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Assessment of the Impact of Variations in Riparian Landuse on Stream Channel Morphology and Flow Regime in the Kilange River Catchment, Adamawa State, Nigeria

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Abstract:- Stream channels and flow regimes in the River Kilange catchment reflect a pattern of both natural and anthropogenic disturbances in the riparian corridors. This study examined the channel morphology and stream flow characteristics in three landuse (Urban, Agriculture and Abandoned Agriculture) settings in the River Kilange catchment. Stream channel geometric properties were measured and the derived values used to evaluate the channel parameters were determined through ancillary data and field observation. Channel morphology adjustments and variations in stream flow characteristics were related to the different landuses at riparian level. Metrics for channel morphology and flow characteristics were quantified in 18 sampling units. Pearsons' correlation analysis was applied to determine association between landuse and channel morphology. Students' T-test was used to compare estimated bankfull discharge in the abandoned agriculture landuse category and that of the urban landuse setting. Results revealed both channel widening, increase in wetted-perimeter and bankfull discharge in urban channels. The means of discharge for abandoned-agriculture and urban landuse categories were not equal, signifying increased discharge with increase in human activities. Bivariate linear regression relationship between channel depth and discharge was significant (r =.701, p = 0.035). The result further explained that 42% of the variation of discharge emanated from changes in channel depth. Regressing Cross-sectional area with bankfull discharge also yielded significant relationship (r = .835, p = 0.005), where the regression model explained 65% of the variation. The findings reveal that the identified landuse practices influence stream channel and flow adjustments. Changes in the channel morphology accelerate the river flow process culminating into lateral erosion, flooding and reduction in groundwater recharge. These environmental challenges, if left unchecked could result to land and water resources problems in the area. Therefore, the establishment of forest buffer zone along riparian corridors in the River Kilange catchment is recommended.

Keywords:- *Channel Morphology, Stream Flow, Channel Lateral Erosion, Riparian landuse, River Kilange.*

I. INTRODUCTION

Since the expansion of human civilization, effects of landuse change especially conversion of forests to croplands has become a major research issue in fluvial geomorphology, due mainly to significant influences on river water quality, basin hydrology and sediment supply (Roy and Sahu, 2016). Modifications to the landscape, hydrologic regime and alteration to channel morphology are major threats to the functioning of riparian ecosystem health, but can rarely be linked to single common stressor (Jayakaran *et al*., 2016). The flow regime is the cumulative result of climate, geology, topography and land use. All of these independent variables affect each portion of a river or stream and subsequently discharge. Landcover is an important control over the pattern of stream flow, because under natural conditions, vegetation slows surface runoff and encourages infiltration.

Channel geometry and characteristics of stream flow are inherently related (Horton, 2003; Kwamboka, 2014; Yousefi, Moradi, Keesstra, Pourghasemi, Navratil and Hooke 2019; Olutoyin and Adeyemi 2017; Luo, Apip, He, Duan, Takara and Nover, 2018). An important balance exists between the erosive force of the flow and the resistance of the boundary to erosion, which determines the ability of a river to adjust, and modify the morphology of its channel (Charlton, 2008). In order to reach an equilibrium condition, where energy input to the stream channel is balanced with the minimal channel boundary resistance, land-use alteration will result in streambank erosion and changes in channel morphology (Tufekcioglu *et al*., 2020). The flow velocity is directly related to the hydraulic radius and channel slope; and inversely related to channel roughness (Ritter, 2016).

Rivers reflect the imprint of a long history of human interventions to control the spatial and temporal dynamics of water availability, natural hazards such as floods and droughts, and to make the best use of water resources (Fernandes *et al.*, 2020). Headwater stream morphology is a direct reflection of watershed characteristics and therefore can inform our understanding of anthropogenic influence on channel geometry and sediment dynamics (Shepherd *et al.* 2010). Headwater streams are generally recognized as major external links within the river system contributing more than 90 % of catchment stream flow and represents 50-70 % of total stream length within a river basin (Roy and Sahu, 2016).

Understanding how difference in land use/land cover (LULC) types influence the basin hydrology would greatly improve the predictability of the hydrological consequences of LULC dynamics for sustainable water resource management (Woldesenbet, Elagib, Ribbe and Heinrich, 2017). The quick and reliable technique for estimating stream flows, which does not require years of record collecting is through measuring channel geometry (Bhatt and Tiwarri, 2008). The flow of water in river channels can be described by defining some basic channel parameters, particularly channel size, which can be defined by its cross-section (Charlton, 2008). For example, changes in the geometry of the channel can impact stream velocity and discharge. Stream flow estimation through channel geometry is an alternative method for ungauged catchments, particularly where flow characteristics are poorly related to catchment area and other catchment characteristics (Bhatt and Tiwarri, 2008).

The River Kilange catchment, like most river catchments in the developing countries is characterised by inadequate hydrological data. Physical measurement of the stream geometric properties is the best way to understand stream channel morphology. It is therefore imperative to determine the dimensions of stream channels (width, Depth and streambed elevation) with a view to understanding the implications of riparian landuse on channel morphology and stream flow characteristics. Information on the relationship between hydrologic response and landuse /cover change is vital for the proper management of water resources and land use planning across the world (Dilnesa, 2018|).

Description of the Study Area

The River catchment covers an area of 5,323 km^2 encompassing parts of Fufore, Girei, Gombi, Hong, Maiha, Mubi-North, Mubi-South and Song Local Government Areas of Adamawa state Nigeria. It is located between latitudes 9° 23´ 26'' N to 10° 19´ 00'' N and longitudes 12° 15´ 00' E to 13° 17´ 25'' (Figure 1).

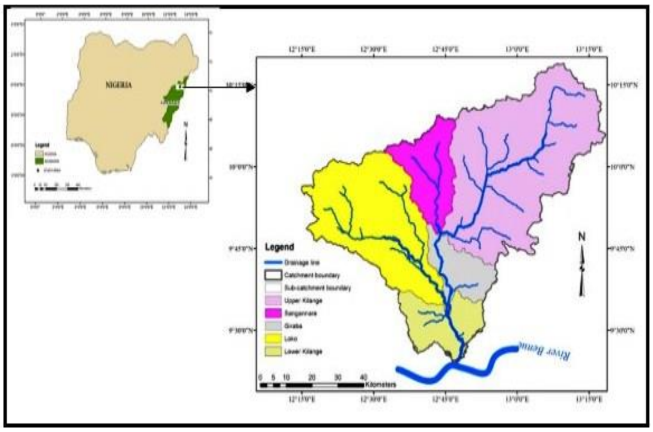

Figure 1: Location of the River Kilange Catchment
Source: Arc-GIS 10 Analysis (2019)

In the River Kilange catchment, the geology is characteristically of the granitic crystalline Pre-Cambrian Basement Complex rocks. Overlying the older Basement Complex are the sedimentary and volcanic rocks of relatively younger age ranging from the upper Cretaceous to Quaternary periods (Bawden, 1972; PFP-Nigeria, 1981).

Elevation in the River Kilange catchment ranges from 170 metres to 1200 metres above mean sea level. The highest points are confined to the peaks of hills in headwater areas, while the lowlands bordering the floodplains of the River Benue into which the River Kilange discharges its water constitute the lowest levels.

The major drainage feature in the study area is the River Kilange, which originates from the hills bordering the northern extreme of the catchment. Major tributaries of River Kilange are the Rivers Loko and Song draining the western portion, whereas numerous minor tributaries, prominent among, which are Mayo-Nguli and Giraba drain the eastern part. The River Sanganare drains the central portion of the study catchment. The River Kilange flows into the River Benue at an outlet near Wuro-Bokki, a settlement located some 45 kilometres upstream of the bridge at Jimeta (Pell, Frischmann &Partners-PFP Nigeria, 1981).

The River Kilange catchment lies in the Sub-Sudan climatic zone. The months from May to October constitute the rainy season, while the months from November to April make up the dry season period. Mean annual rainfall in the study area is about 900 mm based on data for the years1987 to 2016.

Temperature in the area is characterised by little diurnal, monthly and seasonal variations. The hottest period in the year is in the month of April, with temperatures rising to 37º C and 39.6º C in the northern and southern extremes of the study area respectively (Adebayo and Dayya, 2004). December and January constitute the coldest months when temperatures drop to 15.3º C and 18.3º C in the northern and southern extremes of the study area respectively. The dominant soil types in the River Kilange catchment are sandy loam to sandy clay with or without concretionary iron pan. The weakly developed soils of erosion and non-leached ferruginous tropical soils dominate the northern part of the Kilange catchment. These occur as shallow skeletal soils on the upper slopes with deeper colluvial soils in the valleys. Rock outcrops, raw mineral soils and weakly developed soils of erosion dominate the middle portion of the Kilange catchment. These are shallow, skeletal soils over granite, basalt, sandstone and ironstone. The southern segment of the Kilange catchment comprises of sandy loam and clay loam with varying degrees of concretion (Bawden, 1972).

Adamawa State and River Kilange catchment inclusive is located within the Sudan Savannah belt of Nigeria (Adefioye, 2013). The natural vegetation of River Kilange catchment is lightly wooded, characterized by sparse, relatively short 5-10 metre semi-deciduous trees with shrubs and grasses constituting the dominant cover. The upland pediments are characteristically shrub savannah type of vegetation (PFP-Nigeria, 1981). Near the towns, the indigenous species of trees are gradually being replaced by some exotic species.

Agriculture is the major source of livelihood for the majority of people in the study area. Two basic patterns of rain-fed agriculture are practiced in the area in relation to the two fundamental soil types, the residual highland soils at the foot of hills and alluvial floodplain soils. Maize, guinea corn, cowpea, millet, groundnuts and cassava are the main crops grown on the upland pediment soils (Akinbile and Ndaghu, 2005).

The alluvial floodplain soils are more fertile than the upland soils and are, therefore more productive and in addition are better supplied with and better able to retain moisture. For these reasons, the floodplains are relatively more extensively cultivated and to a certain extent on a more permanent basis in respect to individual plots. The apparent pattern of cultivation observable in the floodplain areas is that, rice, sugar cane and banana are planted in the poorly drained areas, while maize, guinea corn, cassava and a variety of mixed vegetables including onions and okra are restricted to the better drained sites (PFP- Nigeria, 1981).

II. METHODOLOGY

To establish the relationship between landuse change and bankfull discharge in the River Kilange catchment, direct measurements of channel geometric properties were made at sample streams with different riparian landuse settings. To determine river channel dimensions due to changes in land use, the difference in channel width, depth and channel bed slope in the various riparian landuse settings were measured.

For detailed survey, each of the sample stream reaches in Mayo-Nguli, Mbila-Song and Loko was further divided into three segments. A segment within a stream reach was determined on the basis of dominant landuse within the riparian zone. Using this criterion, the sample stream reaches were sub-divided into urban, agriculture and abandoned-agriculture landuse settings.

Six measurement points spaced at equal intervals across the breadth of the stream were determined in Google Earth before the commencement of field survey. The stream reaches were nearly contiguous, so all significant channel-forming variables except riparian landuse are held constant (Hession *et al.*, 2003). Attempts were also made to locate the sample stream reaches on fairly straight segments and where no tributary joins the sample reach of the River Kilange.

In each landuse-defined segment of the sample stream reach, three basic channel parameters (width, depth and bed elevation) were measured at both the upstream and downstream sections. The measured values of channel width and depth were subsequently used to calculate other channel geometric properties, such as channel cross-sectional area, wetted perimeter and hydraulic radius.

The values of bed elevation were used to determine the average channel bed slope, which is required for calculating velocity of flow in a given stream reach. Following the method of Shepherd *et al.* (2010) photographs of river channel hydraulic elements, brief descriptions of streambed and stream bank characteristics based on field observations and reference to standard tables, Mannings' roughness coefficients for the sample stream reaches were determined.
Materials used include measuring tape, hand-held GPS, staff gauge, metal pegs and polythene rope. The data on the stream channel variables were used to estimate bankfull discharge for the sample reaches in the following procedure:

(i) River cross-sections were gridded to form small rectangles, which were used to calculate cross sectional area at each sample stream reach.
(ii) Cross-sectional area of flow (A) (m^2). Area of Small rectangle multiplied by number of rectangles covering the river profile area.
(iii) Wetted perimeter (WP): Length of wetted contact between water and the stream bed along a cross-sectional transect (m).
(iv) Cross-sectional profile produced from stream survey dataset was used to compute wetted perimeter. Using appropriate measurement scale, piece of thread was used to measure length of line representing area of contact between water and river bed on a graph.
(v) Hydraulic Radius (R): Area of the river cross-section divided by wetted perimeter: A/WP.
(vi) Velocity (V): Rate of water flow. The velocity of flow was determined by longitudinal slope (S) in relation to the channel roughness, which is represented by Manning's (n).

The drop in elevation, in combination with the distance between the upstream and downstream, otherwise known as 'rise and run' method was used to determine the average channel bed slope within a given cross section using Equation 1 (Smoot, 2011):

$$S = \frac{Zu - Zd}{x} \qquad (1)$$

Where S is the slope (dimensionless), Z_u is the upstream absolute elevation (m), Z_d is the downstream absolute elevation (m) and x is the curvilinear distance of the stream (m)

The relationship of these parameters is expressed mathematically as Equation 2 (Bent and Waite, 2013):

$$V = 1/n\,(R^{2/3} S^{1/2}) \qquad (2)$$

Where:
V = velocity of flow (m/s)
R = hydraulic radius of flow (m)
S = channel slope (as a ratio, (for example, 0.001)
n= Manning's n (no units)
Discharge (Q) can be calculated using Equation 3 (Bent and Waite, 2013):

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$Q = A * V$ (3)

Where:

Q = discharge (m^3/s)

A = area of stream cross section (m^2)

V = predicted velocity of stream flow (m/s)

The Manning's roughness coefficient "*n*" was determined from the observed stream channel characteristics and use of standard tables (Ibrahim and Abdil-Mageed, 2014).

All data used in this study were grouped into three classes. (1) Two *stream flow indices* (mean velocity and bankfull discharge) treated as both dependent and independent variables depending on the type of analysis. (2) Nine riparian *land use variables* comprising three land use categories all treated as independent variables, and (3) nine *channel morphology variables*, which include bankfull width, channel depth, stream slope, and stream roughness treated as dependent or independent depending on the analysis.

III. RESULTS AND DISCUSSION

The estimation of bankfull discharge was carried out in the three sample areas, namely; Mayo-nguli, Mbila-song and Loko. In each of these stream reaches of the River Kilange, cross-sectional areas, wetted perimeter and hydraulic radius were determined. The hydraulic radius is a parameter required for the calculation of discharge using the Mannings' formula.

Stream Cross-sections at Different Riparian Landuse Categories

Using stream channel dimensions obtained through field survey at the Mayo-Nguli, Mbila-Song and Loko, cross profiles of the streams for the three landuse categories for Mayo-Nguli, Mbila-Song and Loko plotted in Microsoft Excel spreadsheet are presented in Figs 2,3 and 4. The results revealed that the stream cross sectional profiles for urban and agricultural landuses were much wider. This is an indicating active channel lateral erosion process resulting from high run offs and sediment scour as influenced by urbanization and agricultural activities. The river channels over abandoned agricultural land uses portrayed less wide profiles owing to minimal anthropogenic disturbance and lateral erosion activity.

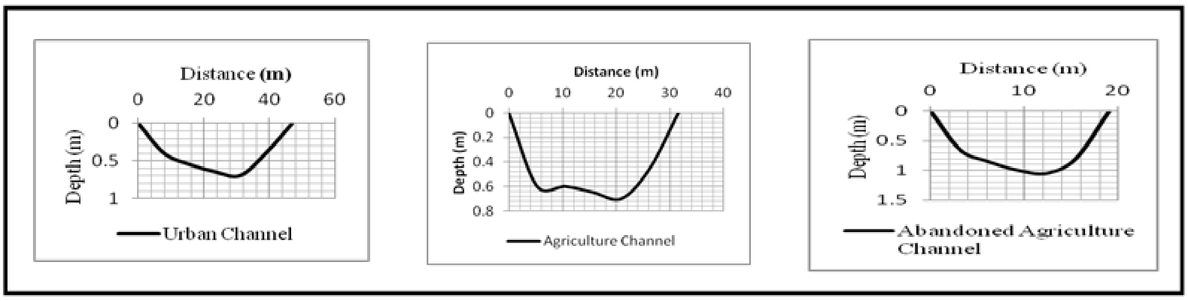

Figure 2: Stream Channel Cross-sections by Riparian Landuse Categories at Mayo-Nguli

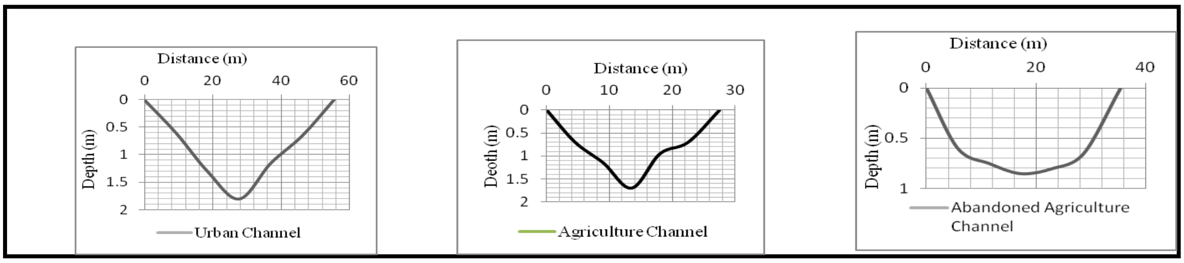

Figure 3: Stream Channel Cross-sections by Riparian Landuse Categories at Mbila-Song

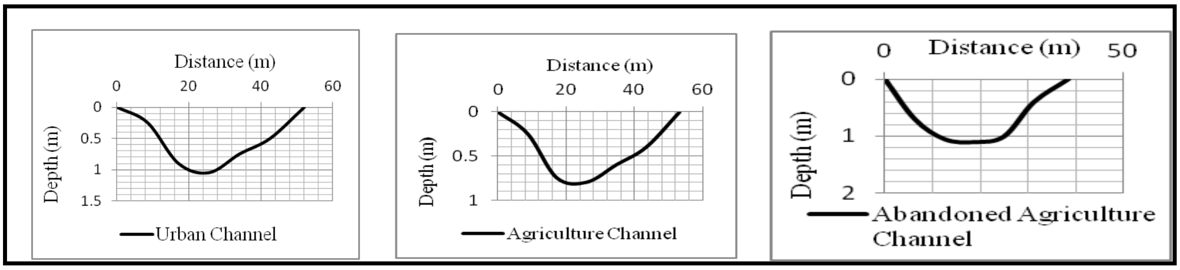

Figure 4: Stream Channel Cross-sections by Riparian Landuse Categories at Loko

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Variations in Channel Morphology and Flow Characteristics by differences in Riparian Landuse

Channel morphology and stream flow characteristics in all the three riparian landuse categories differ regardless of stream reaches where relevant data were obtained. Channel sections over the urban riparian landuse found to be wider (48.25m) than those over agriculture and abandoned-agriculture landuse types (Table 3.1). Other channel parameters whose values increased with changes to urban landuse were wetted perimeter and cross-sectional area. The mean bankfull channel depth ranged from 0.52m in the agriculture landuse setting to 0.58m in the abandoned-agriculture category. This revealed minimal channel depth difference (mean =0.5533; SE=0.0176; SD=0.0306) over the various landuses, indicating almost uniform activity of vertical channel erosion. Another stream morphological variable that varied greatly across the sample stream reaches was wetted perimeter. The mean value of wetted perimeter ranged from a minimum of (49.63m) in the abandoned agriculture landuse to a maximum of (90 m) in the urban landuse setting. Another important morphological characteristic of the surveyed stream reaches is. Bankfull cross-sectional area value was higher in the urban landuse category (34.2m), while the lowest was in the abandoned-agriculture landuse setting (19.92m) as shown in Table 1. The results also revealed higher estimated mean bankfull discharge ($44.97 m^3 s^{-1}$) in the urban riparian landuse category in comparison to estimates over the other land uses. The variations in bankfull discharge with change of landuse from abandoned-agriculture to urban landuse setting are shown on the boxplot (Figure 5.) On a general note, urbanization was found to be more influential on changes in the Kilange channel morphology and flow regime than the other landuses.

Table 1: Mean Bankfull Channel Parameters and Flow Characteristics of River Kilange

Landuse category	W	D	V	WP	R^2	A	'n'	S	Q
Abandoned- agriculture	28.58	0.58	1.22	49.63	0.42	20.67	0.03	0.005	22.97
Agriculture	34.05	0.52	1.39	60.8	0.34	19.92	0.03	0.008	28.086
Urban	48.25	0.56	1.17	90.0	0.37	34.2	0.027	0.006	44.97

Abbreviations: W=Width (m), D=Depth (m), V= Velocity (m/sec.), WP= Wetted perimeter (m), R^2=Hydraulic Radius, A =Area (m^2), 'n'=Mannings'Coefficient, S= Slope, Q=Discharge (m^3/sec.)Source: Fieldwork, 2018

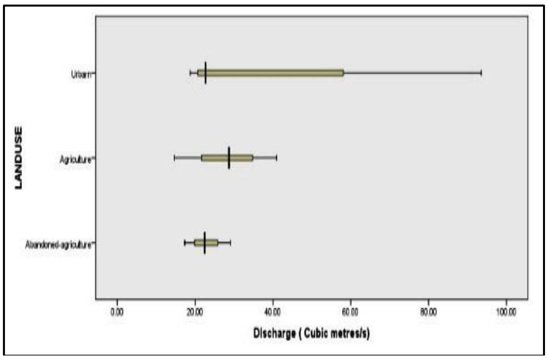

Figure 5: Variation in Bankfull Discharge by Riparian Landuse Category

These findings on the associations between channel morphology and landuse types in the River Kilange catchment are similar to those reported by Horton (2003) for the South Dry Sac Watershed, Southwest Missouri. The results of this study also corroborated the findings of Shepherd *et al*. (2010) who reported an increasing channel cross-sectional area with increasing anthropogenic disturbances as reflected in the mean maximum depth; urban 1.5m, agriculture 1.3m and forests 1.0m. The result of their study also indicated that urban stream channels are significantly wider with a mean of 17m. Similarly, the study findings also validated the findings of Roy and Sahu (2016), who reported that forest conversion to agricultural land, is significantly increasing channel widths (69%) and cross-section area (78%).

Relating Landuse to Stream Morphology and Bankfull Discharge

Some stream morphological variables have been found to correlate with landuse and with each other. Landuse and stream bankfull width, were found to correlate positively (r = 0.764, p = 0.017) as shown in Table 2. Channel wetted perimeter was also positively correlated with landuse (r=0.728, P=0.26). There is no direct correlation between land use and discharge, but channel depth and cross-sectional area are stream channel morphological characteristic of the River Kilange that correlate with bankfull discharge (Table 2). The result of the analyses show that stream channel depth was positively and significantly correlated with river discharge ($r = 0.701$, $p = 0.035$). Similarly, stream channel cross-sectional area was positively and significantly correlated with river discharge ($r = 0.835$, $p = 0.005$. The findings of this study are in line with Ritter (2016) who asserts that channel geometry and characteristics of stream flow are inherently related. For example, changes in the geometry of the channel can influence stream velocity and discharge.

Table 2: Correlations between Landuse, Channel Morphology and Flow Characteristics

	L	W	D	V	WP	R^2	A	'n'	S
L									
W	.764*								
D	-.079	-.084							
V	-.043	-.125	.653						
WP	.728*	.941**	-.116	-.250					
R^2	-.241	-.101	.887**	.513	-.218				
A	.511	.772*	.499	.102	.731*	.493			
'n'	-.231	-.337	-.324	.139	-.543	-.222	-.611		
S	.036	-.250	.061	.666	-.361	-.154	-.438	.659	
Q	.391	.566	.701*	.615	.447	.628	.835**	-.328	.051

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
Abbreviations: L= Landuse, W=Width (m), D=Depth (m), V= Velocity (m/sec.), WP= Wetted perimeter (m), R^2=Hydraulic Radius, A =Area (m^2), 'n'=Mannings'Coefficient, S= Slope, Q=Discharge (m^3/sec.)
Source: Fieldwork, 2018

Relative Contributions of Channel Morphology Adjustments to Bankfull Discharge

Bivariate linear regression tools were used to relate the most correlated stream morphological variables; channel depth and cross-sectional area to stream bankfull discharge (Table 3). These relationships indicated that increasing anthropogenic activities in the study area influence channel depth and cross-sectional area, which consequently affect the rate of river discharge. The values of bankfull channel discharge were chosen as response variables, while stream channel morphology dimensions constituted the predictor variables. Bivariate linear regression relationship between channel depth and discharge was significant (*r*-.701, *p* = 0.035). The result further explains about 42% of the variation of discharge emanated from changes in channel depth. Regressing Cross-sectional area with bankfull discharge also yielded significant relationship (*r*-.835, *p* = 0.005), where the regression model explained 65% of the variation as shown in Table 3.

Table 3: Relative Contributions of Channel Morphology to Discharge

Model	Correlation	Adjusted R	P-Value	Comment
Depth/discharge	0.701	0.418	0.035	Significant
Cross-sectional area/Discharge	0.835	0.654	0.005	Significant

The findings of this study show that one can use statistical methodology to relate land use data to measurable stream variables for predicting the trends of hydrological processes in in a river catchment. This study corroborates Jayakaran *et.al.* (2016) who assert that a set of stream morphological characteristics when combined with landscape variables at specific spatial scales can be used to predict stream discharge.

IV. CONCLUSION

The findings of this study reveal that certain landuse practices, agriculture and urbanisation in particular influence stream channel adjustments. Changes in channel morphology, such as increase in channel width accelerate the process of river flow culminating into erosion, flooding and reduction in groundwater recharge. These environmental problems, if left unchecked would cause land and water resource management problems in the River Kilange catchment.

This study recommends bioengineering practices through the preservation of areas adjoining the stream banks to allow riparian buffer to regenerate. The riparian buffer when established would stabilise steam banks and reduce erosion along riparian corridors in the River Kilange catchment.

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