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# A Comparative Analysis of Morphometry and Morphology of Otamiri Watershed, South-eastern Nigeria

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**Abstract:** A comparative analysis of Morphometry and Morphology of the watershed was examined with the aid of GIS and fieldwork respectively. The catchment is mostly covered by dwindling rainforest vegetation due to intensive anthropogenic activities such as urbanization, farming, sand mining, dredging etc. The study entailed an evaluation of streamflow characteristic of the basin by the delineation of the watershed and determination of morphometric parameters such as the linear, aerial and relief aspects. The focus on Drainage Density (Dd), Stream Frequency (Fs), Bifurcation Ratio (Rb), Stream Order (Nu), Stream Length (Lu), Texture Ratio (T), Elongation Ratio (Re), Circulatory Ratio (Rc), Form Factor (Rf) etc. The result showed that the drainage network is dendritic type, indicating textural homogeneity and requiring less structural controls as well as variation in bifurcation ratio from 2.00 to 5.50. Elongation ratio of 7.00 depicts a basin of elongated shaped category. The stream order ranges from first to sixth order basin. The basin was found to possess low drainage density, drainage texture and stream frequency which indicates highly permeable soils and low relief. Other investigated parameters include low overland flow revealed recharge related measures, surface water augmentation measures that can be undertaken for water resource management as well as soil conservation structures in the study area. Furthermore, the results of fieldwork analyses using the regression and correlation analysis showed that there is a high positive correlation between channel morphology and discharge as well as urbanization index, infiltration capacity showed a negative relationship with channel morphology, but a positive correlation with discharge which is the potent factor that determines channel morphology. Furthermore, sediment yield had a relatively low correlation coefficient that is not statistically significant with channel morphology. Consequently, it can be concluded that urbanization and discharge are the most significant factors that determine the present channel shape and size characteristics of Otamiri river channel.

Keywords: **Urbanization**, watershed, morphology, morphometry, sediment yield

## Introduction

Morphometry is the quantitative evaluation of a watershed and its land surface and river basin morphometry is a geomorphic tool that is useful in the physical measurements of a river basin, and then characteristics such as size, shape, stream network and discharge in the drainage basin can be derived. Drainage basin or watershed is an essential landscape unit in which collection and distribution of water and sediment occur. There is a correlation between hydrological characteristics in a watershed with the physiographic characteristics such as size, shape, slope, drainage density and stream density (Waikar and

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Nilawar, 2014). Hydrological characteristics in a watershed is determined by the geomorphicl processes that occur within the basin and play a significant role, as the patterns of basin morphometry influence the various geomorphic processes such as flood peaks, sediment yield and erosion rates occurring within it. Evaluation of the drainage network of a basin, aided by quantitative morphometric analysis gives information about the hydrological background of the rock formation exposed within the drainage basin (Singh et al, 2013).

Significantly, urbanization decreases infiltration capacities, increases overland flow, and concentrates flows in storm drains and channels. This form of land use change may increase runoff and sediment production and generate substantial responses in flooding, sedimentation and channel morphology downstream. Due to increasing human activities such as dredging, sand mining, agricultureand building near the bank of Otamiri watershed, the morphological characteristics of have changed overtime, resulting to the water level receding; places once covered by water are today bare land. These morphological changes have increased the tendency of flooding in the nearby communities. Therefore, this study is an attempt to evaluate the morphological changes and associated mitigation methods as well as the implemention in order to prevent the occurrence of a major flood disaster.

## Literature Review

Various researches have been carried out with regards to the impact of anthropogenic activities on stream morphology. Most of them share a common idea on how human activities impact the stream form.

Clark and Wilcock (2000) research gave rise to a conceptual phrase known as "Reverse Channel Morphology" which simply refers to a downstream decrease in channel size that is contrary to the expected geometry of self-adjusted channels, but is consistent with the presence of partially evacuated sediment. The researcher explained that from 1830 to 1950 in North Eastern Puerto Rico land was cleared for agriculture this led to a 50% increase in runoff and sediment load in the channel. Over 50 years later there was a shift in land use from agriculture to industrial and residential purposes.

Gregory (2006) argued that the direct consequences of human on the river channels through engineering works, including channelization, diversion and culverting has been long recognized. Some of the anthropogenic activities and their relative impact include barrage construction across the dam to provide irrigational facilities in the agricultural fields especially in the dry season, caused a decrease in the competency and capacity of the river to transport sediment load, sand extraction is intense in countries subject to urban development and this act caused channel deepening which is often referred to as incision, there is an obstruction of the water flow from the river due to the need of drinking water, purification plants were built near the river and these plants obstruct the flow of water, thereby causing a reduction in the ability of the river to carry load because of the lack of water currents and construction work in the river and river banks like bridges caused a sudden flow of unwanteddebris from the banks into the river which in turn causes a decrease in channel depth (Jatan, etal 2015).

Barr (2017) considered anthropogenic activities from a different perspective due to the high level of flooding around the world. The author suggested that an understanding of geomorphology is important, in order to understand urban morphology, an analysis beyond the norms of geomorphic change is required, this means looking past impervious surfaces and into social influence often referred to as human intervention (this refers to channel changes caused by human engineering in order to fit infrastructural need) in river channels which is most often discussed in most studies. The aim of the study was to expand our understanding of urbanized channels by conducting a socio- geomorphologic investigation. That is investigating the natural and policy driven events and processes leading to the current channel form. The conclusion of the research was, not all urban riversundergo the same type of morphological change due to the difference between local socio-political processes and the local contingency.

These relationships are further complicated by variations in sediment texture, the partitioning of sediment between in-channel and overbank deposits, and potential armoring of the channel bed, factors which may be time contravened as fine-grained, in-channel sediments are rapidly deposited downstream while lag gravels and overbank sediments are gradually deposited. Typically, a significant land-use change, such as urbanization and deforestation can increase water and sediment production, may initially result in sediment storage and channel aggradation near the source accompanied by channel widening as coarse materials are channeled to the bed (Gomez et al., 2004. Channel enlargement can involves a

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combination of vertical adjustment by incision or floodplain aggradation, or widening by lateral channel migration. Models of channel response to aggradation indicate that channel morphology evolves through a series of stages that commonly involve degradation in a narrow zone, followed by widening, then by channel bottom aggradation to achieve a new equilibrium state.

Channel enlargement influences energy conditions that govern channel adjustment, the frequency of floodplain inundation, and the delivery of water and sediment downstream. Thus, channel enlargement in upstream areas has downstream consequences. These morphologic changes can decrease the downstream attenuation of flood waves, further increasing flood peaks downstream. Continued channel widening decreases flow depths for a given flow frequency, requiring larger flood magnitudes to generate the same stream power. There is a missing link on the geomorphic factors: the climatological, morphological and hydraulic factors associated with the land use changes in Otamiri watershed. Given these gaps and the attendant consequences, it has become pertinent to seek to identify new trend of land use studies in Otamiri region.

## Aim And Objectives

The study is aimed at the determination of morphometric and morphologic parameters of Otamiri river basin by the delineation of the watershed and measurement of the basin's parameters. Specific objectives include to:

i. delineate and quantify the drainage basin morphometric characteristics (linear, areal and relief).
ii. determine how sediment yield, discharge, infiltration capacity and urbanization index affect channel morphology of Otamiri river basin
iii. develop an explanatory framework model of channel form based on the process variables ofurbanization index, infiltration capacity, sediment yield and bankfull discharge.
iv. recommend sustainable watershed management measures of the basin.

## Study Area

Otamiri river basin was the focal area of study, located within Latitudes 4°54‟N to 5°00N and Longitudes 7°10E to 7°90E and covers an area of about 10,000 km$^2$ (Fig. 1). It is a lowland, underlain by coastal plain sands of Benin formation. The mean annual temperature remains about 27$^o$C throughout the year and, with a total rainfall of about 2,500 mm. The relative humidity is estimated to reach about 90%. The river runs south from Egbu through Nekede in Owerri, Imo State to Ozuzu, Etche, Rivers State, where it flows to the Atlantic Ocean. The river has a total stretch of 30 km. The watershed is majorly enclosed by dwindling rainforest vegetation as a result of intensive industrial and anthropogenic activities such as farming, urbanization, sand mining, dredging etc.

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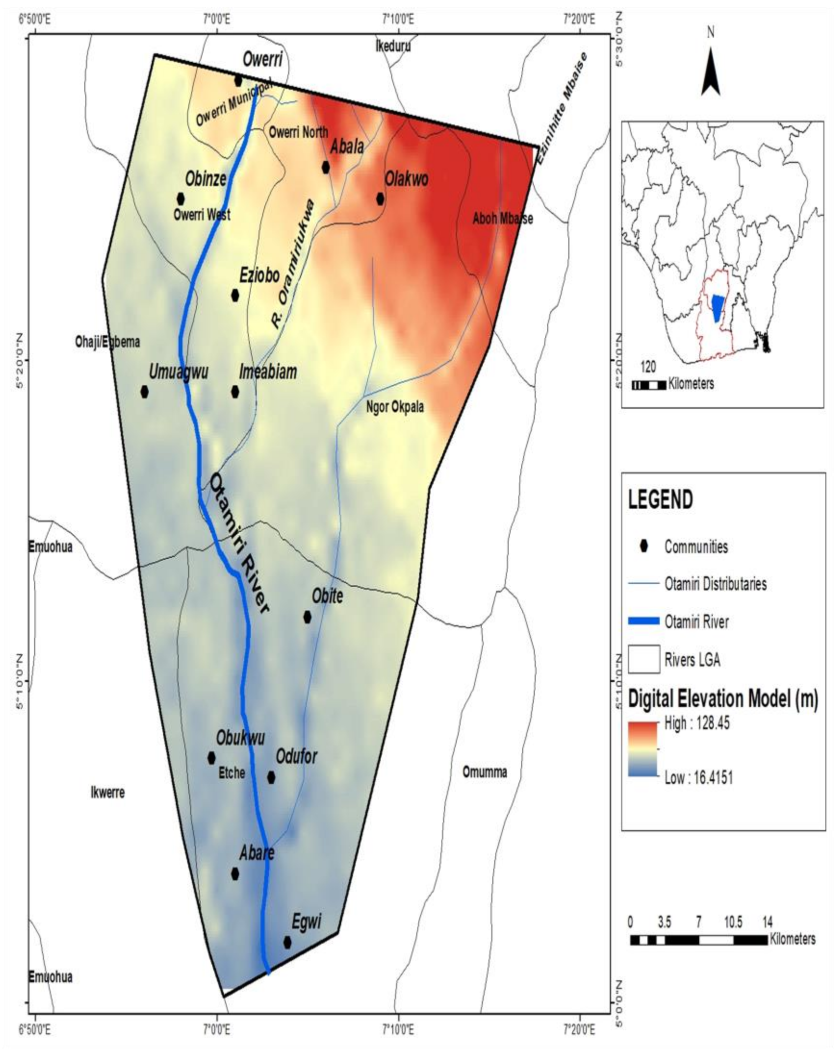


Fig. 1: River Basin Showing Adjoining Regions

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## Materials And Methods

Remote Sensing (RS) and Geographic Information System (GIS) techniques/tools were adopted in the present study to delineate Otamiri river basin, derive the stream network, derive and analyse morphologic parameters. NASA's Shuttle Radar Topography Mission (SRTM) mosaic Digital Elevation Model (DEM) at a resolution of 90 m has been used to delineate the Otamiri river basin (Figs. 2-4).

The obtained watershed margin was then changed to shapefile, from which the area and perimeter of Otamiri river basin was calculated in attribute table of ArcGIS. The stream ordering system of Strahler (1964) of stream length was adopted in Otamiri river basin using ArcGIS 10.8. The results are presented in Table 2.

Similarly, the study adopted the field survey research design, involving on-the spot field investigation and experimentation. Data for this study emanated from two main sources such as primary and secondary. The upper course of the Otamiri river basin is a sixth (6$^{rd}$) order basin. It has a total length of 30 km. The sample size for the study was determined through pilot survey to ascertain the optimumsample size derivable from the sample frame. Hence, only thirty (30) samples were randomly selected from the one hundred and sixty (160) sampling sites. The following variables were obtained: bankfull discharge, channel morphology, sediment and solute, laboratory analysis, infiltration capacity and urbanization index.

Fig. 2: Flow Pattern of Otamiri River (Google Earth)

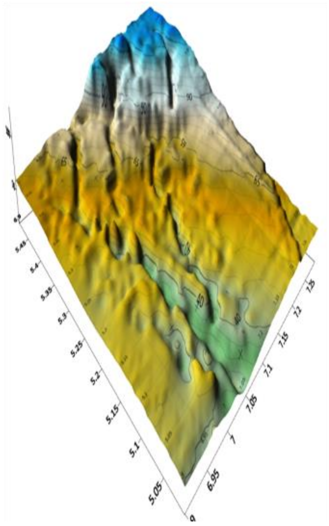

Fig. 3: Digital Elevation Model (DEM) of Otamiri River Basin

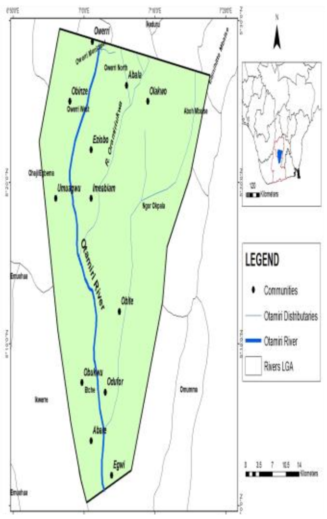


Fig.4: Stream Network Map of Otamiri River Basin

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## Methods Of Data Analysis

### 1. Bivariate Analysis

This analysis seeks to establish the relationship between two variables in order to determine thedegree of co-variation in the variables. The significance of the resulting correlation co-efficient was tested with a null hypothesis($H_0$) stating that there is no correlation between the variables of interest. The student 't' test for testing the difference between sample means was used to test if a significant difference exists between the observed and predicted values of channel morphology.

### 2. Regression Analysis

The equation for this study is of the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + e$$

where:
Y = channel morphology
a, $b_1$, $b_2$................ $b_m$ are regression coefficients
e = error term

$X_1$ = infiltration capacity
$X_2$ = sediment yield
$X_3$ = discharge
$X_4$ = Urbanization Index.

## Results And Discussion

**Table 1:** The Results of Morphometric Parameters Computed in this Study

| S/No | Morphometric Parameters | Values for Otamiri River Basin | Unit | Morphometric Evaluation |
|---|---|---|---|---|
| 1 | Basin Area (A) | 10,000 | $km^2$ | - |
| 2 | Basin perimeter (*P*) | 425.11 | Km | - |
| 3 | Basin length (*L*) | 65.87 | Km | - |
| 4 | Basin width (*W*) | 25 | Km | - |
| 5 | Highest stream order (U) | 6 | No | - |
| 6 | No. of stream segments | 716 | No | - |
| 7 | Stream length (*L*) | 2160.7 | Km | - |
| 8 | Mean stream length | 360.11 | Km | - |
| 9 | Mean stream length ratio (*R*L) | 3.01 | No | - |
| 10 | Bifurcation ratio (Rb) | Mean 2.57 | No | - |
| 11 | Length of overland flow (*L*of) | 0.76 | Km | High |
| 12 | Form factor (*R*f) | 0.17 | No | Low |
| 13 | Texture ratio (*T*) | 1.33 | Km | Low |
| 14 | Circulatory ratio (*R*c) | 0.388 | No | Low |
| 15 | Elongation ratio (*R*e) | 7.00 | $Km^{-1}$ | Low |
| 16 | Compaction coefficient | 1.573 | No | High |
| 17 | Drainage density (*D*d) | 0.54 | No | Low |
| 18 | Constant of channel maintenance C) | 1.82 | No | - |
| 19 | Stream frequency (*F*s) | 0.165 | per sq km | Low |
| 20 | Basin relief (*B*h) | 0.90 | M | Low |
| 21 | Relief ratio (*R*h) | 0.019 | No | Low |
| 22 | Ruggedness number (*R*n) | 646 | No | High |

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The evaluation and discussions of the morphometry of Otamiri watershed are made using linear, relief and areal aspects below.

**i. Linear Aspects**

The drainage pattern in Otamiri river basin is dendritic to sub-dendritic. The drainage dendritic arrangement is an indication of presence of uniform resistance of rock to the drainage in the basin. (Petersen et al., 2017).The geomorphic characteristics of Otamiri river basin confirm to Horton (1932) that the number of stream segments of different orders decreases with increase in stream order. In Otamiri basin, bifurcation ratio shows variation from 2.00 to 5.50 (with a mean of 2.57) across different stream orders (Table 1), an indication of lack of structural control.

**ii. Relief Aspects**

The relief in Otamiri river basin is found to be low at 0.90 m. According to Harsha1etal. (2020), the lower relief found in a river basin indicates lesser energy available in the drainage system of the basin.

**iii. Areal Aspects**

The visual examination of shape of the Otamiri river basin in (Fig. 1) shows that it is elongated. On examination of the indices/parameters shown in Table 1, it is observed that the form factor for Otamiri river basin is 0.17 which is low. Form factor would always be greater than 0.78 for perfectly circular basin and the smaller the value of form factor, the more elongated will be the basin. The circularity ratio and elongation ratio of Otamiri river basin are 0.388 and 7.00 respectively, which are low. From the results for Otamiri river basin, it is observed that the drainage density and stream frequency for the basin are low, i.e. 0.54 and 0.165 respectively, indicating highly permeable soils and low relief. The drainage density of the basin and the long concentration time are dependent not only on the relief but also dependent on the resistance of rocks across different stream orders, vegetation, rainfall and sub-surface material.

The areal aspects of the Otamiri river basin confirm that the basin is elongated and as a consequence, the river basin experiences low peak flows of runoff for longer duration despite flood risk. However, lower drainage density and length of overland flow in the basin confirm longer concentration times for runoff. Therefore, while runoff in Otamiri river basin has large scope for infiltration into the groundwater, intense flooding and erosion are expected in the river basin. Furthermore, the delineation of the drainage pattern to understand terrain parameters such as the infiltration capacity, surface run off, flood peaks, assessment of sediment yield, erosion rates etc., will help in better understanding the status of land form and their processes, drainage management and evolution of groundwater potential for watershed planning and management and will be useful for soil and water conservation and is a positive scientific contribution for the people of Otamiri river basin area.

**The Results of Morphologic Parameters Computed in this Study**

Table 2 below shows data set for width and mean depth acquired at stations A-H. The eight stations were acquired at one meter (1m) interval.

**Table 2:** Width &Depth Dimension at Stations A-H along Otamiri River Channel

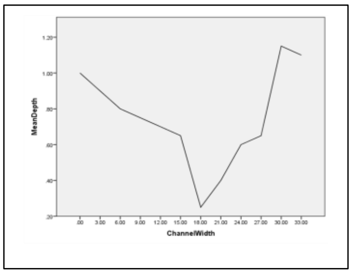
| Station | Right Bank (m) | 3 (M) | 6 (M) | 9 (M) | 12 (M) | 15 (M) | 18 (M) | 21 (M) | 24 (M) | 27 (M) | 30 (M) | Left Bank (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.65 | 0.70 | 0.75 | 0.80 | 0.90 | 1.00 | 1.10 | 1.15 | 0.65 | 0.60 | 0.40 | 0.25 |
| B | 0.25 | 0.70 | 0.45 | 0.35 | 0.30 | | | | | | | |
| C | 0.30 | 0.70 | 0.75 | 0.60 | | | | | | | | |
| D | 0.70 | 0.90 | 0.85 | 0.65 | | | | | | | | |
| E | 0.35 | 0.30 | 0.30 | 0.75 | 0.90 | 0.90 | 0.40 | | | | | |
| F | 0.70 | 0.75 | 0.75 | 0.90 | 0.95 | 1.10 | 1.55 | 1.75 | | | | |
| G | 0.75 | 1.50 | 1.45 | 1.55 | 1.50 | 1.30 | 1.25 | 1.00 | 0.70 | | | |
| H | 0.85 | 1.45 | 0.50 | 1.70 | 2.00 | 2.10 | 1.00 | 1.00 | 1.10 | | | |

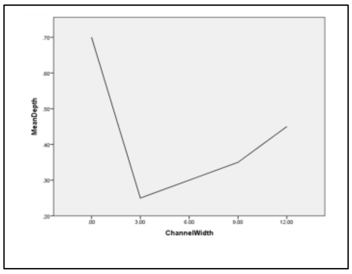
**Source:** Researchers' Fieldwork, June, 2021

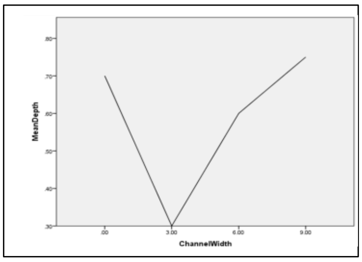
From the table above, a revelation is made regarding variations in depth along the stream channel at different sampling stations. The eight stations shown indicate progressive and sequential changes in depth downstream.

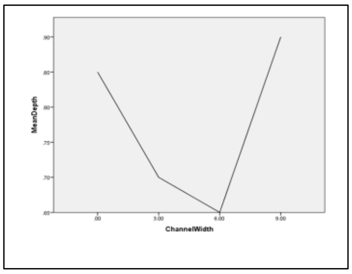
At station 'A', a width of 30 metres (i.e between the right and left bank in the data table above) was recorded. At station B, there was decrease as the widths measured reduced to 12 metres. At another station C, the channel remained 9 metres, and station D, the channel remained 9 metres before increasing to 18 metres at station E.

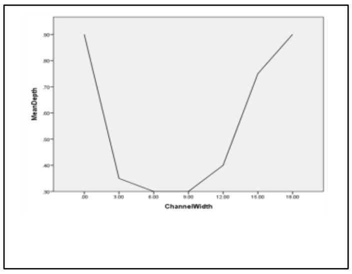
The analysis above shows that station A had the greatest width of this channel, which was taken close to the foot of a bridge at Port Harcourt-Owerri dual carriage way that cut across the river channel. This has given rise the width enlargement of this channel at this point and increased storm runoff from adjacent drainage system running directly into the stream at this point (Figs. 3-10).

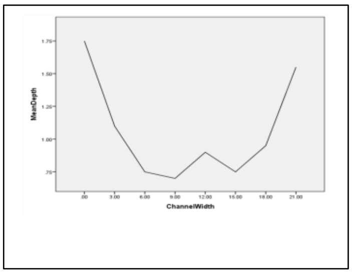


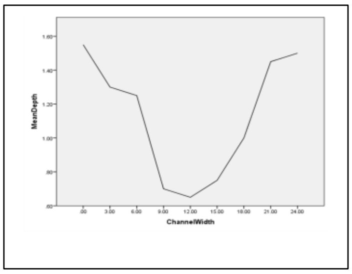



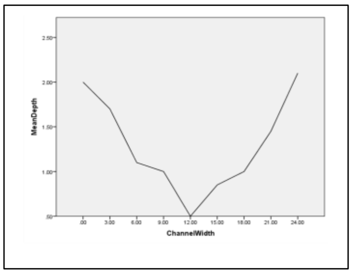




So far, it has been shown that from the data collected at different cross-sectional sampling stations that considerable variations did take place within and between the hydraulic variables. From table 2 below, a number of relations become glaring.

**Table 3:** Hydraulic Variables for Stations A-H

| Stations | Width (m) | Mean depth (m) | Velocity (m/s) | Discharge (cumecs) | Infiltration capacity (ppm) | Sediment yield (ppm) | Urbanizing Index (%) | Channel Morphology |
|---|---|---|---|---|---|---|---|---|
| A | 33 | 0.84 | 0.3551 | 9.840 | 4.00 | 0.65 | 4.5 | 27.52 |
| B | 12 | 0.36 | 0.3639 | 1.570 | 4.20 | 0.83 | 9.3 | 4.32 |
| C | 9 | 0.60 | 0.3654 | 1.970 | 4.10 | 0.90 | 15.84 | 5.40 |
| D | 9 | 0.80 | 0.3666 | 2.640 | 4.08 | 0.69 | 21.12 | 7.20 |
| E | 18 | 0.53 | 0.3731 | 3.560 | 4.73 | 0.73 | 37.98 | 9.54 |
| F | 20 | 0.97 | 0.3805 | 7.330 | 4.69 | 0.84 | 50.00 | 19.40 |
| G | 24 | 1.10 | 0.3805 | 10.039 | 3.93 | 0.89 | 77.41 | 26.40 |
| H | 24 | 1.40 | 0.3822 | 12.842 | 4.50 | 0.88 | 88.00 | 33.60 |

**Source:** Researchers' Fieldwork, June 2021

The Otamiri river channel width variations show a continuous downstream channel response to increment in discharge from urbanization associated activities. The differences revealed in the data acquired

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at different measuring stations show that changes had been experienced downstream as the stream channel adjust to the conditions imposed by urbanization.

Also, the combination of width and depth reflects again important association of stream channel response to urbanization activities. The channel depth is adjusted to present flow conditions which require a deeper channel to accommodate the runoff and flood increment from the urban surfaces

The channel form observed shows that downstream channel is wider, deeper and with increasing velocity as compared with the upstream section. Increments in discharge undeniably cause changes in channel width, depth and velocity. This will be revealed in the preceding section using statistical analysis.

From all the eight (8) stations sampled cross-sectionally along the river channel, discharge generally increases downstream (Table 2). This conforms with numerous findings that stream power increases downstream (Odemerho, 1984, Oyegun, 1984, Sayok and Chang 1990, Oku, 1997, Pizzuto et al., 2000 etc.). It is of interest to note here that this finding contradicts davis (1899), who concluded deductively that stream power decreases down the stream. It was noted in this study that outfalls channels, sewers and gutters designed to convey runoff and stormflow from the urban areas had accounted for this increased discharge.

The increased augmented runoff from paved surfaces with a decrease in sediment yield produced incision at the later part of the stream channel. This accounted for increased sediment yield in the main channel during local storms. This finding is in line with Scumm (1968), Oyegun (1984), Gregory and Gunnel (1988), Royal (2000) etc.

## 1. Statistical Analysis

It is pertinent to establish the joint as well as the individual contributions of the independent variables of discharge, sediment yield, infiltration capacity and urbanization index on the dependent variable of channel morphology of the basin.

The multiple correlation as well as linear regression analysis and the student t-test were therefore employed as a working tool to establish this relationship between these variables stated above. All these variables and their corresponding correlation coefficients are shown in the summary Table 3 of the regression matrix below:

**Table 4:** Correlation Matrix

| | Channel Morphology | Discharge | Infiltration Capacity | Sediment yield | Urbanization Index |
|---|---|---|---|---|---|
| Channel Morphology | 1.000 | .999 | .002 | .092 | .653 |
| Discharge | .999 | 1.000 | .023 | .132 | .692 |
| Infiltration Capacity | .002 | .023 | 1.000 | .068 | .304 |
| Sediment yield | .092 | .132 | .068 | 1.000 | .552 |
| Urbanization Index | .653 | .692 | .304 | .552 | 1.000 |

**Source:** Computer Analysis Output of SPSS
** Correlation is significant at the 95% level

The above table shows the summary of the correlation matrix of the independent variables of urbanization index, discharge, infiltration capacity and sediment yield on the dependent-variable of channel shape and size of the Otamiri river channel.

In testing the research hypothesis, which states that there is no significant relationship between sediment yield and channel morphometric indices in Otamiri river basin, the linear regression/correlation was used. Also, the significance of the individual independent variables contribution to the urbanizing river catchment has been tested with the aid of the student 't' test statistics.

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From Table 3 above, it can be seen that there is a low correlation between sediment and channel morphology. This relationship though positive with a correlation coefficient of 0.092, is not statistically significant at 0.05 significance level of 2.45 at 6 degrees of freedom. The table value is greater than the calculated value; this was further analyzed using the coefficient of determination ($R^2$) to show the percentage variation in the channel morphometric indices. It was found out that the coefficient of determination for this relation was 0.84%, this means that an insignificant 0.84% variation in the channel shape and size characteristics is explainable by the sediment yield capacity of the basin.

From the analysis above, it means that the null hypothesis ($H_0$) of the relationship between channel morphometric indices and sediment yielding capacity of the urbanizing Otamiri river catchment is accepted. Hence, it can be said that there is no significant relationship between channel morphometric indices of size and shape and sediment yielding capacity of the Otamiri river catchment.

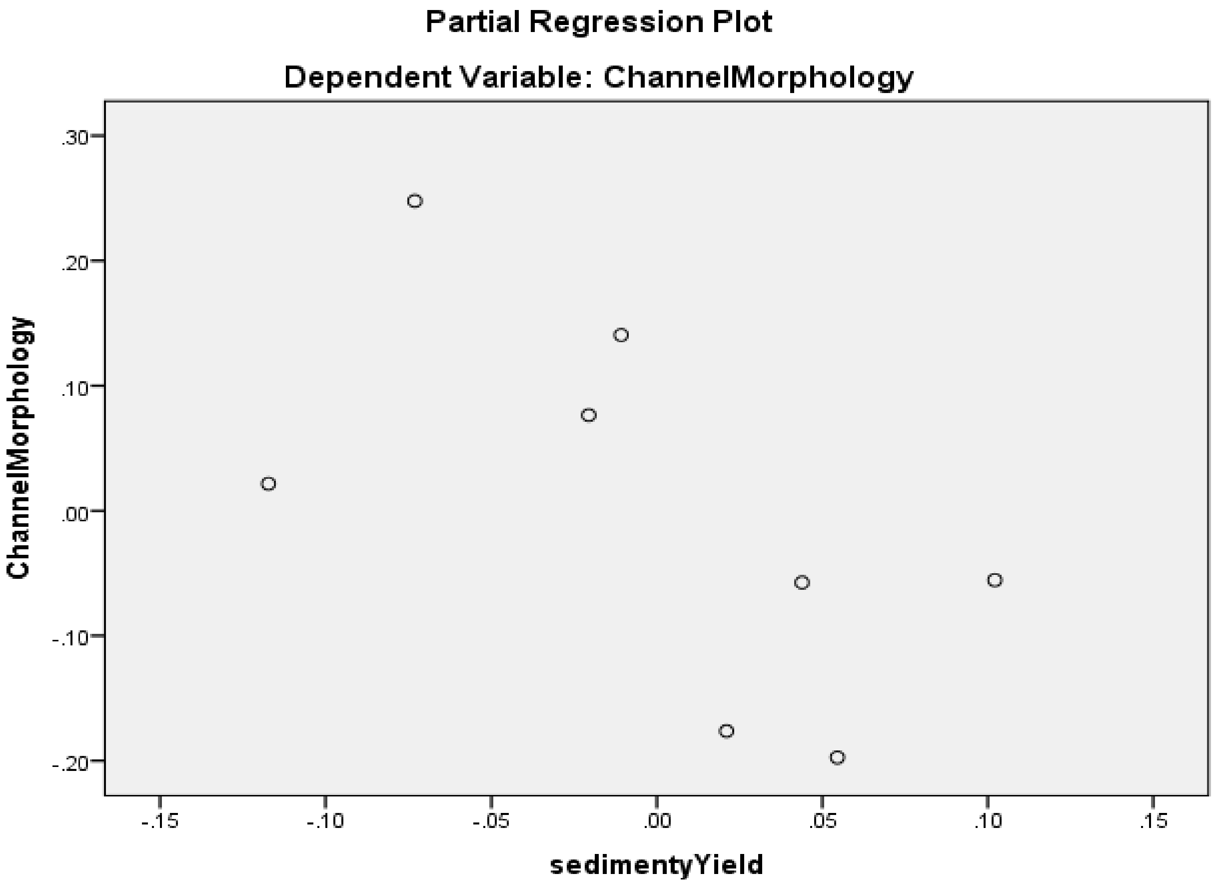


Fig. 11: Correlation Between Channel Morphology and sediment Yield

But on the other hand, the relationship between sediment and urbanization index was looked into. From Table 3, it can be seen that the correlation coefficient between sediment yield and urbanization index is 0.552. The calculated t-statistics and test for significance. The implication of this is that though urbanization processes are in their sediment generating stage, it shows significant relationship with channel morphology.

Also, the second hypothesis, which states that there is no significant relationship between channel morphology and urbanization was tested using the statistical approach, outlined above in the preceding chapter. The linear regression technique was chosen as a tool to show the relationship between these variables. From Table 3, it could be seen that there is a strong positive relationship between channel morphology and urbanization with a correlation coefficient of 0.653. This means that there is a linear and positive correlation between urbanization index and Otamiri river channel.

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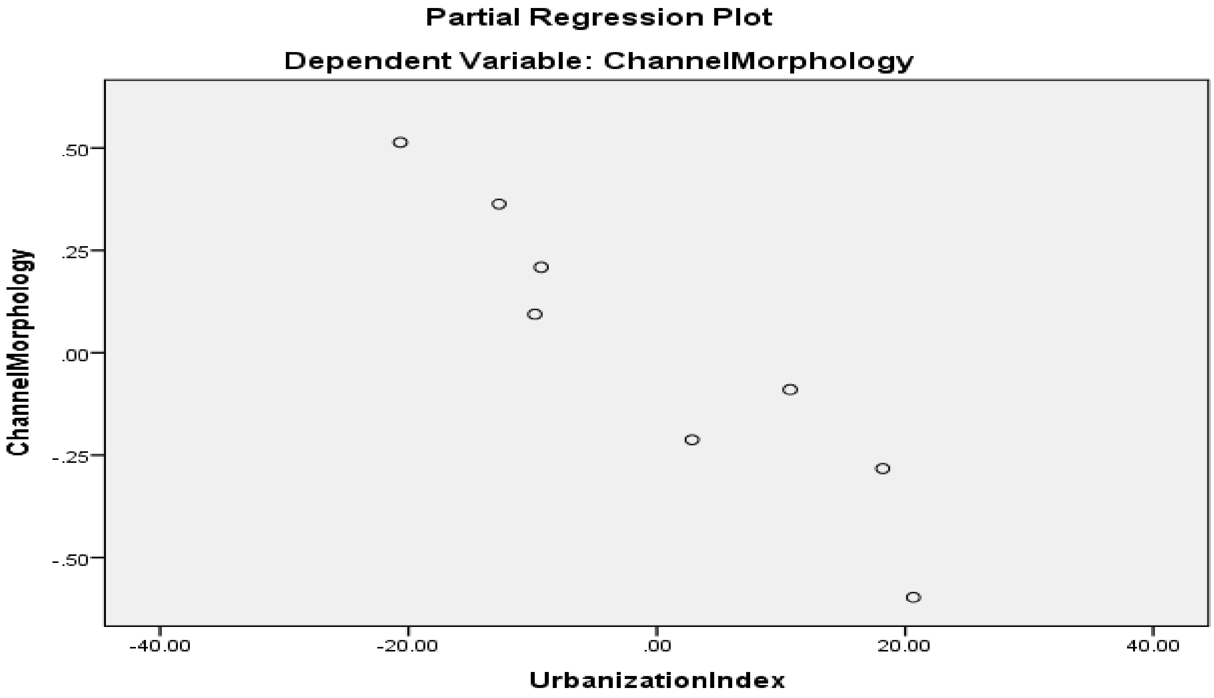


Fig. 12: Correlation Between Channel Morphology and Urbanization Index

Also, the calculated t-statistics of 7.88 is greater than the table value of 2.45 at 0.05 significance level with 6 degrees of freedom. Again, the coefficient of determination ($R^2$) for this relation is 91.20%. This means that about 91.20% of the variation in the urbanizing Otamiri river channel is explainable by urbanization index of the catchment. Hence the null hypothesis is rejected, which states that there is no significant relationship between channel morphology and urbanization index of the basin. Therefore, the alternate hypothesis which was stated earlier on is accepted. This finding is in line with works carried out by previous writers (Hammer, 1973, Gregory and Walling 1973, Knight 1979, Oyegun 1984, Oku 1997, Niezgoda, 2004).

Also, it can be seen from the correlation matrix table that there is a marked linear relationship between discharge and urbanization index. Its correlation coefficient is 0.967 with a coefficient of determination of 93.50%. This means that about 93.50% of the total variation in the level of bankfull discharge is explainable by the urbanization index of the basin for the statistics. The finding is in line with the existing reasoning in fluvial geomorphology (Akintola 1978 and Pizzuto et al., 2000) that as the urbanization processes continue, more impervious surfaces are created which facilitate runoff and subsequent discharge into the basin catchment.

The relationship between the infiltration capacity of the basin soil and Otamiri river channel morphology is also tested as shown in Table 3. It is evident from the table that there is a negative correlation of -0.004 between infiltration capacity and channel morphology of Otamiri river (Fig. 13).

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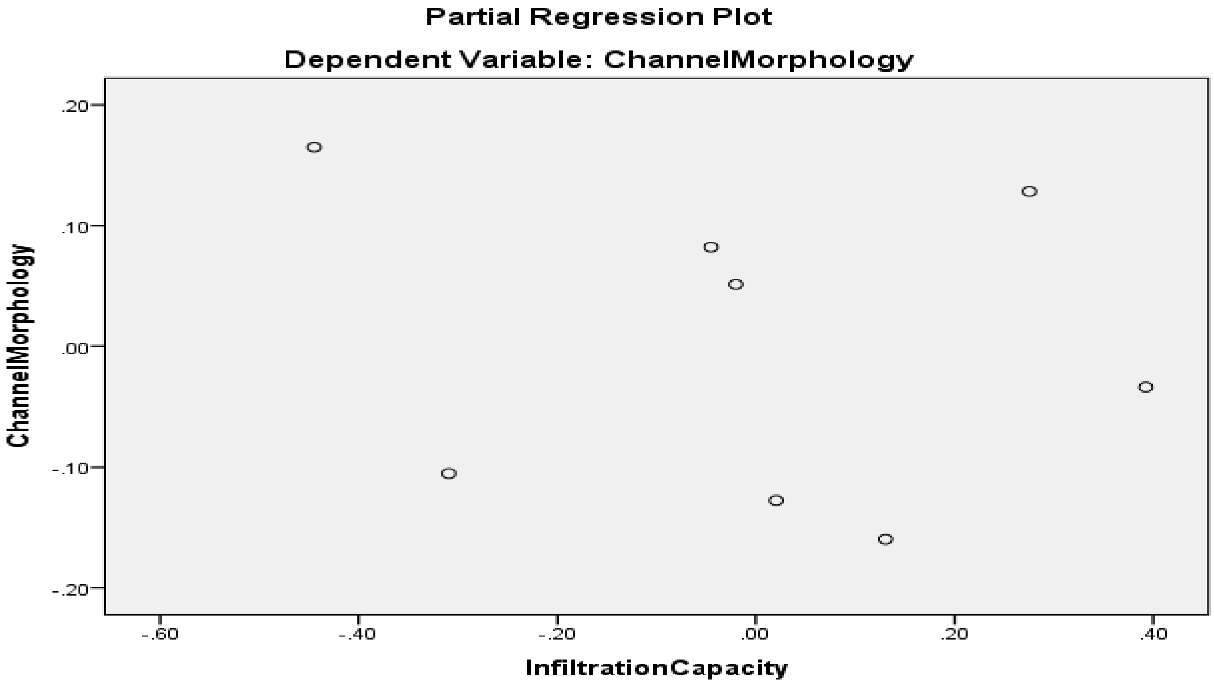


**Fig. 13:** Correlation Between Channel Morphology and Infiltration Capacity

Also, when the infiltration capacity of the basin soil is correlated with other independent variables of discharge, sediment yield and urbanization index, it has a positive correlation with these variables. Despite the fact infiltration capacity of the basin soil is positively correlated with these other variables, but they are not statistically significant. Therefore, the basin soil as well as the urbanization index may well be used to explain this trend. This is attributable to the fact that a large portion of the urbanized catchment has been made impervious, which in turn yields more volume of discharge into the stream channel.

Furthermore, the relationship between the channel discharge and channel morphology was tested. From Table 3, it can be noted that the correlation coefficient between discharge and channel morphology is 0.999. This means that there is a high positive relationship between discharge and stream channel morphology. It can be noted that it is statistically significant at 0.05 significance level with a calculated t-statistics of 54.73 against a table value of 2.45 at 6 degrees of freedom (Fig. 14).

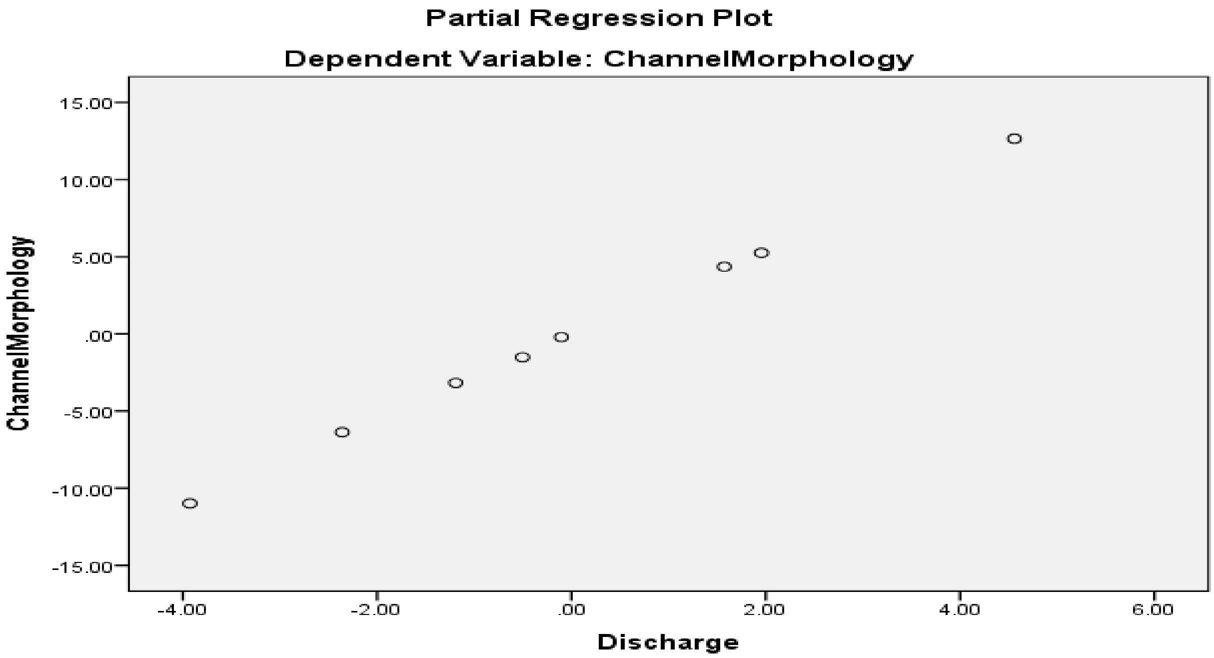

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Fig. 14: Correlation Between Channel Morphology and Discharge

The coefficient of determination for the relation is 0.994%, which means that about 99.50% of the urbanizing Otamiri river morphology is explainable by discharge. This finding is in line with previous works of Odemerho 1984, Starkel et al., 2002.

**Summary And Conclusion**

This study was carried out to examine a comparative study of the morphometry and morphology of Otamiri river basin. It has been noted that there is a progressive increase in human activities in the area. Based on these facts, the hydraulic geometry and channel capacity of the river has been altered. Hence the stream channel has been adjusted to meet the demand imposed on the stream on the upper section of the river basin. The basin was found to possess low drainage density, drainage texture and stream frequency which indicates highly permeable soils and low relief. Other observed parameter such as low overland flow revealed recharge related measures, surface water augmentation measures that can be undertaken for water resource management as well as soil conservation structures in the study area.

Firstly in this study, it has been found that there is a low correlation coefficient between sediment yield and channel morphology. It was not statistically significant at 95% probability level using the 't' statistics as a bivariate technique. This is as a result of the fact that increased sand mining and urbanization leads to increased concretization, hence less sediment yield.

Secondly, the study also found out that the relationship between channel morphology and urbanization index. The study shows that there is a high positive relationship between urbanization index and channel morphology. From the test analysis, a linear relationship of 0.955 was obtained. It was however statistically significant at 95% probability level.

Also, urbanization index has a high positive correlation with discharge. The correlation coefficient for this relationship is 0.967. This is significant at 95% probability level. In essence urbanization index is not a determinant of channel morphology in this study but its impact has been noted as a potent contributor to discharge characteristics of Otamiri river basin. Again, channel morphology was correlated with discharge and it shows a high positive correlation. The relationship was statistically significant at 95% probability level. It can be noted here that discharge, which is influenced by other independent variables of urbanization index, infiltration capacity of the soil etc. was the most single determinant of the Otamiri river channel morphology. Furthermore, because of the greater volume of water passing through the channel as a result of sand mining, urbanization and agriculture, its cross-sectional area has been enlarged.

With urbanization, consisting of built-up areas, the volume of paved area increased rapidly and the grassed areas decrease thus making the predicted runoff and flood larger, hence increased discharge. The increased augmented runoff from paved surfaces with a decrease in sediment yield produced incision at the later part of the stream channel. This accounted for increased sediment yield in the main channel during local storms.

Similarly, infiltration capacity of the catchment soil correlates negatively with the channel morphology of the Otamiri river. This means that it's contribution is not directly significant with the existing channel form and size characteristics though contribute to the basin discharge characteristics which have been found to be the potent factor that determines the channel shape and size characteristics of the Otamiri river channel.

It can thus be inferred from the present study that because of low infiltration capacity resulting from larger areas of the basin being made impervious, groundwater recharge is much likely to be a fundamental problem of some kind of sooner than later in the urban area. There is this problem of the stream water being degraded due to impurities that enter it from the sewers and gutters. Bank instability, vegetal growth along the stream, and stream amenity devaluation are all likely problems that the Otamiri river will encounter.

**Recommendations**

It has been found out from this study that the most potent factor that initiates channel enlargement is discharge. Therefore, flooding is one of the hazards that will likely be affecting the inhabitants of the Otamiri river flood plain. Flooding as an hazard is expensive and can cause loss of lives and property. Then building into the river flood plain should be discouraged, because it reduces the width of the channel and therefore its capacity, which may lead to flooding.

The above can be achieved by working with the local town planning authority in the area to zone the natural flood plain for non-urban structure that have crowded onto and constricted the natural river width. The construction of channel stabilization scheme is also recommended to ameliorate this flooding risk.

The author recommends sustainable forest resource management in the basin. There is need to preserve the already existing forest at certain reaches of the stream. This is recommended because mature vegetation has a higher rainfall interception rate, a tendency to reduce rates of overland flow and generates soil with a higher infiltration capacity and better general structure. This will tend to reduce both overall runoff levels and less extreme flood peaks. The presence of vegetation in this basin can also reduce nutrient and material loss to the river, thereby reducing pollution level. Hence, the continued destruction of original vegetation in this area has led to more dissolved substances in streams which are causing the undesirable effect of water pollution in the area, hence the deterioration in public water supply in Otamiri river basin.

The government, the public and the individuals embarking on production of any kind need to be educated on the usefulness of rivers to the entire life of the people, which range from agriculture, domestic and commercial purposes. Against this background, any waste being channeled to the stream should be well treated.

Finally, the authors equally recommend the possibility of making this river a social asset and aesthetic amenity in the area, since no social amenity like this is known to be existing in the area. This can be achieved effectively by creating parks and paths by the stream side and embarking on mop-up of the sides of the river.

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