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Morphometric Characteristics of the Lower Orashi River, Niger Delta Region, Nigeria

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ABSTRACT: The study examined the spatial analysis of the morphometric characteristics of the Lower Orashi River, Niger Delta Region, Nigeria. The river course was segmented into 30 equal distances of 4.8m from each other and at each point, the morphometric parameters like width, depth, and flow velocity. The discharge was measured from these parameters. Descriptive and inferential statistics were employed for data analysis while results are presented using tables and graphs. Results showed that width of the river ranged from 77.90m to 2788.00m with the mean width of 318.83m. The depth ranged from 2.10 to 7.60m with the mean depth recording 4.14m as it was higher at the upper section of the river while it becomes lower as it is entering the Atlantic Ocean. Furthermore, width was significantly correlated with the depth ($r= -0.556$, $p<0.05$), cross sectional area ($r= 0.989$, $p<0.05$) and discharge ($r= 0.987$, $p<0.05$). Also, elevation was significantly correlated with cross sectional area ($r= -0.506$, $p<0.05$) and discharge ($r = -0.511$, $p<0.05$). More importantly, the cross sectional area was correlated with discharge ($r=0.995$, $p<0.05$). The study concluded that there is significant variation existing in the morphometric parameters namely width, elevation, cross sectional area and discharge among the segments along Orashi River. The study therefore recommended that the water course should be reduced of human activities to reduce the rate of soil loss or discharge and to boost the river floor with adequate morphological property.

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River morphology is the scientific study of how sedimentation and erosion processes affect the plan form and cross section of rivers (El-sayed *et al.*, 2017). Although each river channel has its own distinct features, variations in river channel morphology are caused by a wide range of hydrological conditions, sediment characteristics, and geologic histories of the river (Fashae and Faniran, 2015). The ongoing processes of erosion and sedimentation patterns in rivers have reportedly decreased the capacity of rivers to contain incoming flow from the upstream, depending on the circumstances (El-sayed *et al.*, 2017; Haron *et al.*, 2017). Over the past decades, one-third of the global land use has been changed either once or on multiple occasions (Winkler et al., 2021). The dynamicity of Land Use and Land Cover (LULC) change has triggered issues related to environmental, ecosystem, water, food security, climate change, etc. (Song *et al.*, 2018; Winkler *et al.*, 2021). Any human-induced landscape modification driven by economy or

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politics has impacts on major components in the Earth system, such as carbon cycle, surface hydrology; and atmospheric processes (Zhao *et al*., 2006). These changes also affect social systems and impact food security, energy production, and water resources (Wolde *et al*., 2021). How LULC changes impact a river basin from various perspectives have been studied (Chin, 2006), including runoff (Wang *et al*., 2017), discharge (Petchprayoon *et al*., 2010), and morphology and structure (Kudnar, 2020). River morphology refers to the shape of river channels and identifying their changes in terms of the area/zone and direction (channel migration) over time can help communities residing near the river bank to guide development away from channel migration zones and reduce flood hazards. The land use landscape strongly influences ecological processes. Especially the combination of obstacles, channels and highly heterogeneous regions, largely determines the exchange and flow of matter and energy in the landscape (Liu *et al*., 2019) affects the hydro-chemical characteristics of different water bodies (Hao *et al.*, 2012) and then determines the direction of water quality change (Ding *et al*., 2016). The flow and sediment regimes combine with the landscape's physiographic features and vegetation cover to give alluvial floodplain rivers their dynamic nature (Nath and Gosh, 2022). In the alluvial stretch, the rivers meander frequently and take different courses. Subsequently, the river morphology changes on a spatial and temporal scale. Several variables influence river morphology (Lancaster and Bras, 2002). Many studies have been conducted on meander parameters and the variables that affect them (Nabegu 2014). The sinuosity index is one of the most crucial factors for determining and measuring river morphological changes' spatial and temporal direction (Ozturk and Sesli 2015; Sapkale *et al*., 2016). There are many studies on morphometric of the river but that of the lower Orashi River has not been done. Thus, the present study investigated the spatial analysis of the morphometric characteristics of lower Orashi River, Niger Delta Region, Nigeria.

MATERIAL AND METHODS

Study Area: The study was carried out in the lower Orashi River, Niger Delta Region, Nigeria. Orashi River takes off as a stream, from the rocks, at the base of a waterfall, 183 m above mean sea level, in the Orashi enclave of Ezeama in Dikenafai, Imo State, Nigeria. From Dikenafai, Urashi flows through several towns, including Urualla, Akokwa, Okija, Orsu, Ukpor, Ihiala, Uli, Oguta, Osemotor, Omoku, Obiakpo, Ebocha, Ukodu, Okarki, Mbiama and Epie. The river forms tributaries, along its flow from Imo through Anambra, Rivers to Bayelsa, before empting into the Atlantic. It bifurcates into two at Egbema. The larger portion (right), continued the flow through Eluku before bifurcating further into two and emptying its waters and sediments at Edi Kalama (Degema) and Abonnema into the gulf of Biafra. The Orashi Region is home to over 35% of the oil wells in the Niger Delta States of Imo and Rivers. The Orashi River is located geographically within latitude 4^{0} $47^{'}$ $20^{''}$ N and 5^{0} $06^{'}$ $20^{''}$ N and longitude 6^{0} $24^{'}$ $40^{''}$ N and 6^{0} $43^{'}$ $40^{''}$ N (Figure 1).

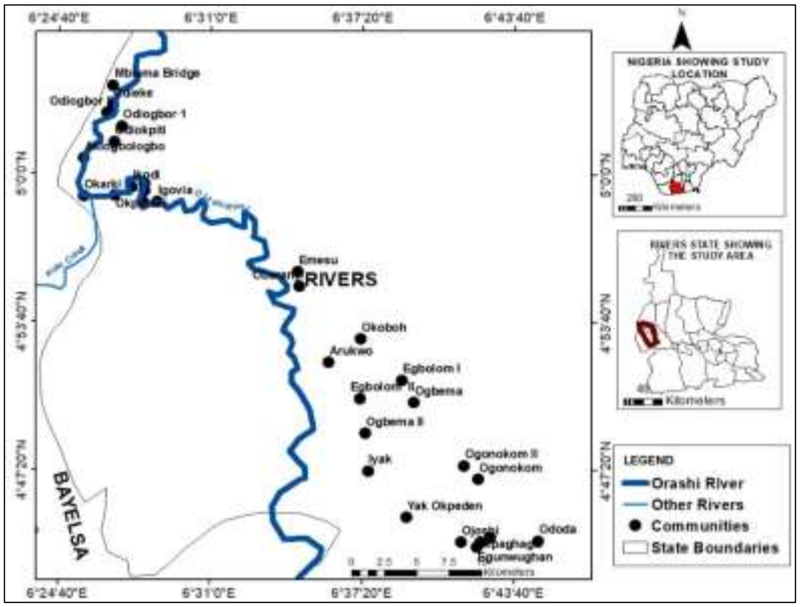

Fig 1: Orashi River and Surrounding Communities
Source: Adapted from Google Earth (2021)

The study area features a tropical monsoon climate, designated by the Koppen climate classification as "Af", and it is mostly found in the southern part of the country. This climate is influenced by the monsoons originating from the South Atlantic ocean, which is brought into the country by the (maritime tropical) MT air mass, a warm moist sea to land seasonal wind. Its warmth and high humidity gives it a strong tendency to ascend and produce copious rainfall, which is a result of the condensation of water vapour in the rapidly rising air (Park, 2004). The tropical monsoon climate has a very small temperature range. Then temperature ranges are almost constant throughout the year. For example, Warri Town in the southern part of Nigeria, records a maximum of 28 °C (82.4 °F) for its hottest month while its lowest temperature is 26 °C (78.8 °F) in its coldest month. The temperature difference of Warri town is not more than 2 °C (5 °F) (Park, 2004). The study area experiences heavy and abundant rainfall. These storms are usually convectional in nature due to the regions proximity, to the equatorial belt. The annual rainfall received in this region is very high, usually above the 2,000 mm (78.7 in) rainfall totals giving for tropical rainforest climates worldwide. Over 4,000 mm (157.5 in) of rainfall is received in the coastal region of Nigeria around the Niger Delta area. Bonny town found in the coastal region of the Niger delta area in southern Nigeria receives well over 4,000 mm (157.5 in) of rainfall annually. The rest of the southeast receives between 2,000 and 3,000 mm (118.1 in) of rain per year (Geographical Alliance of Iowa, 2010). The coastal sedimentary basin of the region has been the scene of three depositional cycles. The first began with a marine incursion in the middle Cretaceous and was terminated by a mild folding phase in Santonian time. The second included the growth of a proto-Niger delta during the late Cretaceous and ended in a major Paleocene marine transgression.

The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger delta. A new threefold lithostratigraphic subdivision is introduced for the delta parts subsurface, comprising an upper sandy Benin formation, an intervening unit of alternating sandstone and shale named the Agbada formation, and a lower shale Akata formation. These three units extend across the whole delta and each ranges in age from early Tertiary to Recent.

They are related to the present outcrops and environments of deposition. A separate member of the Benin formation is recognized in the Port Harcourt area. This is the Afam clay member, which is interpreted to be an ancient valley fill formed in Miocene sediments. Subsurface structures are described as resulting from movement under the influence of gravity and their distribution is related to growth stages of the delta (Short and Staeuble, 1967). The study area is well drained with both fresh and salt water. The salt water is caused by the intrusion of seawater inland, thereby making the water slightly salty. The vegetation of the study area consists mainly of forest swamps. The forests are of two types, nearest the sea is a belt of saline/brackish Mangrove swamp separated from the sea by sand beach ridges within the mangrove swamp. Numerous sandy islands occur with fresh water vegetation. Fresh water swamps gradually supersede the mangrove on the landward side. Some of the forest zone's most southerly portion, especially around the Niger River and Cross Riverr deltas, is mangrove swamp. North of this is fresh water swamp, containing different vegetation from the salt water mangrove swamps, and north of that is rain forest (Geographical Alliance of Iowa, 2010). According to Fabiyi (2011), the region is endowed with mosaic of fragile sensitive and diverse ecosystem. The major ecological zones of the region include mangrove forest and coastal vegetation zone, freshwater swamp forest zone, lowland rainforest zone and the derived savannah zone found in the northern part of the region.

The primary economic activities in most rural communities in the around the Orashi River include peasant farming, petty trading and fishing, shifting cultivation (Slash and burn), which involves cultivating a piece of land for a number of years and then abandoning it for a more fertile land is traditionally practised in the area. Some of the cash crops grown in the study area include oil palm (*Elaeis guineensis*), cacao (*Theobroma cacao*), cassava (*Manihot esculenta*) and rubber (*Herea brasiliensis*) (Enaruvbe and Atafo, 2014).

Pre-field Survey: The study adopted mixed research design which included both descriptive and longitudinal research designs. A pre-field survey was carried out which involved site visitation of the study area which is the lower Orashi River segment in River State. The survey exercise aided in establishing points of references for the study. The possibility of carrying out an empirical survey of this nature was also justified through the reconnaissance survey exercises. The primary data sources involved data gathering of points of references for the study with the help of a hand-held global positioning system (GPS). It also involved the measurements in situ of lower Orashi river physical attributes like depth, width, and flow velocity.

The river length was determined manually and related with measurements obtained from the ArcGIS platform. However, this was conducted by earmarking known points of 50m to 100m distance apart along the river (point A to B) and taking the geographic coordinate of each point. These two locations were aligned with map information in order to determine the exact points of these two locations along the river course. This process served as part of the ground truthing process for mapping analysis. The River depth profiles were determined by measuring the width of the channel, divide the width into equal distances of 4.8m interval each, take measurement at point A – B by placing a long stick into the water body till it gets to the base of the river. The point where the stick surfaces from the water is marked out and removed from the water body. Measurement in metres of this point is recorded and taking as the river depth for each segment to be earmarked as two known points along the course of the River. This process shall be repeated for other segments of the River.

Mathematical Computation: The flow velocity of the river at each segment shall be computed because flow velocity changes at various points along a river course. Thus:

$$Flow\ Velocity = \frac{Tota\ distance\ (A\ to\ B)}{Average\ Time\ (s)} * 0.85 \quad (1)$$

$$Cross\ sectiona\ area = \sum D * W \quad (2)$$

$$Discharge = V * D * W \quad (3)$$

Where Total distance is distance from point A to point B, Where D is the depth of the river at each section; W is the width of the river at each section

RESULTS AND DISCUSSION

Morphometric characteristics (length, depth, width, flow velocity, cross-sectional area and discharge analysis) of the River: The analysis of morphometric characteristics of Lower Orashi River are shown in the Table 2 and these are measured from each segments as displayed in Figure 2. The summary of descriptive statistics of the morphometric characteristics displayed in Table 1 showed that the width of the river ranged from 77.90m to 2788.00m with the mean width of 318.83m. The width of Orashi River was relatively uniform from the upper section and continues to increase at the lower section where the river enters the Atlantic Ocean. Furthermore, it is revealed that the elevation of the river ranged from -2m to 15 m with the mean elevation which was 5.07m.

Table 1: Descriptive Statistics of Morphometric Parameters Along Lower Orashi River

	N	Minimum	Maximum	Mean	Std. Deviation
Width	30	77.90	2788.00	318.8267	526.74501
Elevation	30	-2.00	15.00	5.0667	4.11836
Depth	30	2.10	7.60	4.1367	1.27954
Time	30	1.15	2.30	1.7053	.35744
Distance	30	4.87	4.87	4.8658	.00000
Velocity	30	1.80	3.60	2.5267	.50704
Cross Sectional	30	280.44	12685.40	1303.6107	2320.20044
Discharge	30	723.79	26233.18	3021.5101	4831.90284
Valid N (listwise)	30				

Source: Researcher's Analysis 2022

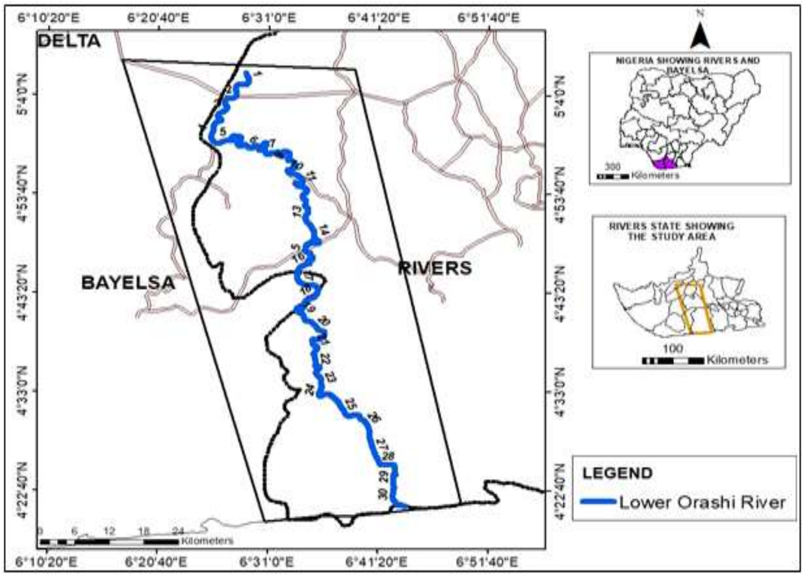

Fig 2: Orashi River with Segment Division

Table 2: Morphometric Characteristics of Lower Orashi River

Latitude	Longitude	Width (m)	Elevation (m)	Depth(m)	Time (s)	Velocity Distance /Time)	Cross sectional area (Width x Depth)	Discharge (Velocity x Cross Sectional)
6.4831	5.0878	148	8	5.5	2.2	2.211746	814	1800.361
6.4578	5.0622	142	7	6.35	2.1	2.317067	901.7	2089.299
6.4388	5.0356	152	8	6.5	1.3	3.742955	988	3698.039
6.4280	5.0015	161	5	2.5	2.3	2.115583	402.5	851.5222
6.4526	4.9869	134	7	2.7	1.15	4.231166	361.8	1530.836
6.4698	4.9850	160	6	7.6	1.55	3.139252	1216	3817.331
6.5001	4.9769	138	7	5.3	2.25	2.162596	731.4	1581.723
6.5108	4.9683	140	5	2.1	1.37	3.551709	294	1044.202
6.5433	4.9685	93.6	7	4.5	1.4	3.475601	421.2	1463.923
6.5537	4.9393	93.3	6	3.6	1.53	3.180288	335.88	1068.195
6.5697	4.9161	150	6	3.85	1.45	3.355752	577.5	1937.947
6.5718	4.8953	111	14	3.6	1.35	3.604327	399.6	1440.289
6.5755	4.8588	154	4	3	1.53	3.180288	462	1469.293
6.5882	4.8208	102	6	3.9	1.42	3.426649	397.8	1363.121
6.5748	4.8010	126	8	4.75	1.55	3.139252	598.5	1878.842
6.5778	4.7735	158	5	4.5	1.27	3.831371	711	2724.105
6.5655	4.7418	99	6	5	2.2	2.211746	495	1094.814
6.5913	4.7199	77.9	6	3.6	1.55	3.139252	280.44	880.3719
6.5674	4.6971	101	9	2.95	1.45	3.355752	297.95	999.8464
6.5872	4.6674	152	7	3.9	1.42	3.426649	592.8	2031.317
6.5959	4.6420	159	2	4.35	1.59	3.060277	691.65	2116.641
6.5893	4.6120	307	0	5.5	2.1	2.317067	1688.5	3912.368
6.5957	4.5770	209	0	2.75	2.23	2.181991	574.75	1254.1
6.6053	4.5445	161	2	4.5	2.1	2.317067	724.5	1678.715
6.6308	4.5210	205	15	3.5	2	2.432921	717.5	1745.62
6.6614	4.5001	447	0	2.95	1.54	3.159637	1318.65	4166.455
6.6738	4.4624	619	0	3	1.57	3.099262	1857	5755.329
6.6852	4.4183	1006	0	3.8	1.59	3.060277	3822.8	11698.83
6.7021	4.3972	1071	-2	3.5	2.1	2.317067	3748.5	8685.526
6.7079	4.3587	2788	-2	4.55	2	2.432921	12685.4	30862.57

Source: Researcher's Analysis 2022: Distance: 4.8m

The elevation of Orashi River displayed in Figure 4 showed that at segment 11 and 12 it is observed that the elevation was relatively high but the highest was noticed at the segment 25 and whereas at the mouth of the river, the elevation reduced to negative.

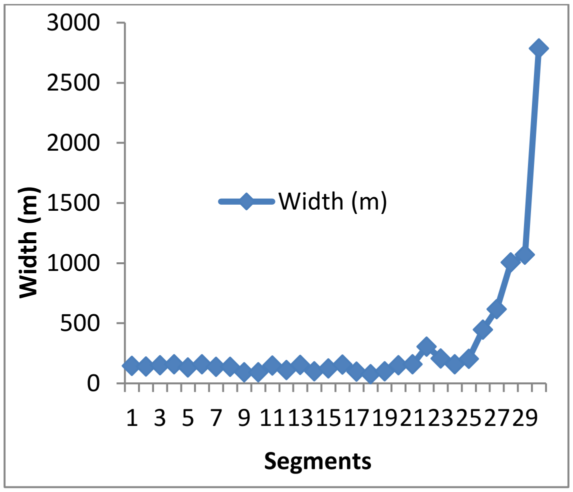

Fig 3: Width of the River along the Segment

This is also displayed in the 3 dimensional topographic representation of the basin whereby places due to the Southern part of the study location is having a gradual rise in the flood plain which could be possibly depend on the depth ranged from 2.10 to 7.60m with the mean depth recording 4.14m. In

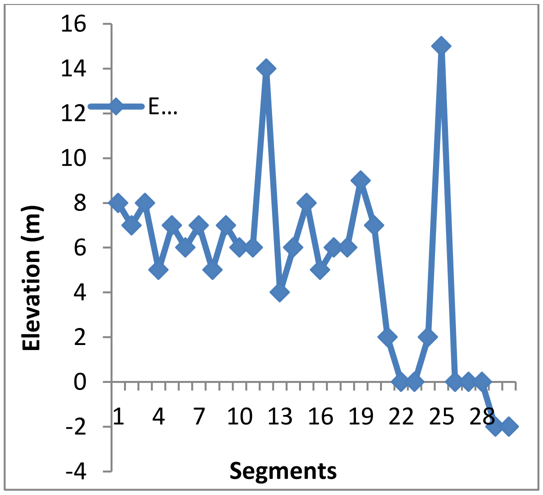

Fig 4: Elevation of the River along the Segment

Figure 5, it is shown that the depth of Orashi River was higher at the upper section of the river while it becomes lower as it is entering the Atlantic Ocean. The time of flow between the segments was also recorded and this ranged from 1.15s to 2.30s with the mean time of 1.71s. It is also recorded that the velocity flow in the Orashi River ranged from 1.80m/s to 3.60 m/s with the mean velocity of 2.53 m/s. In addition, the cross sectional area was found to range from 280.44 m^2 and 12685.40 m^2 with the mean cross sectional area of 1303.61 m^2.

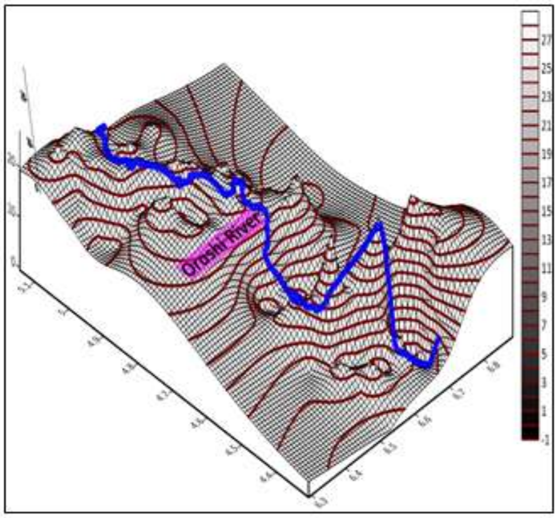

Fig 5: Three Dimensional Landscape of Orashi River Region showing the Contours

The discharge ranged from723.79 m^3/s to 26233.18 m^3/s with the mean discharge which was 3021.51 m^3/s. The analysis of variance of morphometric parameters is displayed in Table 3 shows that the width (F=4.917, p=0.015) elevation (F= 8.649, p=0.001), cross sectional area (F=3.613, p=0.041) and discharge (F= 3.627, p=0.040) were found to be significantly varied among the segment along Orashi River. Meanwhile the velocity and depth were not significantly varied among the segments. The similar velocity could be attributed to the nature of the entire study area being at the lower section of the entire River profile which enjoys more of depositional activities.

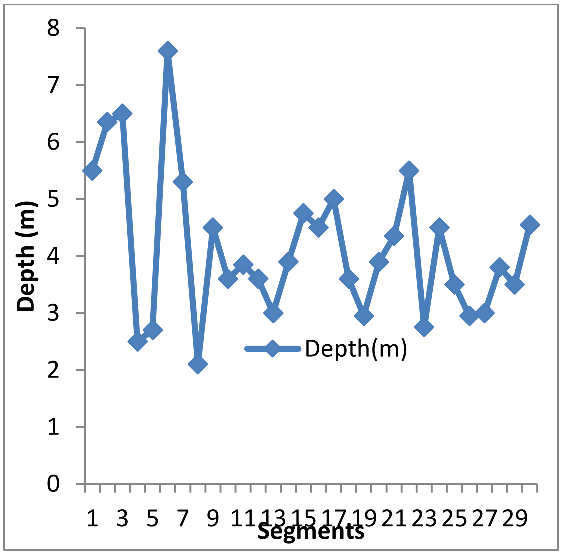

Fig 6: Depth of the River along the Segment

Table 3: Analysis of Variance of the Morphometric Parameters

Parameters		Sum of Squares	df	Mean Square	F	Sig.
Width	Between Groups	2148353.741	2	1074176.870	4.917	.015*
	Within Groups	5897995.218	27	218444.267		
	Total	8046348.959	29			
Elevation	Between Groups	192.067	2	96.033	8.649	.001*
	Within Groups	299.800	27	11.104		
	Total	491.867	29			
Depth	Between Groups	4.208	2	2.104	1.313	.286
	Within Groups	43.272	27	1.603		
	Total	47.480	29			
Time	Between Groups	.660	2	.330	2.927	.071*
	Within Groups	3.045	27	.113		
	Total	3.705	29			
Velocity	Between Groups	1.448	2	.724	3.254	.054
	Within Groups	6.008	27	.223		
	Total	7.456	29			
Cross Sectional	Between Groups	32962331.05	2	16481165.52	3.613	.041*
	Within Groups	123154241.2	27	4561268.194		
	Total	156116572.2	29			
Discharge	Between Groups	143385616.8	2	71692808.43	3.627	.040*
	Within Groups	533685649.7	27	19766135.17		
	Total	677071266.5	29			

Source: Researcher's Analysis 2022

Relationship between the morphometric Parameters: The correlations among the morphometric characteristics displayed in Table 4 reveal that width was significantly correlated with the depth (r= -0.556, p<0.05), cross sectional area (r= 0.989, p<0.05) and discharge (r= 0.987, p<0.05). Also, elevation was significantly correlated with cross sectional area (r= -0.506, p<0.05) and discharge (r = -0.511, p<0.05).

More importantly, the cross sectional area was correlated with discharge (r=0.995, p<0.05). The trend surface analysis in form of scatter diagram also depicts the relationship between some of the morphometric characteristics. It is found that width had positive relationship with discharge and the R square was 0.9744 suggesting that the width can explain 97.44 % of the trend of discharge in the study area (Figure 7). Similarly in Figure 8, the regression between elevation and discharge showed that the regression coefficient was 0.2607 suggesting that elevation can explain 26.07% of the variation in the discharge while regression coefficient between discharge and depth was very low (R^2 = 0.00074) (Figure 9). In Figure 10, the regression coefficient between the cross sectional area and the discharge was 0.9894 suggesting that the cross sectional area can explain 98.94% of the variation in the discharge.

Table 4: Correlations among the morphometric Characteristics

Parameters	Width	Elevation	Depth	Time	Velocity	Cross Sectional	Discharge
Width	1						
Elevation	-.556*						
Depth	-.023	.120					
Time	.201	-.244	.176	1			
Velocity	-.232	.274	-.186	-.987*	1		
Cross Sectional	.989*	-.506*	.087	.211	-.239	1	
Discharge	.987*	-.511*	.086	.143	-.174	.995*	1

**Correlation is significant at the 0.05 level (2-tailed).*

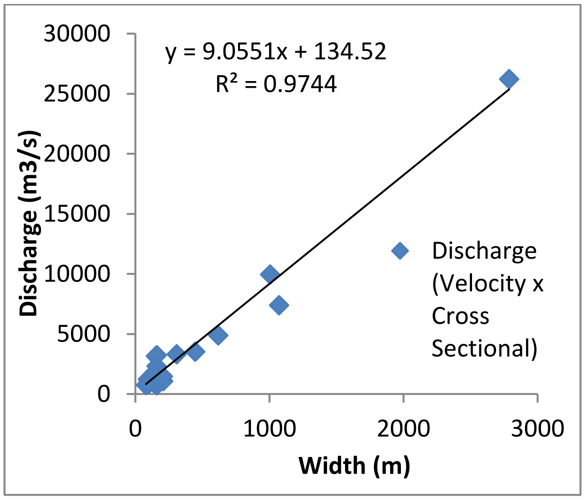

Fig 7: Trend Surface between the Width and Discharge

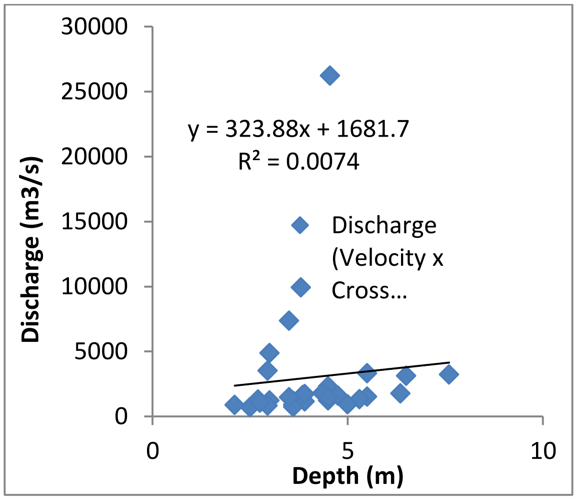

Fig 9: Trend Surface between Discharge and Depth

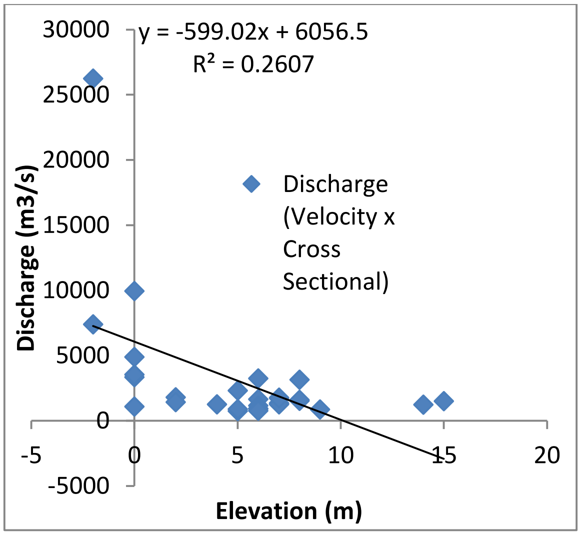

Fig 8: Trend Surface between the Discharge and Elevation

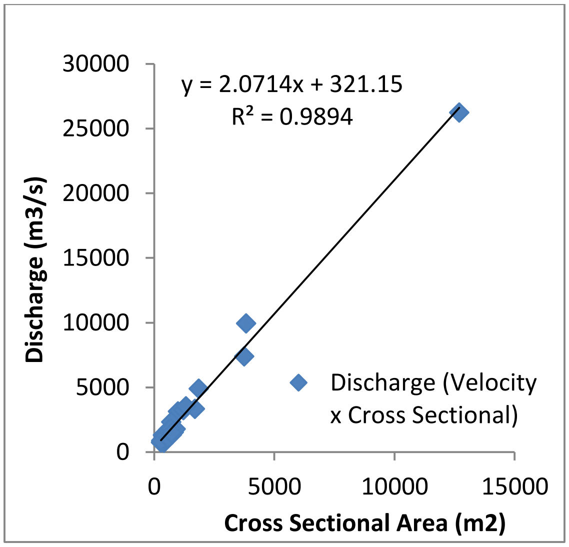

Fig 10: Trend surface analysis between Discharge and Cross sectional Area

Regression Model was generated among the morphometric characteristics along the Orashi River to find out the contribution of the influence of other characteristics against the discharge. The analyses are displayed in Table 5, Table 6 and Table 7. It is shown that there was a significant relationship between other morphometric characteristics and the discharge in the Orashi River. The regression coefficient was 0.998 and the R square was 0.996. This showed that the combination of cross sectional area, depth, time, elevation, velocity and width can explain 99.6% of the variation in the discharge in the study area River.

Among them, the only parameters that are included in the regression model are width, depth, and cross sectional because they have $p<0.05$ (Table 7).

The model is thus:

$Y_{\text{Discharge}} = 1766.57 + 3.532_{\text{ Width}} + 208.67_{\text{ Depth}} + 1.29_{\text{ Cross Sectional Area}} + 4119.02$

Table 5: Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.998[a]	.996	.995	345.65801	.996	940.640	6	23	.000

a. Predictors: (Constant), Cross Sectional, Depth, Time, Elevation, Velocity, Width

Table 6: [a]ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	674323239.003	6	112387206.501	940.640	.000[b]
	Residual	2748027.580	23	119479.460		
	Total	677071266.583	29			

a. Dependent Variable: Discharge

b. Predictors: (Constant), Cross Sectional, Depth, Time, Elevation, Velocity, Width

Table 7: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1766.578	4119.022		.429	.672
	Width	3.532	1.383	.385	2.555	.018
	Elevation	-8.484	20.912	-.007	-.406	.689
	Depth	208.671	78.867	.055	2.646	.014
	Time	-1214.133	1152.522	-.090	-1.053	.303
	Velocity	-121.807	823.980	-.013	-.148	.884
	Cross Sectional	1.294	.306	.621	4.229	.000

a. Dependent Variable: Discharge

The width of lower Orashi River increases as it is going southwards toward the Atlantic Ocean. Similarly, the depth of the River was higher at the upper section while it becomes lower as it is entering the Atlantic Ocean. The increase in the width at the lower section could be linked to the volume of the river at the lower section while the decrease of the depth could be attributed to the silting up of the river bed due to the depositional nature of lower Orashi River. The depositional rate of the river also affects the time of flow between segments which is low generally. This is also in accordance to Galster, *et al* (2008) study reporting that topographic changes show that the river is decreasing with depth in the land area at about the same elevation as a result of sand deposited due to lack of maintenance by dredging, which implies that the basin is morphometrically elevated and sensitive to erosion and flooding. The significant variation in the width, depth, cross sectional area and discharge could be attributed to different human activities along the river course which could include sand mining, fishing and wetland farming.

Conclusion: The study concludes that there is significant variation existing in the morphometric parameters namely width, elevation, cross sectional area and discharge among the segments of the Lower Orashi River. The study therefore recommended that the water course should be reduced of human activities to reduce the rate of soil loss or discharge and to boost the river floor with adequate morphological properties.

REFERENCES

Ding, JJ; Y. Liu, Q; Hou, Z; Liao, J; Fu, L; Peng, Q. (2016). Influences of the land use pattern on water quality in low-order streams of the Dongjiang River Basin, China. *A multi-scale analysis Sci. Total Environ,* p. 205-216. DOI: 10.1016/j.scitotenv.2016.01.162

El-sayed RM; Abdelazim MN; Ghaly S; Ali KA. (2017). Morphological variation of the Nile river fourth reach. *Twentieth international water technology conference*, IWTC20 Hurghada, 10p. https ://www.researchgate.net/publicatio n/310327662

Enaruvbe, GO; Atafo, OP (2014). Analysis of deforestation pattern in the Niger Delta region of Nigeria. *Journal of land use science* 11, 113-130. https://doi.org/10.1080/1747423X.2014.965279

Fabiyi, OO (2011). Geospatial analysis of temporal difference in ecosystems of coastal areas and the effects on rural communities in Nigeria. *Ife J. Sci.* 17(2)

Fashae OA; Faniran A. (2015). Downstream morphologic characteristics of the alluvial section of Lower River Ogun, Nigeria. *J Environ Geogr* 8(1–2):1–10. https ://doi.org/10.1515/jengeo-2015-0001

Galster, JC; Pazzaglia, FJ; Germanoski, D. (2008). Measuring the impact of urbanization on channel widths using historic aerial photographs and modern surveys *JAWRA J. Am. Water Resour. Assoc.* 44(4), 948–9601.

Hao, F; Zhang, X; Wang, X; Ouyang W. (2012). Assessing the relationship between landscape patterns and nonpoint-source pollution in the Danjiangkou Reservoir Basin in China. *J. Am. Water Resour. Assoc.* 48 (6): 1162-1177,

Haron NA; You GQ; Sulaiman MS; Yusuf B; Abood MM. (2017). Evaluation of river stability by morphological assessment. *Infrastruct Univ Kuala Lumpur Res J*. 5(1):11–20

Ibitoye, MO (2021). A remote sensing-based evaluation of channel morphological characteristics of part of lower river, Nigeria. *SN Appl. Sci.* 3(3), 340. https://doi.org/10.1007/s42452-021-04215-1.

Kudnar, NS (2020). GIS-based assessment of morphological and hydrological parameters of Wainganga River Basin, Central India. Model. *Earth Syst. Environ*. 6 (3), 1933–1950. https://doi.org/10.1007/s40808-020-00804-y.

Lancaster, ST; Bras, RL (2002). A simple model of river meandering and its comparison to natural channels. *Hydrological Processes* 16, 1–26. doi:10.1002/hyp.273.

Liu, X., Kong, L, Xiao, Y. and Zheng H. (2019): Relationship between landscape pattern and ecosystem water purification services in the Yangtze River Basin *Acta Ecol Sin*. 39 (3). 844-852

Lui GV, and Coomes DA (2015) A comparison of novel optical remote sensing-based technologies for forest-cover/change monitoring. Remote Sens 7:2781–2807

Meseko AA, Obieje DI, and Karpenko O (2018) Tourism potential of the confluence between river Niger and river Benue in Nigeria: implication for project finance. J Glob Entrep Res. 8(6):1–14

Nabegu, A. B. (2014): Impact of urbanization on channel morphology: some comments. *IOSR J. Environ. Sci. Toxicol. Food Technol. 8: 40*–45

Nath, A; Ghosh S. (2022): Assessment of river morphology based on changes in land use and land cover and the spatial and temporal variation of meandering parameters of the Barak River. *Water Practice. Technol.* 00 (0): 1 DOI: 10.2166/wpt.2022.114

Ozturk, D; Sesli, F. A. (2015): Determination of temporal changes in the sinuosity and braiding characteristics of the Kizilirmak River, Turkey. *Polish J. Environ. Studies* 24(5), 2095–2112.

Petchprayoon, P., Blanken, P.D., Ekkawatpanit, C., and Hussein, K., (2010). Hydrological impacts of land use/land cover change in a large river basin in central–northern Thailand. *Int. J. Climatol.* 30 (13), 1917–1930. https://doi.org/10.1002/joc.2131.

Sapkale, J. B., Kadam, Y. U., Jadhav, I. A. & Kamble, S. S. (2016): River in planform and variation in sinuosity index: a study of Dhamni River, Kolhapur (Maharashtra), India. *Inter. J. Sci. Engineer. Res.* 7, 863–867.

Short, KC; and Stauble, AJ (1967).Outline of geology of the Niger Delta. *Am. Assoc. Petrol. Geol. Bull.* 51 (5) 761-779.

Song, X.-P., Hansen, M.C., Stehman, S.V., Potapov, P.V., Tyukavina, A., Vermote, E.F., and Townshend, J.R., (2018). Global land change from 1982 to 2016. *Nature* 560 (7720), 639–643. https://doi.org/10.1038/s41586-018-0411-9.

Wang, F., Ge, Q., Yu, Q., Wang, H., and Xu, X., (2017). Impacts of land-use and land-cover changes on river runoff in Yellow River basin for period of 1956–2012. Chin. Geogr. Sci. 27 (1), 13–24. https://doi.org/10.1007/s11769-017-0843-3.

Winkler, K., Fuchs, R., Rounsevell, M., and Herold, M., (2021): Global land use changes are four times greater than previously estimated. *Nat. Commun*. 12 (1), 2501. https://doi.org/10.1038/s41467-021-22702-2.

Wolde, Z., Wei, W., Likessa, D., Omari, R., and Ketema, H., (2021). Understanding the impact of land use and land cover change on water-energy-food nexus in the Gidabo Watershed, East African Rift Valley. *Nat. Resour. Res.* 30 (3), 2687–2702. https://doi.org/10.1007/s11053-021-09819-3.