209–225.

Gregory, K., 1987a. Environmental Effects of River Channel Changes. Regulated Rivers, Research and Management 1, 358-363.

Hammer, T.R., (1972). Stream channel enlargement due to urbanization. *Water Resources Research* 8(6): 1530-1540.

Haruna Talatu (2010): Assessment of the structure of the unemployed in Maiduguri urban, Borno state. B.Sc Geography thesis, Adamawa state university, Mubi.

Hawley, R.J.Making streamrestorationmore sustainable (2018) A geomorphically, ecologically, and socioeconomically principled approach to bridge the practice with the science. BioScience **2018**, 68, 517–528.

Hawley, R.J.; Bledsoe, B.P. (2013) Channel enlargement in semi-arid suburbanizing watersheds: A southern California case study. J. Hydrol. **2013**, 496, 17–30.

Jeje, L.K., Ikeazota, S.I., (2002). Effects of Urbanization on Channel Morphology: The Case of Ekulu River in Enugu, Southeastern Nigeria. *Singapore Journal of Tropical Geography 23 (1), 37–51.*

Jimme, M.A. (2014) examined the spatial pattern and socio-economic effects of urban flash floods and inundation on River Ngadda Channel. PhD Thesis Summited to the Department of Geography, Aliyu Modibbo Federal University of Technology, Yola

Jimme, M. A., Bashir, A., Adebayo, A. A Spatial Distribution Pattern and Terrain Analysis of Urban Flash Floods and Inundated Areas in Maiduguri Metropolis, Borno State, Northeast, Nigeria **Journal of Geographic Information System, 2016, 8, 108-120** Published Online February 2016 in SciRes. http://www.scirp.org/journal/jgis

Julian, J.P.; Torres, R. (2006) Hydraulic erosion of cohesive riverbanks. Geomorphology **2006**, 76, 193–206. Lane, E.W. Importance of fluvial morphology in hydraulic engineering. Proc. Am. Soc. Civ. Eng. **1955**, 81, 1–17.

Leopold, L.B.;Wolman, M.G.; Miller, J.B. (1964) Fluvial Processes in Geomorphology;W.H. Freeman: San Francisco, CA, USA, 1964.

Leopold, L.B. (1968) Hydrology for Urban Land Planning—A Guidebook on the Hydrologic Effects of Urban Land Use. Geological Survey Circular 554; U.S. Geological Survey: Washington, DC, USA, 1968.

Leopold, L.B.; Huppman, R.; Miller, (2005) A. Geomorphic effect of urbanization in forty-one years of observation. Proc. Am. Philos. Soc. **2005**, 149, 349–371.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, and E.B. Welch, (2002). Effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. *Watershed Protection Techniques* 2(4): 483-494.

Morisawa, M.; LaFlure, E. (1979) Hydraulic geometry, stream equilibrium and urbanization. Adjust. Fluv. Syst. **1979**, 10, 333–350.

Nyanganji J.K. (1994). The morphology and hydrography of the Ngadda catchment and the Bama Beach Ridge. Frankfurt, Germany; 1994.

Nyanganji J.K. (2011). Settlement pattern on the Bama Beach Ridge in Borno State, Nigeria. Journal of the Environmental and Social Sciences. Published by Ahmadu Bello University Press lmt. Zaria, Nigeria; 2011.

Odemerho, F.O., (1992) Limited downstream response of stream channel size to urbanization in a humid tropical basin. Professional Geographer 44 (3), 332–339.

Paul, M.J. and J.L. Meyer, (2001). Streams in the urban landscape. *Annual Review of Ecologyand Systematics* 32: 333-365.

Roberts, C.E. (1989) Flood frequency and urban-induced channel change: Some British examples. In Floods: Hydrological, Sedimentological and Geomorphological Implications; Beven, K., Carling, P., Eds.; Wiley: Chichester, UK, 1989; pp. 57–82.

Russell, K.L.; Vietz, G.J.; Fletcher, T.D. (2020) How urban stormwater regimes drive geomorphic degradation of receiving streams. Prog. Phys. Geogr. Earth Environ. **2020**, 44, 749–778.

Schueler, T. The importance of imperviousness. Watershed Prot. Tech. **1994**, 1, 100–111.

Schumm, S.A.; Harvey, M.D. (1984) Watson, C.C. Incised Channels: Morphology, Dynamics, and Control; Water Resources Publications: Highlands Ranch, CO, USA, 1984.

Shelley, D.C. (2007) Geology, Geomorphology, and Tectonics of the Congaree River Valley, South Carolina. Ph.D. Thesis, University of South Carolina, Columbia, SC, USA, 2007; p. 384.

Trimble, Stanley W. (1997). Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed. Science, 278: 1442-1444.

Utz, R.M.; Hopkins, K.G.; Beesley, L.; Booth, D.B.; Hawley, R.J.; Baker, M.E.; Freeman, M.C.;

Jones, K. (2016) Ecological resistance in urban streams: The role of natural and legacy attributes. Freshw. Sci. **2016**, 35, 380–397.

Vietz, G.J.; Sammonds, M.J.;Walsh, C.J.; Fletcher, T.D.; Rutherford, I.D.; Stewardson, M.J.

(2014) Ecologically relevant geomorphic attributes of streams are impared by even low levels of watershed e_ective imperviousness. Geomorphology **2014**, 1, 67–78.

Walsh, C., Roy, A., Feminella, J. W., Cottingham, P., Groffman, P., & Morgan, R. (2005). The urban stream syndrome: Current knowledge and the search for a cure. *Journal of the North American Benthological Society* , 24 (3): 706-723.

Wohl, E. Rivers in the Anthropocene: The U.S. perspective. Geomorphology **2018**, 366, 106600.

Wolman, M.G., (1967). A cycle of sedimentation and erosion in urban river channels.

Geografiska Annaler 49(A): 385-395.