THE EFFECT OF URBAN STORM DRAINAGE ON STREAM CHANNEL MORPHOLOGY IN RIVER AJILOSUN, ADO-EKITI, EKITI STATE, NIGERIA

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ABSTRACT

Geomorphologically, urban storm sewers are like tributaries of streams. They are ephemeral "streams" since they carry flow only during rainfall events. Stream channel processes at tributary junctions have been studied both in laboratories and in the field (Aziegbe, 1991; Church, 1992; Eliot et. Al.). the channel morphological changes associated with these processes induced by the entry of a tributary flow into the mainstream flow also have been documented in these studies which reveal that significant changes take place in the morphology of stream channels at and downstream of tributary junctions. This study reveal that urban storm sewer do have important effects on the morphology of urban streams and that the changes which occur are similar to those reported for tributary junctions.

Keywords: channel morphology, urbanization, drainage basin, urban storm sewer

INTRODUCTION

Rivers, like any other open system, have input and output of energy and matters and as a result, they are not in a state of static equilibrium. Rather, they are dynamic, due to responses to changes in their system parameters. Over a long period of time, a river adjusts its energy and work done under the unique environmental conditions of its basin as manifested by its morphology. When there is alteration in the condition of the determining environmental factors, there is also a response on the part of the river which alters its dynamics and morphology.

One of the most effective agents of change in a watershed is mankind. Man can alter the drainage basin surface through activities such as farming, building, construction, road construction, compaction of the soil of the basin as a result of movement of man and man's activities on it, or change the morphology of the river directly by damming its course, dredging and thereby enlarging the channel, lining the channel to prevent bank collapse and land encroachment by channel widening, straightening of the channel, linking of the channel with artificial channels like concrete drains or through the construction of culverts and bridges (Chin, 2006; Nabegu, 2014; Wang et al., 2000; Schucler, 1994; Arnold et al., 1996).

An extensive literature exists on the effects of urbanization on the geomorphology, hydrology, and sedimentology of urban rivers (Chin and Gregory, 2005: Morisawa, 1985; Ebisemiju, 1989; Jeje et al., 2002; Roesner et al, 2003). The present study is aimed at studying the effect of urban storm drainage on stream channel morphology.

THE HYDROGEOMORPHOLOGICAL SIGNIFICANCE OF URBAN STORM SEWERS

Perhaps the most important hydrological changes induced by urbanization is the considerable increase in runoff as a result of the extensive impervious surfaces characteristic of urban settlements. The need to rapidly convey this huge volume of runoff to streams arises from the desire to prevent accelerated erosion and flooding of urban surfaces. Networks of sewers or gutters – open and covered, unpaved or concrete drains are constructed for the rapid evacuation of the urban runoff as well as domestic sewage to streams. Storm sewers, therefore, are important elements in the urban landscape.

Under natural conditions, a raindrop falling more than a few metres from one of the widely spaced stream channels in an urbanized catchment would infiltrate into the soil and eventually reach the stream as groundwater discharge or throughflow. Following urban development, storm water drains now carry storm runoff directly to stream channels. Where storm water is carried direct to streams, the baseflow is greatly reduced and the storm flow increased. Reduction in the redirection of water from paved surfaces directly to storm water drains and stream channels results in a loss of recharge to the groundwater reservoir. The contributions of surface runoff and throughflow to the discharge of urban streams, therefore, are relatively minor (Odemerho, 1992; Simon 1992).

The hydrogeomorphological significance of urban storm sewers is further underscored by the fact that some of them may in fact cut across natural drainage divided, thereby extending in varying degrees the catchment areas of the urban streams. Such inter-basin water transfer increases the normal discharge of the stream and distort the widely documented strong allometric relationship between basin area and stream discharge, a relationship which has informed the use of drainage basin area as surrogate for discharge by hydrologists and fluvial geomorphologists (Klein, 1979; Ebisemiju, 1989; Chin, 2006; Nabegu, 2010).

Geomorphologically, urban storm sewers extend the drainage network over and at times beyond the drainage basin in which they are located. The total length of these sewers in an urban area is several orders of magnitude greater than that of the natural streams. Urban sewers, therefore, increase the drainage density of an urbanized basin. Also importantly, their junctions with the natural streams are geomorphologically active zones given the huge volume of concentrated runoff and sediment they pour into the stream and the velocity at which this is carried out.

However, the pattern of response of these factors has received little attention, therefore, called for more detailed empirical studies of spatial variations in stream channel response to these and other parameters of urbanization. This paper is a contribution to the limited efforts made so far in this fruitful area of research. Specifically the research seeks to examine the effect of urban storm sewers on the morphology of the urban stream channels into which they convey runoff and sediment from urban surfaces.

STUDY AREA AND METHODOLOGY

The study area is Ado-Ekiti which is located between latitude $7^{0}40'$ and longitude $5^{0}51'$ the area lies within the tropical rainforest belt and therefore experiences two types of seasons yearly. These are dry season otherwise called the harmattan season (November to March) and the rain season (April to October). The temperature is generally high throughout the year and especially during the dry day. There is high humidity during the wet season and intense solar radiation.

The area is underlain by the Nigerian basement complex rock and has an undulating topography produced by differential erosion of crystalline rocks. Ado-Ekiti is made up of seven small urbanized headwater basins, the largest of which is the Ajilosun basin. River Ajilosun has been selected for this study out of the seven urbanized headwater basins in the town because studies have shown that it is the only drainage basin in which the channels have almost completely adjusted to the urban hydrological state, the others being in varying states of disequilibrium (fig. 1).

Since this study is concerned primarily with the effect of urban storm drainage on stream channel morphology, the stream network of River Ajilosun in Ado-Ekiti was mapped from 1:50,000 scale topographical map. The possible locations of points at which the sewers and gutters enter the River Ajilosun are identified on the map (Fig. 2). These were then cross checked during a reconnaissance study along the entire length of the river. Out of the total of ten entry points, seven were selected for detailed study. Some entry points were omitted because the sewers are too close to one another to enable the effect of one to be distinguished from another. Channel cross-section morphology was determined from measurements made at 3m above the junction and downstream of the stream at a distance of 0.7 of the channel width at the junction. The selection of this downstream distance is informed by the results of studies which show that the velocity of the downstream flow increases by a factor of 1.3 as the combined flow is constructed for 0.9 to 0.6 of the channel width with the growth of the separation zone. Therefore, fourteen channel cross-section were surveyed.

In testing for relationship between drainage basin parameters measured to examine the effects of urban storm drainage on stream channel morphology, the data analysis was performed in three stages. First, the descriptive statistics were calculated for the parameters; secondly the students't-test was used to test the differences between the upstream and downstream channel dimensions. Thirdly, the simple correlation analysis was employed to examine the extent to which the channel morphological parameters were interrelated.

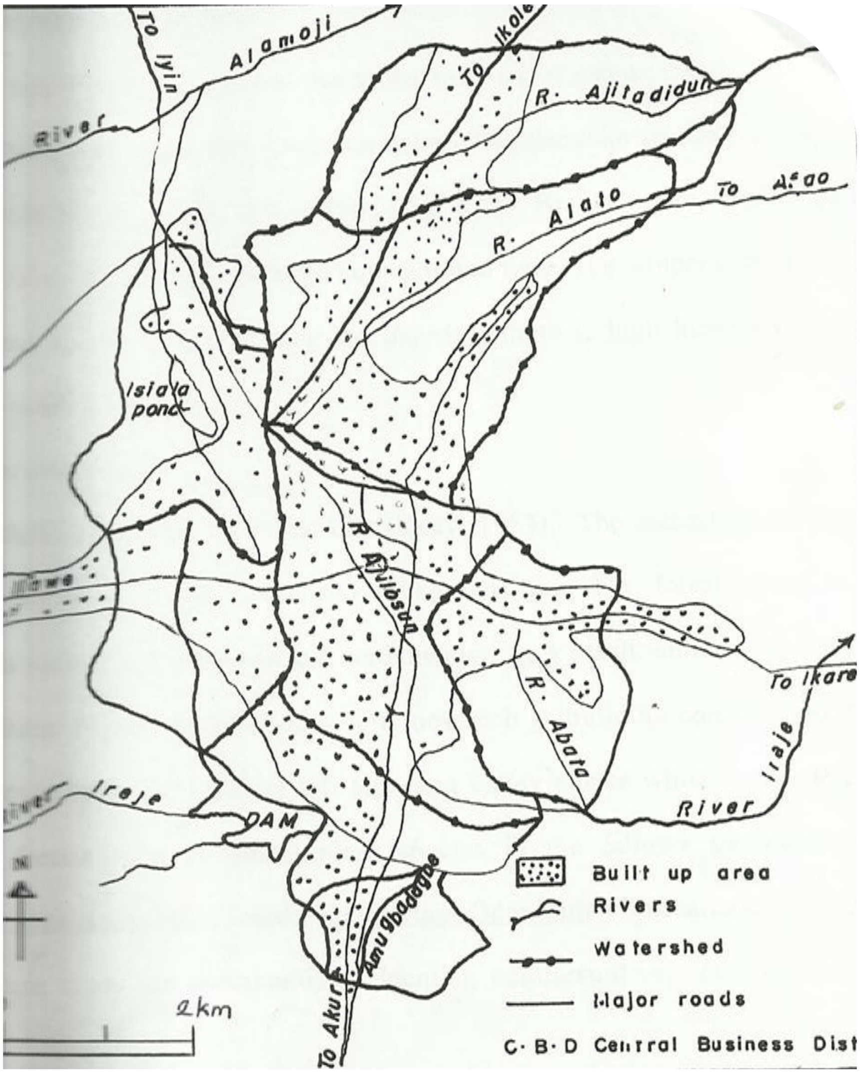

Fig. 1 Urbanized Catchments of Ado-Ekiti

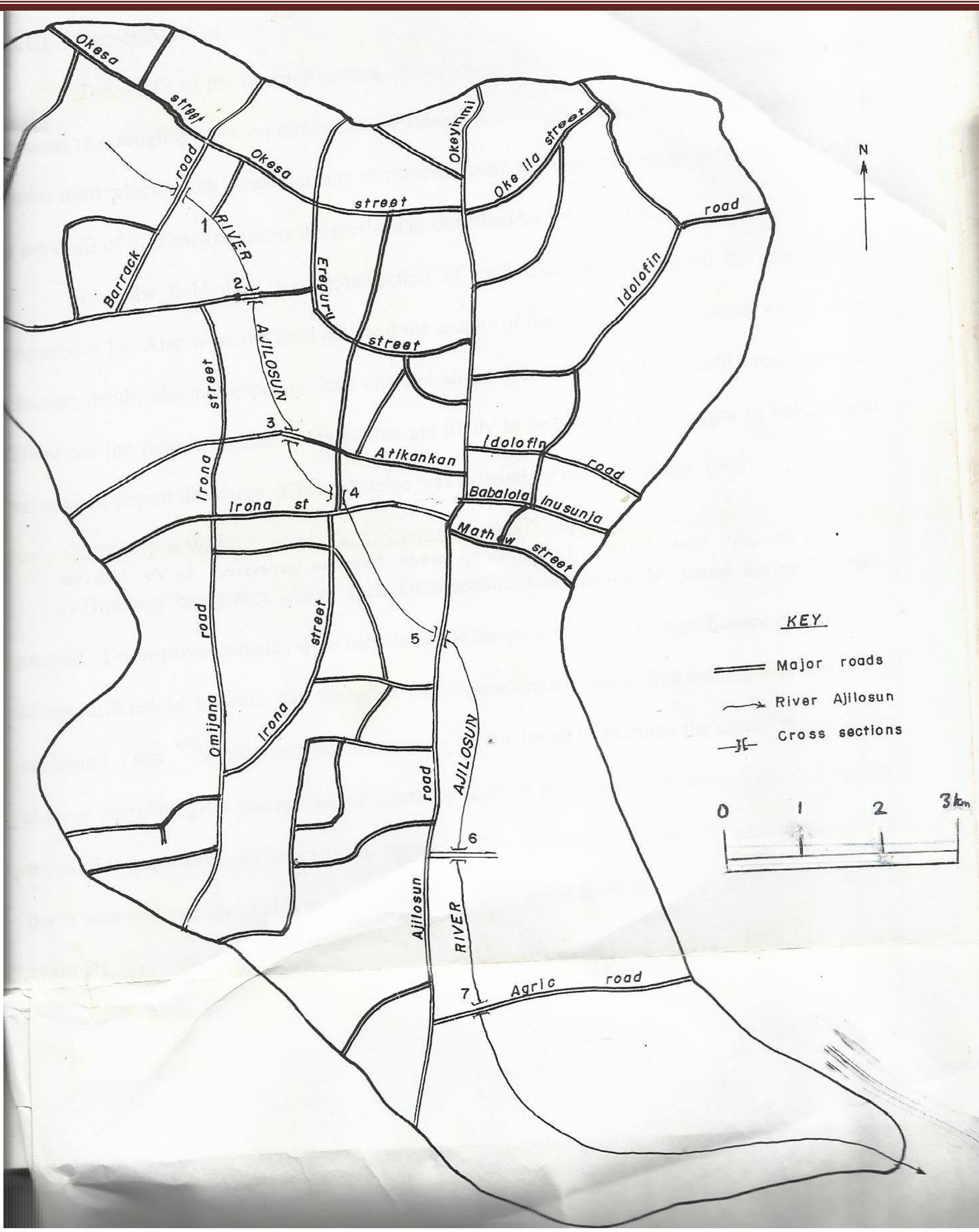

Fig. 2: Cross Section of River Ajilosun

RESULTS AND DISCUSSION

Channel Morphological Characteristics

The mean, standard deviation and the coefficients of variation of the variables are presented in Table 1. From the table, it could be observed that the stream channels are generally small in size. The channel capacity have a mean of 0.94m^2 and coefficient of variation of only 38.3% for the upstream channels. The channel capacity of the downstream cross-sections have a mean of 1.26m^2 and coefficient of variation of 31.7%. The small channel size has been attributed by Ebisemiju (1989) to aggradation processes and the limited ability of the river to erode vertically because of low gradient and discharge and frequent duricrust outcrop along the channel bed. The result is that increases in channel capacity are due mainly to channel widening rather than deepening. When the two data sets are combined, however, the coefficient of variation is high (37.3%). This together with the means suggested some subtle differences in the channel morphology of the two data sets. The channels downstream of the entry points of sewers are larger than those upstream, the average enlargement ration being 0.34.

The channels are generally narrow, the shoulder widths have a mean of 3.00m and a coefficient of variation of only 16.7% for the upstream channels. The widths of the downstream section have a mean of 3.74m and a coefficient of variation of only 12.3%. The downstream channels, therefore, are wider than their upstream counterparts. The higher coefficient of variation (17.8%) for the fourteen cross-sections further confirms the observed differences between the two sets of data. Channel widths have the lowest variation among the four parameters analyzed. The channels also are generally shallow, as mean channel depth for the upstream channels have a mean of 0.31m^2 and a coefficient of variation of 32.3%. The channel depth for the downstream channels have a mean of 0.34m and a coefficient of variation of 32.4%. The similarity in the two means suggests that the additional discharge brought into the stream through the sewers has no effect on channel depth, and the observed increase in channel capacity is attributable mainly to increase in channel width. The form factor is high as a result of the relatively greater width compared to depth. There are difference between the two data sets in respect of the form factor. There are also some other major difference between the two sets in respect of other channel characterisitics. However, those of the downstream channels are undulating as a result of the development of bars of sediments on channel floor. Upstream channels are more or less symmetrical while downstream channels are asymmetrical in varying degrees. This is due to concentration of erosive activities of water from the sewers on the channel banks opposite the entry points of the sewers while deposition takes place in mid-channel or near thechannel banks on the same side of the entry points

Students t-test

From Table 2 below, it could be observed that only the difference between the means of channels width is statistically significant at more than 95%level. The differences in other variables, however, were not statistically significant. This further lends support to the conclusion drawn earlier that channel enlargement of the entry points of storm sewers is due principally to increase in channel width rather the depth. The null hypothesis that there are no significant differences between the morphology of stream channels upstream and downstream of the entry points of storm sewers, therefore, is rejected in respect of channel width only.

Simple Correlation Analysis

The bivariate relationships between the morphometric parameters of the channels are presented in Table 3. The table reveals similarities in the interrelationship among the variables of both upstream and downstream channels, except in respect of the relation between channel capacity and channel width with a correlation coefficient of 0.635 for upstream channels and only 0.352 for downstream channels. This suggests that there is greater adjustment and equilibrium among the two parameters in the upstream channels.

Table 1: Means, Standard Deviations and Coefficients of variation of the variables

	Channel Capacity (c)			Channel Width (w)			Average Depth (d)			Channel Shape (ʃ)		
	Upstream	Downstream	All	Upstream	Downstream	All	Upstream	Downstream	All	Upstream	Downstream	All
M	0.94	1.26	1.1	3.00	3.74	3.4	0.31	0.34	0.32	10.61	12.39	11.5
S.D	0.36	0.40	0.41	0.50	0.46	0.6	0.1	0.11	0.11	3.24	4.23	3.87
C.V	38.3	31.7	37.3	16.7	12.3	17.8	32.3	32.4	31.3	30.5	34.1	33.7

Table 2: Students' t-test of the variables

	1	2	3	4	5	6	7	8	9
	(a-b)	Σa	Σb	$Σa^2$	$Σb^2$	$Σa^2 + Σb^2$	$\frac{Σa^2 + Σb^2}{7}$	$\frac{\sqrt{Σa^2 + Σb^2}}{7}$	$\frac{(a-b)}{\sqrt{\frac{Σa^2 + Σb^2}{7}}}$
C	0.32	0.39	0.44	0.15	0.19	0.34	0.05	0.22	1.45*
W	0.74	0.54	0.50	0.29	0.25	0.54	0.08	0.28	2.65+
D	0.03	0.11	0.12	0.01	0.01	0.02	0.003	0.05	0.60*
F	1.78	3.50	4.57	12.26	20.89	33.15	4.74	2.18	0.82*

Degrees of freedom = (7 + 7) – 2 = 12

*= Not Significant at 95% level;

+ = Significant at 95% level.

Table 3: Simple Correlation Analysis

	Upstream					Downstream			
	Basin Area (A)	C	W	d		Basin Area (A)	C	W	d
C	0.853				C	0.445			
W	0.615	0.635			W	0.385	0.352		
D	0.707	0.909	0.283		D	0.303	0.901	-0.082	
F		-0658	0.150	-0.896	F		-0.808	0.224	-0.970

The Relationship between Basin Area and Channel Capacity

Studies carried out in different parts of the world have shown very strong relationship between stream discharge (index by basin area) and channel capacity. In the case of River Ajilosun, the relationship is strong in respect of the upstream channels but weak for downstream channels. For the upstream channels, the simple correlation coefficient is 0.853 and is significant at the 99% level. The squared correlation coefficient of 0.73 suggests that 73% of the variations in channel capacity is due to variations in basin area. As for the channels downstream of the entry points, the correlation is low (0.445) and statistically insignificant at the 95% level. This difference suggests that the upstream channels are stable and in equilibrium while the downstream channels are unstable. More importantly, the squared correlation coefficient of 0.20 suggests that only 20% of the variations in channel capacity is due to basin discharge. It is suggested that a substantial part of the remaining 80% unexplained variance is due to the runoff contribution from the areas drained by the sewers. This further confirms that urban storm sewers do have important effects on the morphology of urban streams.

Conclusion

Urbanization brings about changes in hydrological processed which in turn affect channel processes and forms. Urban storm sewer which concentrate urban runoff, and discharge them into urban streams can be likened to stream tributaries which bring additional discharge to the main river. Just as this additional discharge from tributaries modify channel processes and form at tributary junctions, so it is likely that channel processes and forms may be altered at and around the points at which storm sewers enter urban stream.

The statistical analysis of data on channel morphology upstream and downstream of seven entry points along River Ajilosun in Ado-Ekiti confirms this. Comparison of the means of channel capacity, width, mean depth and channel shape of the two sets of data reveals that channel enlargement takes place downstream of the entry points. The differences, however, are more pronounced in respect of channel capacity, width and shape. The almost identical means of channel depth is attributed to the aggradations of channels downstream of the entry points by the eroded sediments brought into the river by the storm sewers. The flows are not competent to transport the sediments which are then deposited in the form of bars. Channel enlargement, therefore, is mainly through channel widening. This is further confirmed by the result of the students't-test which shows that the observed differences between the two data sets are statistically significant only in respect of channel width. The simple correlation analysis reveals similarities in the strength and direction of correlations among the morphometric parameters of the two data sets. The findings reported here, therefore suggest that urban storm sewer do have important effects on the morphology of urban streams and that the changes which occur are similar to those reported for tributary junctions.

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