

Environmental Impact of River Bank Erosion on Stream Morphology: A Study of the Mini Piti Stream, Obio-Akpor, Nigeria

ABSTRACT

This study was designed to assess the impact of river bank erosion on the environment and the channel morphology for the Mini-Piti stream in Obio-Akpor local government area of Rivers State, Nigeria. This study determined the depth variations from width measurements due to bank erosion activities and the impact of indiscriminate waste dumps on the river channel. Physical water quality parameters of temperature, turbidity, transparency and TSS were determined using standard methods. The stream was divided into three stations; upstream 2.5km, midstream 2.5km, and downstream with intervals of 1km measured to differentiate each station as 5 samples were obtained per station at intervals of 0.5km apart. The flow velocity and discharge were estimated as the average depth recorded upstream being DS 0.9m, WS 1.4m, Midstream DS 1.3m, WS 1.7m, and Downstream=DS 1.5m WS 1.7m. The maximum width of 11m and minimum of 0.1m were recorded though natives confirmed that the stream is closing up unless maintenance dredging to expand the depth and width, the loss of this channel cannot exceed 20 years. The field observation and the impacts of precipitation and storm water from the built area of midstream were very intensive whose action increased the water level above its channel capacity and eroded the bank. From t-test analysis, there were significant seasonal variations in the depth for the measured widths for the upstream $T(8) = 2.1$, $p = 0.036$ and the midstream, $T(8) = 2.36$, $p = 0.023$. Similarly using the one-ANOVA, a significant variation in the depths of five locations during the dry season downstream $F(4, 60) = 2.79$, $p = .03$ was recorded. The Tukey's HSD post hoc test showed the locations have no significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$). A one-way ANOVA revealed a significant variation in the depths of five locations during the wet season upstream $F(4, 60) = 5.966$, $p = .000$. The Tukey's HSD post hoc test showed the locations have significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$) at locations $L_2:L_4$ at $Q = 5.53$ ($p = 0.00216$), $L_2:L_5$ at $Q = 4.72$ ($p = 0.1214$), $L_3:L_4$ at $Q = 4.90$ ($p = 0.00841$) and $L_3:L_5$ at $Q = 4.10$ ($p = 0.0403$). The studied physical parameters were all above WHO permissible standards and there were no significant variations between dry and wet seasons (38% turbidity midstream, TSS-33%, 31% and 30.6% variation upstream, midstream and downstream respectively) as well as spatial changes. The collapsed sediments and waste dumped at the bank of the stream were transported downstream due to reduced velocity and coarser sediments trapped at the stream bed causing shallow depth while the suspended fine sediment on the water column reduced the clarity of the stream resulting in adverse flooding over 20 years now. The research revealed that bank erosion has significant impact on water quality due to poor transparency and geometry of stream by the alterations of the channel depth and width, flow rate, scouring and deposition of sediments in the stream. The need for regulatory agencies to control anthropogenic inputs and enhance bank erosion prevention programmes cannot be over-emphasized. The monitoring of indiscriminate urbanization programmes to limit excess scouring activities by National Inland Waterways Authority (NIWA) is very essential to reduce excessive sand mining.

Key Words: Precipitation, Depth, Scouring, Sediment, Built area, NIWA

1.0 INTRODUCTION

There are many forms of hazard in our environment, directly or indirectly which have impact on man, aquatic organisms and properties which are either anthropogenic or naturally occurring. Riverbank has been described as the land besides the river (Rutherford, 2000; Tripathy & Mondal, 2020). Riverbank erosion has now become a serious threat to man and one of the major environmental hazards that requires urgent attention. River morphology is one of the most important fields of river engineering and the study of the changes in the flow direction and cross-sections of a river (Dehkordiet *al.*, 2024). River morphology involves the lateral migration of matters deposited by flowing water in the river channel across its floodplain (Ali *et al.*, 2017). Yearly, millions of people are affected by riverbank erosion due to pollution of water body, obstruction of inland water transport routes, declined aquatic

population and scouring activities (Tuhin *et al.*, 2014). Scouring is the phenomenon of removing sediments from the riverbanks and riverbeds by the actions of flowing water which also facilitates siltation. The stream morphology infers the shape, form and structure of the stream channels and adjoining landscape including the channel shape, size, bends, meander geometry, riffle and pools, bank materials, sediment, floodplain and headwater and tributary features. Research has shown that stream morphology is affected by fluvial processes, tectonic actions, climate, hydrology, vegetation, land cover and anthropogenic activities (Dehkordiet *et al.*, 2024). The primary causes of river bank erosion are geological and human activities such as dredging (sand mining), construction, storm water, tidal current, wave and shore deforestation practices along the bank which is one of the most unpredictable and critical type of disaster that accounts for the quantity of rainfall, soil structure, river morphology, topography of the river and flood (Tripathy & Mondal, 2020). Environmental degradation implies the deterioration of the environment through the depletion of natural resources which leads to the destruction of ecosystems and wildlife extinction waste pollution (Ali *et al.*, 2017). The process might occur naturally but activities such as uncontrolled deforestation, dumping of waste, improper agronomic practices and rapid urbanization will make the scenario worsen (Yamani *et al.*, 2011). According to World Bank, Nigeria Erosion and Water-shed Management Project (NEWMAP) gully erosion and associated processes such as river bank failure are the major environmental challenges affecting the South-east region of Nigeria, causing estimated damage of over 100 million US Dollars (Okeke & Ede, 2019). However, the constant dredging of rivers poses a negative impact to the river bank and water-shed which includes chemical, physical and ecological impacts. The dredging of river channel for the purpose of land reclamations alters the riverbed profile.

River bank erosion can also be caused by house placement, water saturation and load on bank, vegetation and tectonic activities. According to Rooijen and Lotsari (2024), river bank erosion supplies sediments to river systems, sustaining many river functions. When structures are built too close to the bank of the river, the weight may exceed the weight which the bank can hold thereby causing slumping or acceleration of slumping that may already be active. Every year, river bank failure and erosion causes unemployment, landlessness and increases poverty which contributes to unstable economic conditions of the country (Rahman, 2010). Stream morphology is the study of the physical features and processes of the flowing water that is limited by the channel. Tide is a periodic regional rise and fall of water levels caused by gravitational effects of the sun, moon and the centrifugal forces of the earth own rotation (Eze, 2004; Box *et al.*, 2018). According to Thaet *et al.* (2024), majority of neighbouring inhabitants are affected by river bank erosion.

Gobo and Abam (2006) analyzed rainfall anomalies and flooding over the world in recent times and stated that dredging is the process of digging, scrapping, gathering, scoping, sucking or pulling out material from the bed or bank of the river and depositing it in another environment or another part of the river. During dredging, waterway sediment, soil, creek banks and vegetation along the right of way (ROW) are removed and because of lack of better ways to manage the concomitant dredged materials, they are deposited as spoils at the bank of the newly dredged canals (Ohimainet *et al.*, 2010). Dredging not only causes vertical instability in the channel bed but also causes lateral instability in the form of accelerated stream bank erosion and channel widening (Kabirulet *et al.*, 2019). According to Abam (1993), bank erosion leads to the continuous adjustment of channel geometry which affects the utility of rivers by man, and increases the level of risk in the commercial development of the rivers.

Abam and Okagbue (1986) on the construction and performance of riverbank erosion protection structure in the Niger Delta, emphasized the mechanical properties of bank protection structures. Ohaeri *et al.* (2021) studied environmental impact of sand mining in some selected coastal communities and stated that sand mining activity is one of the serious environmental problems when the river is widely exploited for river bed materials resulting in land degradation as well as loss of riparian habitat.

The Min Piti stream forms the basis of the navigation and fishing expeditions not until recently when siltation and erosion actions have narrowed the width and depths limiting its activities. Many have likened the transverse of this stream as River Thames that has high tourism impact and so high economic value. The flooding in Port Harcourt city is a recent happening as the elderly have always said nothing of such ever occurred at their youthful years instead the Mini Piti Stream was their best river for fishing, bathing and swimming

which is the opposite today due to indiscriminate dumping of waste and erosion narrowing navigation. The Mini Piti stream flows from the New Calabar River and with the Ntawogbacreek all empty into the Bonny River onward to the Atlantic Ocean and serves as one of the boundaries for communities and the major drainage channel but its blockage has led to so many ugly menace in the capital city of the oil rich region of the Niger Delta called Port Harcourt.

These activities are of great concern to the conservation of the ecosystem and so the impacts are considered for the Mini-Piti stream based on the economic value of this stream to the Obio-Akpor and Rivers State based on the topography and nearness to the capital city of Port Harcourt and its environs. The physical water quality status of this stream is essential for improvement in tourism and navigation if properly managed. This study becomes so significant for the town planners and government seeking sources of revenue which is embedded in tourism and reduces road transport to traverse the city of Port Harcourt.

2.0 METHODOLOGY

2.1 Study Area

Mini Piti stream is located in ObioAkpor Local Government Area of River State, South - South Nigeria and is one of the major hydrographic streams in Port Harcourt Metropolitan. This is located in the tropical belt with an equatorial climate characterized by dry and wet seasons. The Apamini road, Market road, Abrikka road, OgbogoroRoad, Iwofe road, New road, were the access roads that leads to the study area on land, while New Calabar River served as the means of entrance to the stream.

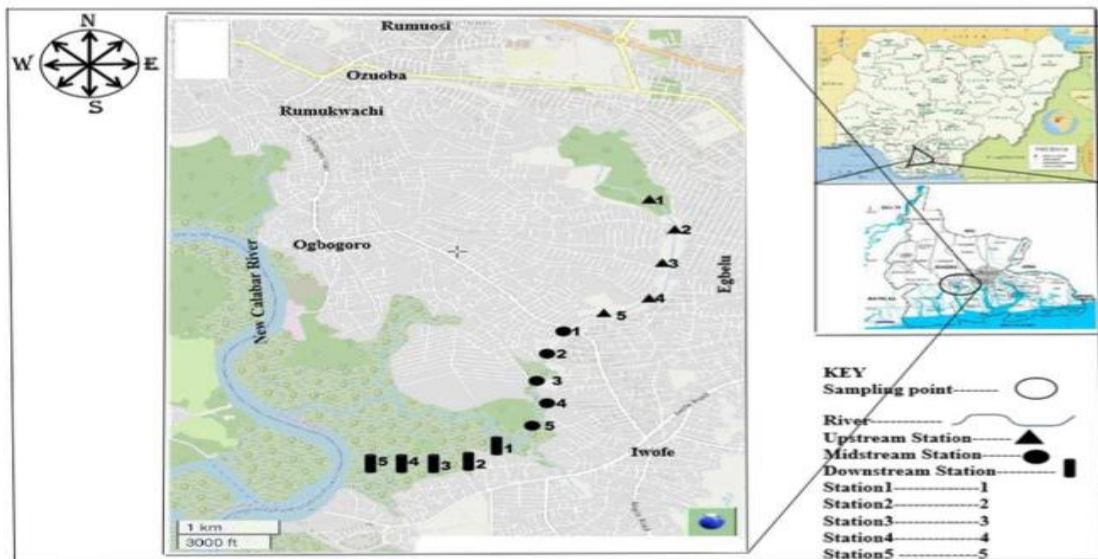


Fig.1: Map of River State showing study Area

2.2 Sample Analysis

2.2.1 Data Collection

The study was carried out during the wet and dry season (December 2023 to May 2024), samples were obtained at 15 locations during the dry season and 15 locations during wet season, by using 5 sampling locations upstream, 5 locations midstream and 5 locations downstream at intervals of 500m per sample and a distance of 1000m was used to separate the three sections of the stream.

2.2.2 Bathymetry Survey

Bathymetry Survey was carried out with the help of Echo sounder and the meter rule was to measure the depth of the stream. In order to facilitate the river bed profile, the study area was divided into three stations.

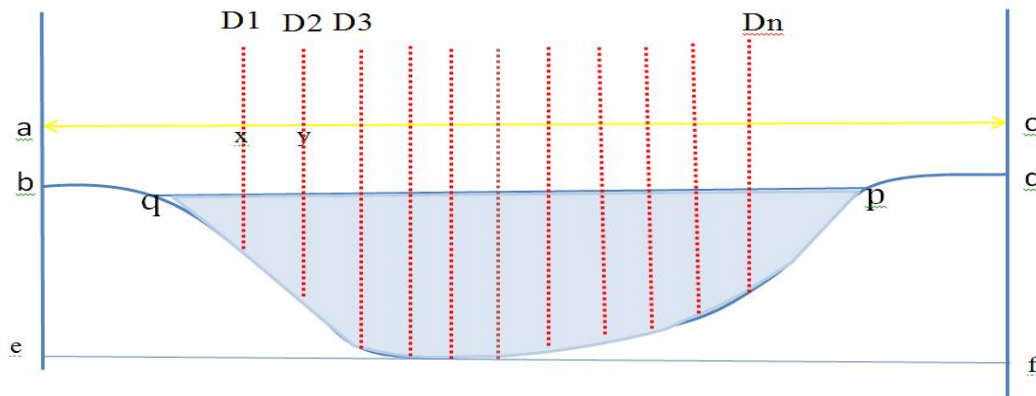


Fig. 2: The Cross Section of the Stream

The upstream extended from upper Egbelu to New road and cuts across Mgaraja. The depth profile was carried out in 5 sampling locations at intervals of 500m apart and labeled as location 1 to 5 during dry and wet seasons. The bathymetry data obtained was properly recorded, after the last location at the upstream, a distance of 1000m was measured to begin midstream profiling for 5 sampling at intervals of 500m. The midstream section covered Mgbuakara community at right bank and Egbelu community at the left bank. The downstream section covered Elioparanwo, upper Egbelu and Iwofe. The same method for upstream and midstream was used at the downstream for five sample points. Figure 2 above shows the cross section of the stream, a calibrated rope **ab** from right to left bank to measure the width of the stream. **D1** to **Dn** indicate depth sounding at every 0.5m intervals to measure the stream depth, **qp** which is the water level, while **bq** and **pd** represent the right and left bank. This procedure was applied to the upstream, midstream and downstream during the dry and wet season to generate bathymetry data as shown in Tables 1 to 7. In the measurement of depth and width, the discharge or flow rate is determined from the cross-sectional area and the mean velocity. The area of cross-section of the river is determined from the profile of the river bed obtained by lead lines (Otuagomaet *al.*, 2015). This lead line is made of heavy weight attached to the lower end of a rope. The depth of water is measured when the lead touches the river bed. A small canoe was used to navigate the Mini Piti stream holding the lead line vertically.

The river cross-section is divided into a suitable number of vertical segments. The total discharge in the stream was computed as the sum of the discharges in various segments and each segment is equal to the area of the segment multiplied by the mean velocity of flow (Arora, 2009).

2.2.3 Flow Dynamics

The manual approach was employed during the study. A floating object was suspended at a known distance '**AB**' of length 10m along the bank and width measurement was obtained as '**CD**', a horizontal distance from right bank to left bank, with average depth of the stream **D** measured (vertical sounding from a platform). The time taken for the object to flow from point **A** to **B** was carefully recorded and the process was repeated three times and the average time calculated using equations 1, 2, 3, 4 below for velocity, cross sectional area, discharge.

- AB** = length of the stream measured = 10m
- CD** = width of the stream
- D** = Average depth of stream

$$\text{Velocity} = \frac{\text{Float object length}}{\text{average time TT}} = \frac{AB}{T} \text{ (m/s)} \quad 2$$

$$\text{Cross sectional area} = \text{average depth} \times \text{velocity} = D \times \frac{AB}{T} \quad 3$$

$$\text{Discharge} = \text{Area} \times \text{velocity} \quad 4$$

2.2.4 Water Quality for Physical Parameters

The physical parameters under investigation were temperature, turbidity, transparency and total suspended solids (TSS) which were all measured *insitu* using the HANNA 9828 water quality checker model multi-meter. The water samples were analyzed for physical and parameters by using standard methods.

2.2.5 Data Analysis

The result was displayed using charts to show some trends while mean and analysis of variance (ANOVA) was to show spatial variation amongst the 5 study stations and also that for the upstream, midstream and downstream data. The t-test was used to show the difference in measurements for the dry and wet seasons.

2.3 Results and Discussions

The results of the study are shown in Tables 1 to 8 below for the wet and dry seasons upstream, midstream and downstream of the study locations as well as their corresponding widths.

Table 1: Bathymetry Data of Upstream (Wet Season)

Location 1		Location 2		Location 3		Location 4		Location 5	
Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)
0.50	0.20	0.50	0.10	0.50	0.10	0.50	0.30	0.50	0.40
1.00	0.40	1.00	0.10	1.00	0.30	1.00	0.40	1.00	0.40
1.50	0.70	1.50	0.30	1.50	0.40	1.50	0.50	1.50	0.50
2.00	0.80	2.00	0.50	2.00	0.50	2.00	0.70	2.00	0.70
2.50	0.90	2.50	0.70	2.50	0.50	2.50	0.80	2.50	1.00
3.00	1.00	3.00	0.90	3.00	0.60	3.00	1.10	3.00	1.10
3.50	0.90	3.50	0.70	3.50	0.60	3.50	1.20	3.50	1-10
4.00	0.70	4.00	0.60	4.00	0.70	4.00	1.00	4.00	1.00
4.50	0.60	4.50	0.40	4.50	0.50	4.50	1.40	4.50	0.90
5.00	0.40	5.00	0.20	5.00	0.40	5.00	1.30	5.00	1.00
5.50	0.30	5.50	0.10	5.50	0.40	5.50	1.10	5.50	0.80
6.00	0.20	-	-	6.00	0.20	6.00	1.00	6.00	0.60
6.50	-	-	-	6.50	0.10	-	-	6.50	0.40
Mean	0.59		0.38		0.44		0.90		0.73
Total									

The result in Table 1 has that the average depths(m) of locations 1 to 5 were 0.59, 0.38, 0.44, 0.90 and 0.73 respectively.

Table 2: Bathymetry Data of Mid-stream (Wet Season)

Location 1		Location 2		Location 3		Location 4		Location 5	
Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)
0.5	0.20	0.50	0.40	0.50	0.10	0.50	0.10	0.50	0.20
1.0	0.70	1.00	0.70	1.00	0.20	1.00	0.30	1.00	0.60
1.5	0.70	1.50	0.70	1.50	0.30	1.50	0.40	1.50	0.60
2.0	0.90	2.00	1.10	2.00	0.70	2.00	0.60	2.00	0.70
2.5	1.30	2.50	1.10	2.50	1.00	2.50	0.70	2.50	0.80
3.0	1.40	3.00	0.90	3.00	1.30	3.00	0.70	3.00	0.80
3.5	1.60	3.50	0.90	3.50	1.30	3.50	0.50	3.50	1.00
4.0	1.60	4.00	1.30	4.00	1.60	4.00	0.50	4.00	0.70
4.5	1.30	4.50	1.40	4-50	1.60	4.50	0.60	4.50	0.80
5.0	1.30	5.00	1.60	5.00	1.30	5.00	0.90	5.00	1.00
5.5	1.70	5.50	1.50	5.50	1.40	5.50	1.10	5.50	1.30
6.0	1.60	6.00	1.30	6.00	1.50	6.00	1.30	6.00	1.40
6.5	1.40	6.50	0.80	6.50	1.30	6.50	1.40	6.50	1.60
7.0	0.80	7.00	0.60	7.00	1.10	7.00	1.50	7.00	1.60
7.5	0.60	7.50	0.40	7.50	0.90	7.50	1.50	7.50	1.40
8.0	0.40	8.00	0.30	8.00	0.60	8.00	1.50	8-00	1.20
8.5	0.40	8.50	0.40	8.50	0.40	8.50	1.40	8.50	1.00
9.0	-	9.00	0.30	9.00	0.30	9.00	1.40	9.00	0.80
9.5	-	-	-	9.50		9.50	1.20	9.50	0.60
10.0	-	-	-	10.0		10.00	1.00		
Mean	0.90		0.79		0.80		0.93		0.99
Total									

Similarly, the result in Table 2 has that the average depths (m) of locations 1 to 5 were 0.90, 0.79, 0.80, 0.93 and 0.99 respectively.

Table 3: Bathymetry Data of Downstream (Wet Season)

Location 1		Location 2		Location 3		Location 4		Location 5	
Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)
0.50	0.20	0.50	0.40	0.50	0.30	0.50	0.40	0.50	0.30
1.00	0.30	1.00	0.40	1.00	0.40	1.00	0.60	1.00	0.50
1.50	0.50	1.50	0.30	1.50	0.40	1.50	0.90	1.50	0.80
2.00	0.60	2.00	0.30	2.00	0.40	2.00	0.90	2.00	0.90
2.50	0.90	2.50	0.40	2.50	0.60	2.50	0.90	2.50	0.60
3.00	0.90	3.00	0.60	3.00	0.80	3.00	0.70	3.00	0.70
3.50	1.10	3.50	0.70	3.50	0.90	3.50	0.70	3.50	0.80
4.00	1.00	4.00	0.90	4.00	1.00	4.00	0.80	4.00	1.00
4.50	0.90	4.50	1.10	4.50	1.20	4.50	1.00	4.50	1.30
5.00	0.90	5.00	1.20	5.00	1.50	5.00	1.20	5.00	1.50
5.50	1.20	5.10	1.30	5.50	1.80	5.50	1.50	5.50	1.70
6.00	1.50	6.00	1.50	6.00	1.90	6.00	1.60	6.00	1.90
6.50	1.60	6.50	1.80	6.50	1.90	6.50	1.80	6.50	2.10
7.00	1.70	7.00	1.80	7.00	1.90	7.00	2.10	7.00	2.00
7.50	1.50	7.50	1.80	7.50	1.70	7.50	2.10	7.50	1.70
8.00	1.30	8.00	1.70	8.00	1.50	8.00	2.00	8.00	1.50
8.50	1.00	8.50	1.70	8.50	1.30	8.50	1.70	8.50	1.30
9.00	0.80	9.00	1.50	9.00	1.00	9.00	1.50	9.00	1.00
9.50	0.60	9.50	1.30	9.50	1.00	9.50	1.30	9.50	0.70
10.00	0.40	10.00	1.30	10.00	0.80	10.00	1.20	10.00	0.70

Table 5 showed that the average depths (m) of locations 1 to 5 were 0.93, 0.61, 0.60, 0.76 and 0.65 respectively.

Table 6: Bathymetry Data of Downstream (Dry Season)

Location 1		Location 2		Location 3		Location 4		Location 5	
Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)
0.50	0.10	0.50	0.30	0.50	0.20	0.50	0.30	0.50	0.20
1.00	0.20	1.00	0.30	1.00	0.40	1.00	0.50	1.00	0.30
1.50	0.30	1.50	0.30	1.50	0.40	1.50	0.60	1.50	0.50
2.00	0.40	2.00	0.40	2.00	0.50	2.00	0.80	2.00	0.70
2.50	0.70	2.50	0.60	2.50	0.80	2.50	0.80	2.50	0.80
3.00	0.80	3.00	0.80	3.00	1.00	3.00	1.00	3.00	1.10
3.50	1.00	3.50	1.00	3.50	1.10	3.50	1.10	3.50	1.20
4.00	1.20	4.00	1.10	4.00	1.20	4.00	1.20	4.00	1.40
4.50	1.10	4.50	1.30	4.50	1.40	4.50	1.40	4.50	1.60
5.00	1.30	5.00	1.40	5.00	1.60	5.00	1.60	5.00	1.70
5.50	1.50	5.50	1.50	5.50	1.50	5.50	1.80	5.50	1.90
6.00	1.30	6.00	1.40	6.00	1.30	6.00	2.00	6.00	2.00
6.50	1.20	6.50	1.50	6.50	1.20	6.50	2.00	6.50	1.90
7.00	0.90	7.00	1.30	7.00	1.00	7.00	1.70	7.00	1.70
8.00	0.70	8.00	1.10	8.00	1.00	8.00	1.50	8.00	1.60
8.50	0.50	8.50	0.90	8.50	0.70	8.50	1.30	8.50	1.40
9.00	0.40	9.00	0.70	9.00	0.70	9.00	1.00	9.00	1.20
9.50		9.50		9.50	0.60	9.50	0.80	9.50	0.90
10.00		10.00		10.00	0.60	10.00	0.70	10.00	0.80
10.50		10.50		10.50		10.50		10.50	
Mean	0.68		0.80		0.86		1.11		1.05
Total									

Table 6 showed that the average depths (m) of locations 1 to 5 were 0.68, 0.80, 0.86, 1.11 and 1.05 respectively.

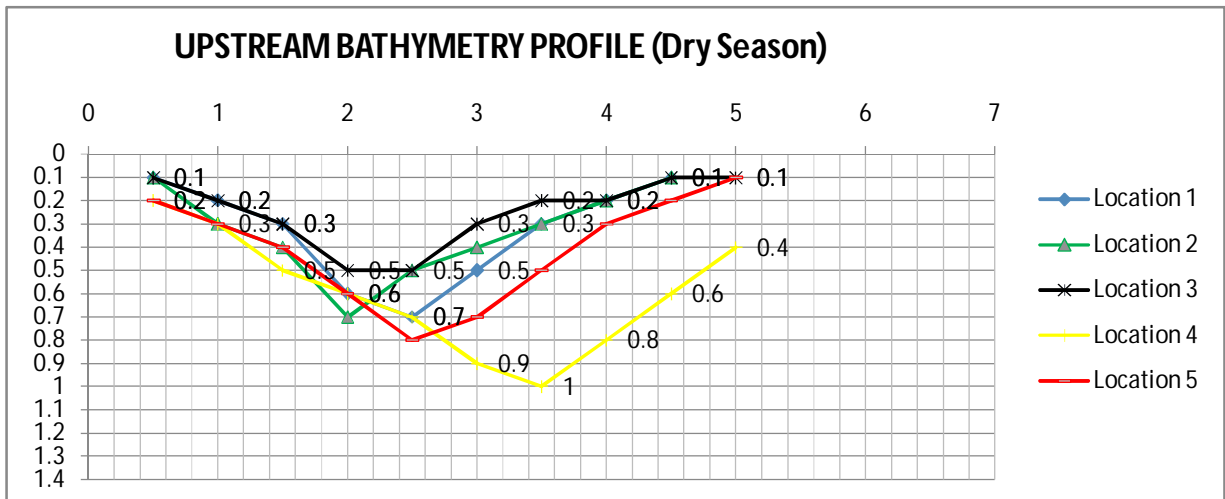


Figure 3: Graphical interpretation of upstream dry season bathymetry profile

The chart in Figure 3 shows the cross sectional depth profile of the upstream of the study area during the dry season where a total of five stations were surveyed across the channel. Maximum depth of 1m was recorded at location 5 indicated in the graph as red line and 0.5m depth observed at location 3. Observation at field indicated an average of 1.4m of water regression from the bank full stage and point bar. No serious bank erosion was recorded at the upstream of the study area, and is highly vegetated with farmland and distance built houses. The profile shows a well-defined, uniform and undisturbed channel basin.

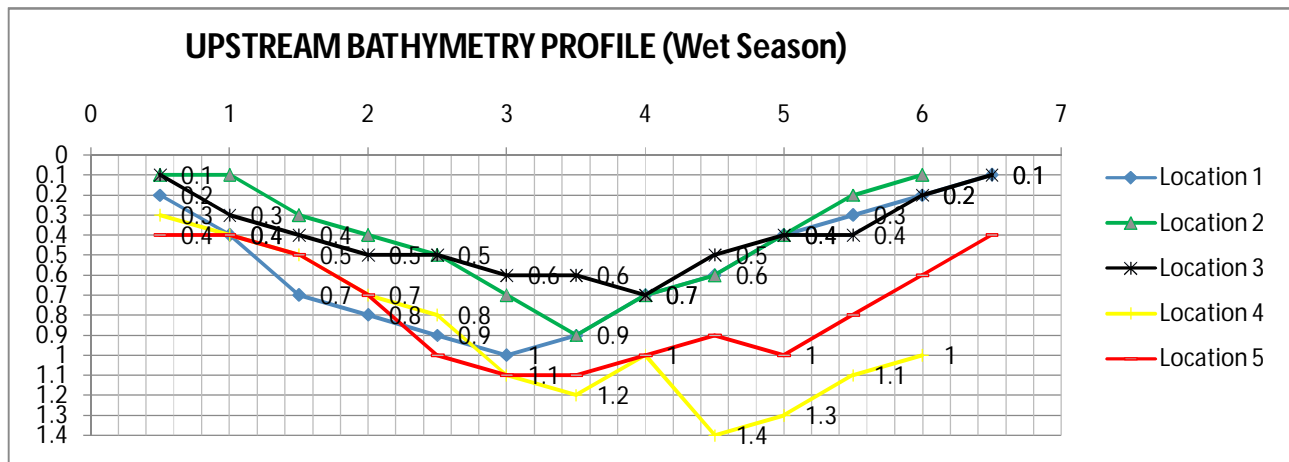


Figure 4: Graphical interpretations of wet season upstream bathymetry profile

There were significant changes in the depth and width of the upstream of the study area during the wet season as shown in Figure 4, the maximum width of the stream was 6.5m at location 5 and maximum depth of 1.4m at location 5. The changes in depth and width of the channel is as the result of input from the rain and runoff from the watershed which is between 1.2m and 1.4m depth. There was deposition of about 0.2m height of sediment in the stream bottom and bed erosion at location 5.

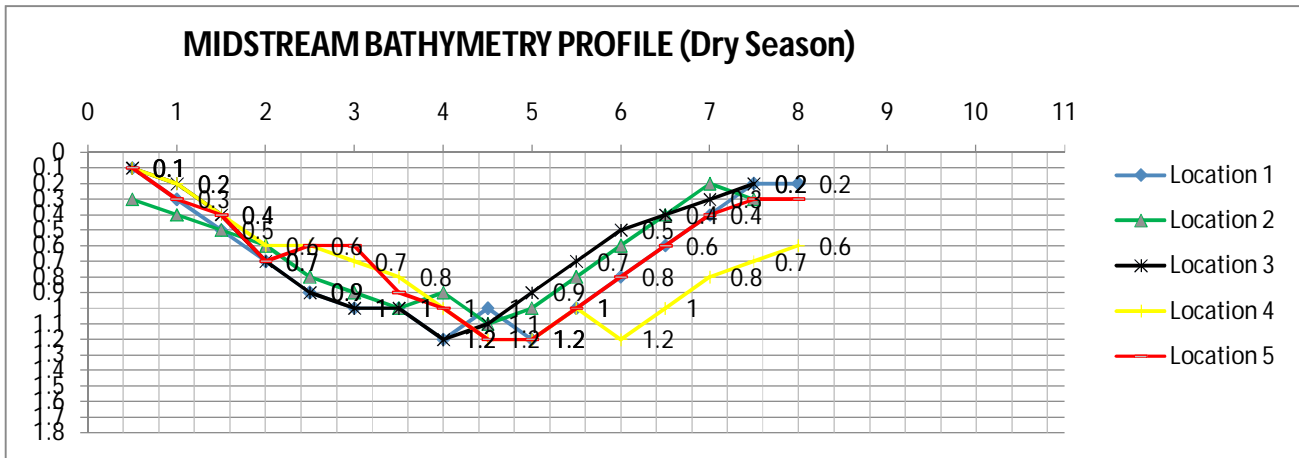


Figure 5: Graphical interpretations of dry season midstream bathymetry profile

The midstream of the study area covered five sample locations. The eroded zone of the bank was well exposed during the dry season as waste and debris dumped along the bank extended about 1.5m into the water channel, scarp, and bank full dimension was observed during the study (Figure 5). The maximum depth of the stream was 1.2m at location 2, 3, 4 and 5 and maximum width of 8.5m during the dry season.

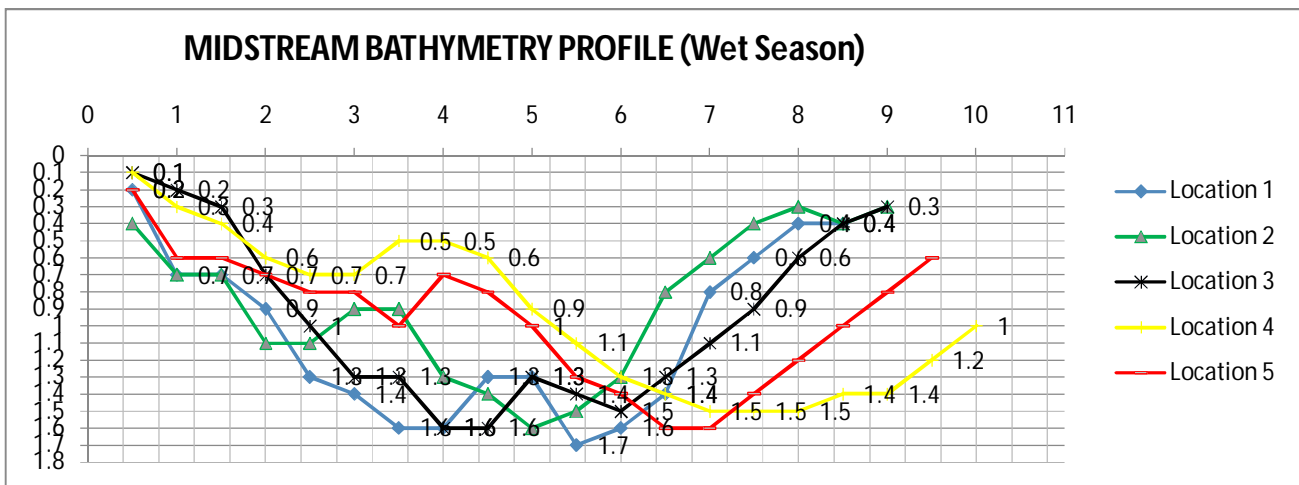
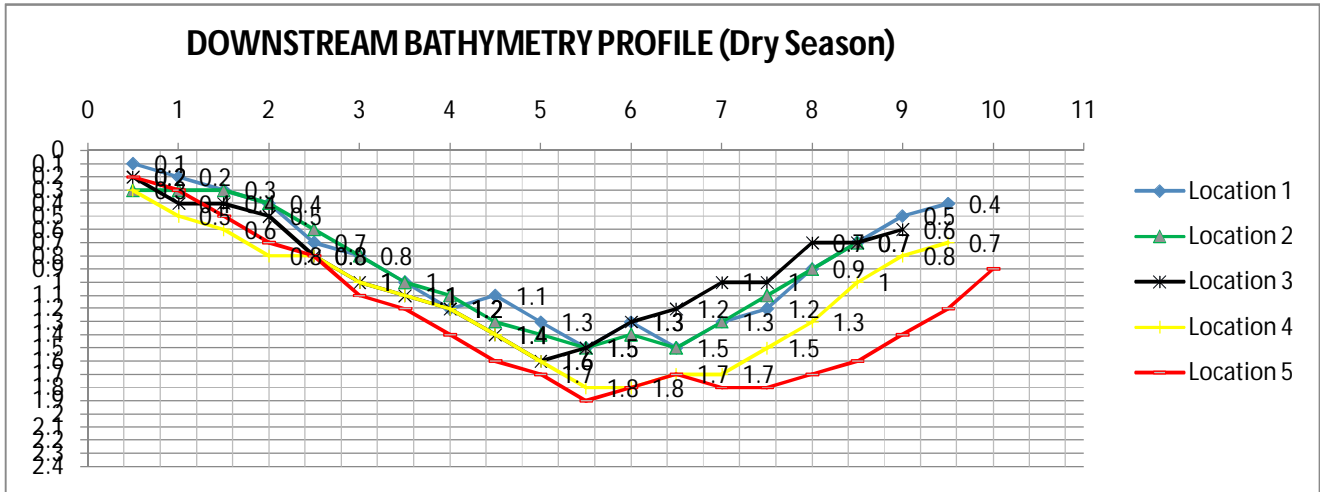


Figure 6: Graphical interpretation of midstream wet season bathymetry profile

The horizontal distance of about 2m from the floodplain exposed during the dry season was completely covered at the wet season as shown in Figure 6. The width distance of 0-2m at 0.2-0.6m depth showed bank erosion across the five locations of the midstream at the right bank. The scarp that was visible at the dry season was completely submerged during the wet season and for locations 1 and 3 at 1.3m depth, there was sediment accumulation on the bed of the stream and bed erosion at 1.6m depth and at location 1 and 1.7m depth at location 2. The maximum depth of the midstream during the wet season was recorded at location 1 and the width of 10.5m at location 4. From the field observation, the midstream was characterized by sharp sand.



2.5 Flow Dynamics of the Stream during Wet and Dry Season

The flow dynamics are shown in Figures 9, 10 and 11 from Table 7 below where BH and AVBH are bathymetric heights and average bathymetric heights respectively.

Table 7: Flow Dynamic of Upstream, Midstream and Downstream

Upstream	BH (m)	SW (m)	AV depth (m)	Float distance (m)	Time (s)	Vel. (m/s)	Area (m)	Discharge	AVBH
Dry	1.00	4.00	0.70	10.00	40.20	0.25	3.15	0.78	1.5
Wet	0.60	6.50	1.10	10.00	18.50	0.54	7.50	3.87	1.2
Midstream									
Dry	1.40	7.00	1.00	10.00	32.70	0.30	7.00	2.10	4.2
Wet	0.80	9.50	1.70	10.00	20.50	0.47	16.15	7.91	3.7
Downstream									
Dry	0.70	10.00	1.50	10.00	39.60	0.25	15.00	3.75	1.0
Wet	0.50	11.00	1.70	10.00	28.00	0.36	18.00	6.74	0.8

amics upstream during the dry season were 1.00 (B.H in meters), 4.00 (SW in meters), 0.70 (average depth in meters), 10.00 (float distance in meters), 40.20 (time in seconds), 0.25 (velocity in m/s), 3.15 (area in meters), discharge as 0.78 and 1.5 (AVBH in meters). During the wet season upstream, the flow dynamics similarly recorded 0.60 (B.H in meters), 6.50 (SW in meters), 1.10 (average depth in meters), 10.00 (float distance in meters), 18.50 (time in seconds), 0.54 (velocity in m/s), 7.50 (area in meters), discharge as 3.87 and 1.2 (AVBH in meters). The midstream result showed that dry and wet seasons observed flow dynamic patterns respectively as BH (1.40 and 0.80m), SW (7.00 and 9.50 m), average depth (1.00 and 1.70 m), float distance (10.00 and 10.00 m), time (32.70 and 20.50), velocity (0.30 and 0.47), area (7.00 and 16.15 seconds), discharge (2.10 and 7.91) while AVBH was 4.2 and 3.7. The downstream flow dynamics showed that dry and wet seasons recorded BH (0.70 and 0.50m), SW (10.00 and 11.00 m), average depth (1.50 and 1.70 m), float distance (10.00 and 10.00 m), time (39.60 and 28.00), velocity (0.25 and 0.36), area (15.00 and 18.00 seconds), discharge (3.75 and 6.74) while AVBH was 1.0 and 0.8 respectively.

Table 8: Seasonal Variations for Physical Parameters of the Mini Piti Stream

Parameters/Locations	Upstrm		Mdstrm		Downstrm		WHO	FEPA
	Dry	Wet	Dry	Wet	Dry	Wet		
Tempt °C	29.66 ±0.152	28.92 ± 0.335	29.66 ±0.114	29.58 ±0.083	30.00 ±13.416	30.62 ±0.383	25.0	6-9
Turbidity (NTU)	3.718 ±0.065	4.916 ±0.211	5.196 ±0.393	8.432 ±0.452	11.386 ±0.732	15.454 ±0.510	5.0	5.0
Transparency (m)	NIL	NIL	NIL	0.89 ±0.042	0.72 ±0.057	0.58 ±0.060	-	-
TSS (Mg/l)	4.31 ±0.317	6.48 ±0.350	10.79 ±1.161	15.65 ±1.049	16.87 ±7.810	24.32 ±1.517	10.0	30

Table 8 gives the results of the physical parameters for both seasons in the study stream. The result showed that temperature (°C) recorded for dry and wet seasons respectively for the upstream 29.66 ± 0.152 and 28.92 ± 0.335 ; midstream as 29.66 ± 0.114 and 29.58 ± 0.083 and downstream as 30 ± 13.416 and 30.62 ± 0.383 . Similarly, the turbidity (NTU) for upstream in dry and wet seasons were 3.718 ± 0.065 and 4.916 ± 0.211 ; midstream were 5.196 ± 0.393 and 8.432 ± 0.452 ; downstream were 11.386 ± 0.732 and 15.454 ± 0.510 respectively. The transparency of the stream was not visibly captured in the upstream (both dry and wet seasons) and also during the dry season midstream but 0.89 ± 0.042 by the wet season midstream. The both seasons (dry and wet) downstream recorded 0.72 ± 0.057 and 0.584 ± 0.060 . The total suspended solids (TSS) in the upstream for both dry and wet were 4.31 ± 0.317 and 6.48 ± 0.350 ; midstream were 10.79 ± 1.161 and 15.646 ± 1.049 ; downstream were 16.87 ± 7.810 and 24.318 ± 1.517 respectively.

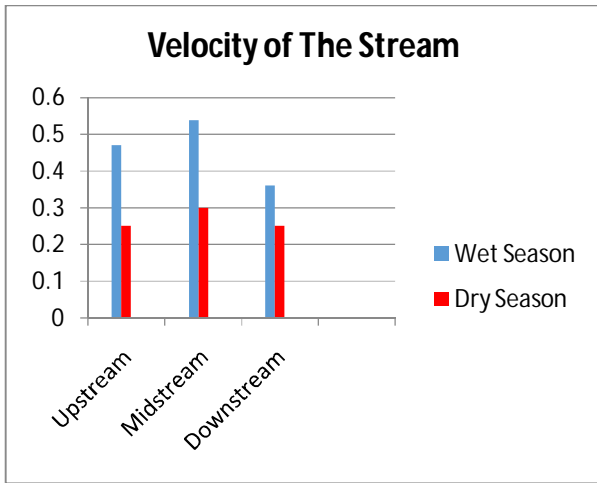


Fig. 9: Wet & dry season velocity

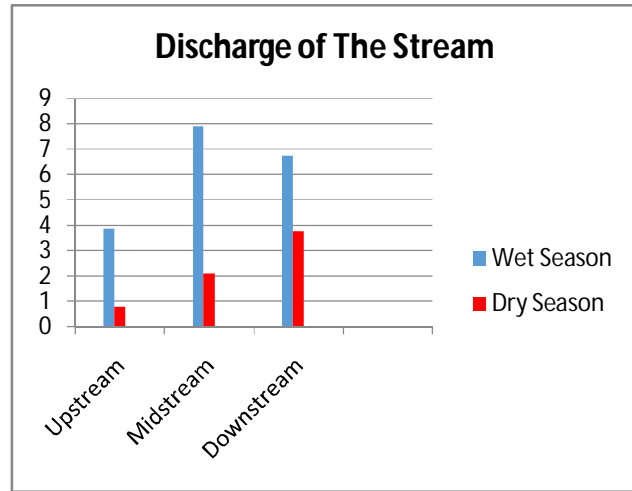
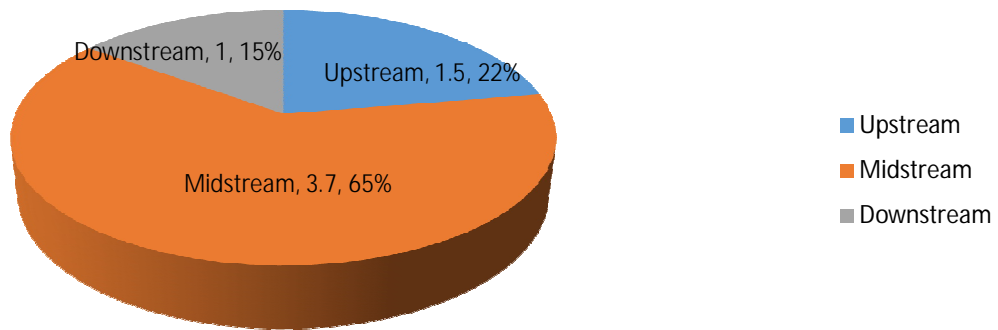


Fig.10: Wet & dry season discharge

Average Bank Height (Dry Season)



Average Bank Height (Wet Season)

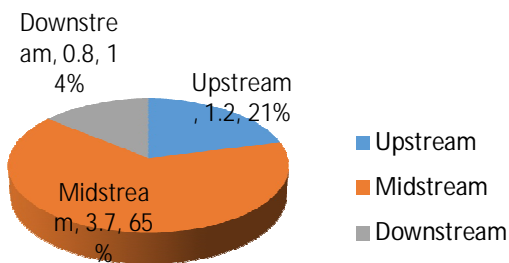


Fig.11: Average Bank Height

High velocity and discharge were recorded at midstream station of the study area during the wet season. The statistical t-test analysis showed that there was a significant difference in values of the depth of the upstream alongside the width of the Mini Piti stream for the wet season ($W = 0.61$, $SD = 0.18$) compared to the dry season ($D = 0.37$, $SD = 0.08$), $T(8) = 2.1$, $p = 0.036$. Similarly, for the midstream, that there was a significant difference in values of the depth of the midstream alongside the width of the Mini Piti stream for the wet season ($W = 0.88$, $SD = 0.03$) compared to the dry season ($D = 0.71$, $SD = 0.08$), $T(8) = 2.36$, $p = 0.023$.

Conversely, considering the downstream of the Mini Piti stream, there was no significant difference in values of the depth of the midstream alongside the width of the Mini Piti stream for the wet season ($W = 0.88$, $SD = 0.03$) compared to the dry season ($D = 0.71$, $SD = 0.08$), $T(8) = 2.36$, $p = 0.023$.

A one-way ANOVA revealed a significant variation in the depths of five locations during the dry season downstream $F(4, 60) = 2.79$, $p = .03$. The Tukey's HSD post hoc test showed the locations have no significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$). A one-way ANOVA revealed a no significant variation in the depths of five locations during the dry season midstream $F(4, 75) = 0.52$, $p = .710$. The Tukey's HSD post hoc test showed the locations have no significantly high depths for the studied

five locations during the dry season upstream $F(4, 45) = 4.07$, $p = .007$. The Tukey's HSD post hoc test showed the locations have significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$) at locations $L_1:L_4$ at $Q = 4.32$ ($p = .02969$), $L_2:L_4$ at $Q = 4.32$ ($p = .02969$), $L_3:L_4$ at $Q = 5.04$ ($p = .00753$). Similarly, a one-way ANOVA during the wet season revealed a no significant variation in the depths of five locations downstream $F(4, 105) = 1.28$, $p = .282$. The Tukey's HSD post hoc test showed the locations have no significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$). A one-way ANOVA conducted during the wet season revealed a no significant variation in the depths of five locations midstream $F(4, 95) = 0.21$, $p = .930$. The Tukey's HSD post hoc test showed the locations have no significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$). Conversely, a one-way ANOVA revealed a significant variation in the depths of five locations during the wet season upstream $F(4, 60) = 5.966$, $p = .000$. The Tukey's HSD post hoc test showed the locations have significantly high depths for the studied widths sizes ($p < 0.01$ and $p < 0.05$) at locations $L_2:L_4$ at $Q = 5.53$ ($p = 0.00216$), $L_2:L_5$ at $Q = 4.72$ ($p = 0.1214$), $L_3:L_4$ at $Q = 4.90$ ($p = 0.00841$) and $L_3:L_5$ at $Q = 4.10$ ($p = 0.0403$).

2.5 DISCUSSION

2.5.1 Impacts of Bank Erosion on Stream Bathymetry

Bank erosion has significant impacts on Mini-Piti stream bed. The eroded sediments from the bank, transported along the channel were deposited on the stream bed depending on the flow dynamics and channel geometry. Comparatively, the three sections of the stream (upstream, midstream and downstream) for wet season and dry season were based on the conclusion drawn from analyzed data which indicates that there were changes in bed profile due to bank erosion. The cross section surveyed for the upstream showed a plane bed across the five locations of the two seasons with maximum depth of 1.4m and width 7m for wet season, 1m depth and 5.0m width for dry season. There were no significant bed and bank erosion at the upstream section. The midstream section of the study area was characterized by bank and bed erosion from the analyzed bed profile data during the dry season. This was because the riparian area was well exposed as a result of water transition but was covered at the wet season due to increased surface runoff and storm water impact eroding the bank sediment and shaping the channel width. These led to accelerated stream scouring potential and sediment load in the water column as well as high rate of bed deposition causing shallow depth at the downstream as corroborated by Ohimain (2010) on similar studies. The downstream section of the study area was relatively shallow at locations 1, 2 and 3 with average depth of 1.5m for dry season and 1.7m depth at wet season while the width recorded 10m and 11m for dry and wet seasons (Iyama&Edori, 2014a; Iyama&Edori, 2014b). The eroded sediments, debris and dirt washed from the bank at the midstream is transported downstream by water current and the accumulations of sediment load on the stream bed over time. This results in the shallow depth of downstream section of study area irrespective of sand mining at stations 4 and 5 which may cause economic devastation as agreed by Okeke and Ede (2019) previously.

2.5.2 Impacts of Stream Flow Rate on the Bank

The nature of sediment transports and bank erosion were highly affected by the stream flow rate. It was observed that large particles rested on the bottom as bed load and were only moved during rapid flows due to flooding and impacts of storm water entering the stream. Smaller particles were carried on siltation and suspension depending on increased or decreased velocity at certain points along the channel. Increase in the flow rate resulted in rapid erosion of the bank materials. The study area experienced decreased velocity and discharge during the dry season and increase at the wet season. The decrease was due to high evaporation rate and recharge of ground water during the dry season. The stream shows significant increase in water level during the wet season causing increase in velocity and high discharge of stream during the wet season as agreed earlier by Rentier and Cammeraat (2022) during sand mining activities. The highest velocity of 0.54m/s and discharge of 7.9m/s were recorded at the midstream section during wet season while minimum velocity of 0.25m/s was obtained at downstream of the study area. The high rate of velocity at midstream section contributed to bank and bed erosion at the midstream while reduced velocity at the downstream could lead to deposition of fine grain material on the channel similar to the observations of Abam and Okagbue (1986), Abam and Nwankwoala (2020) on mechanical properties of bank protection structures.

From field observation, erosion was high during the wet season as the flow depth and velocity increased. The force of water flowing against the bank erodes the sediments and waste dump at the stream bank. The midstream and part of upstream section of the stream were dredged about ten years ago to help evacuate floods from the residential area of the section but dredged materials were not transported out of the site. The abandoned materials left at the bank increased the bank height and inserted load on it to which impact of rain and stream velocity over time collapsed the bank into the water, causing adjustment of the bank, changes in water quality (Iyama *et al.*, 2017) as well as sediment loads on the water column and bed deposition.

2.5.3 Impacts of Bank Erosion on Water Quality



Figure 12: Cross section of the Mini Piti Stream by Egbelu Bridge, Port Harcourt

The impact of river bank erosion on water quality has been examined in the study area by comparing the variation in water quality of the upstream, midstream and downstream and also using seasonal variation in the physical parameters of 15 sample locations during the wet season and 15 samples location during the dry season. The concentrations of physical parameters (temperature, turbidity, transparency and total suspended solids) of midstream (Figure 12) and downstream of the study area were generally well above World Health Organization (WHO, 2017) standards for drinking water during wet season indicating that eroded materials could have contaminated the midstream and downstream of the study area especially by the habitual and indiscriminate waste dumps even at the foundations of the bridge. According to unconfirmed sources from the locals and natives, about 40-50 years ago, the Mini Piti stream was their major source of drinking and domestic water and the best stream for swimming and recreation which has been absolutely lost to urbanization and poor waste management practices.



Figure 13: Waste Dumps into Channels of the Mini Piti Stream Bank

Results have showed that erosion rates significantly increased with increasing water temperature for example, a 10 °C increase in water temperature increased median erosion rates by as much as a factor of eight (Hoomehret *al.*, 2018). Assessment of the impact of climate change on riverbank erosion was a result of increased temperature of the stream resulting from poor land cover hence surface water exposure is essential for planning climate change mitigation measures for the country (Aktara, 2013). Similar type of work could be applied to any other climate vulnerable countries which are prone to riverbank erosion. According to Bolanet *al.* (2024), warmer global temperatures in the atmosphere and oceans lead to climate change affecting rainfall patterns, storms and droughts, growing seasons, humidity etc. Results have also showed that warmer climatic conditions are associated with numerous hydrologic changes that may impact riverbank erosion in cold regions though net effect is not well understood (Brown *et al.*, 2020). Even though the waste dumps at the banks of the Mini Piti stream serve as bond walls and embankments, the water quality is compromised as shown in Figure 13. The cover-waste dumps make the water temperature to be low usually taken as the mid-stream in this study as accentuated by Brown *et al.* (2020) earlier. Recent studies in temperate regions posit that subsurface erosion, mostly from riverbanks, can contribute significant proportions of suspended sediment (turbidity) loads and associated nutrient losses (Abbas *et al.*, 2023). These are higher temperatures comparable with the work of Sargaret *al.* (2024) on the review of permissible limits of physicochemical parameters in drinking water.

There exists a similar relationship between deposition and erosion which affects water quality especially the clarity (transparency) of the surface water as earlier reported by Dehkordiet *al.* (2024) for the assessment of morphological changes of river bank erosion using landsat satellite time-series images. The wet season recorded relatively higher stream depths as mean values for dry and wet were respectively 0.61 to 0.37 (upstream), 0.88 to 0.71 (midstream) and 1.09 to 0.90 (downstream). This is in agreement with previous studies (Abam, 1995 & 1997) and is as a result of high stream velocity and flow rate which is found higher by the wet or rainy seasons. The following are considered to be the major factors responsible for bank erosion in Mini Piti stream; the protective cover provided by vegetation to help stabilizes the stream bank were completely removed for the purpose of farming and constructions at the midstream station of the stream. This action exposed the bank to erosion due to intensive rain and run off from the built environment (Abam, 1997; Tripathy & Mondal, 2020; Tuhin *et al.*, 2024). The midstream was dominated with series of human activities due to development of the area as earlier reported in similar reports (Garanaik, & Sholtes, 2013; Gobo & Ngah, 2021). During the wet season from field observation, there were rapid flows of storm water channeled from the built environments into the stream without resistance. These weakening and weathering of the bank materials destabilizes and widens the pre-existing crack which eventually results to rapid bank failure and erosion (Andrew *et al.*, 2013). There is the deepening of the stream channel as a result

of more volume of water during the wet season and so more waste was dumped into the stream with the thinking of pushing it into the bigger river known as the Bonny River to which the Mini Piti stream empties and finally into the Atlantic Ocean. This has caused a lot of flooding issues as most of these wastes end up blocking the entire channel leading to flooding and its associated public health concern due to pollution. Many persons have literally parked out of their houses during this period even though flooding is expected as this area is below sea level. This was similar to water level variation from less than 1.5 m in the estuaries to about 8 m at the apex of the delta, with Nun River having a slightly higher elevation compared to Forcados River. This implies that canals connecting both rivers at the same reach would experience water movements from Nun to Forcados River (Abam&Fubara, 2022). The flow rate of the stream was high during the wet season which increased the stream water column as this also has significant impact on the stream bank. This also had an impact on the shear stress exerted by the water volume as velocity increase exceeded the strength of the bank material causing erosion (Hagerty *et al.*, 1981). The height of the bank and slope are the critical factors responsible for erosion of the bank along the midstream station of the stream with average height of 4.5m and upstream of 0.9m. The absence of much vegetation (except shrubby types due to urbanization) by the river bank has immensely contributed to Mini Piti riverbank erosion as was confirmed by Arora and Kumar (2024) as morphological analysis showed complete riverbank erosion in both cases of the un-vegetated riverbank (without or with an upstream pit).

The concentrations of the TSS in the midstream and especially the downstream were all higher than the WHO permissible limits but lower than the FEPA standards. This is the local permissible limit hence is threatening especially that recorded downstream during the wet season. This is similar to results of TSS during dredging around the Isiodu river axis of the New Calabar River (Iyama&Edori, 2014a and 2014b). This was at variance with the works of Yeole (2021) earlier which could be attributed to the influence of water turbulence during rains and the flow regime towards the downstream direction. The trend pattern of the physical parameters of the Mini Piti stream is shown in Figure 14.

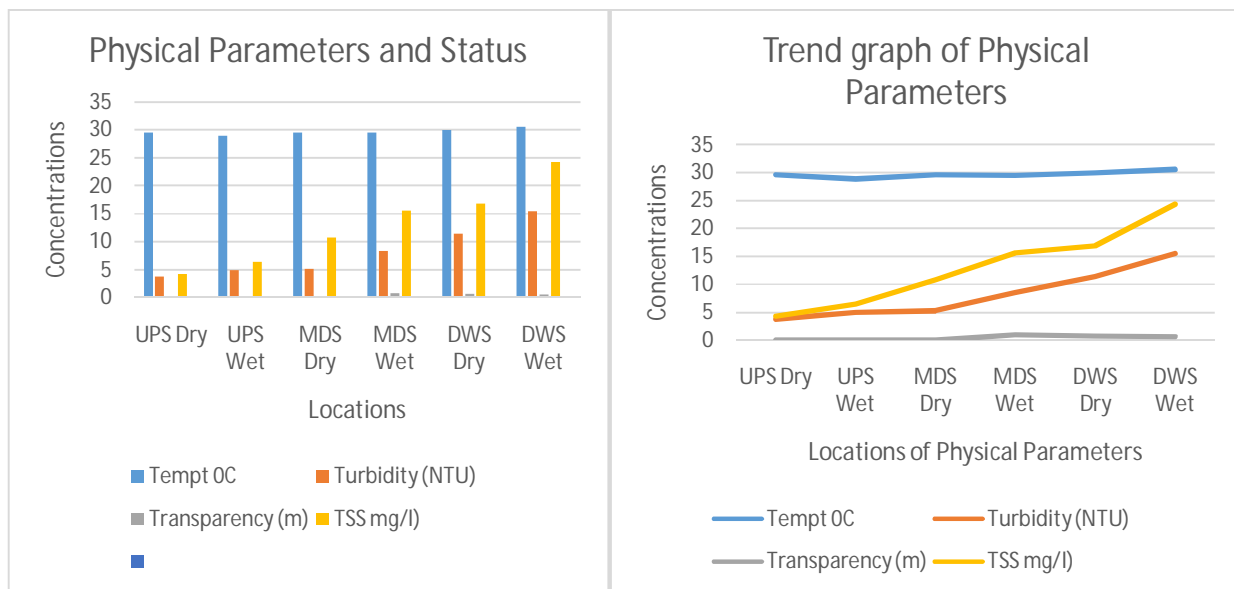


Figure 14: Trend of the Physical Parameters for the Mini Piti Stream

2.6 CONCLUSION

The assessment of environmental impacts of bank erosion on the channel morphology of Mini Piti stream was carried out between the months of December 2023 to May 2024. The results revealed that there was a significant difference between the stream depths for the wet and dry seasons in the midstream and downstream of the study area during. The bathymetric survey carried out also revealed that there was constant bed and bank erosion at the midstream and deposition at the downstream section of the stream. The high rate of bed sediment load makes the downstream to be relatively shallow with increased depth and

width during wet season due to impact of rain and storm water recharge from the watersheds. The stream flow velocity and discharge was higher at the midstream section especially during the wet season. The results obtained also showed high velocity and discharge at the midstream section as the increased flow rate also increase the stress on the bank and bed of the stream increasing the erosion rates as flow overcomes the shear stress of the bank sediment. Similarly, transparency was very low showing that the water was filled with much particles which may affect benthic organisms requiring light for growth and development. There is the pressing need to regularly observe and monitor stream water parameters to avoid bank failures occasioned by anthropogenic activities by government regulatory agencies but most importantly enforcement against indiscriminate dumping of waste into the Mini Piti stream channel to avoid public health implications and challenges associated with water borne diseases. This study has revealed the present depth and width of the Mini Piti stream which has created loopholes for flooding due to the narrow nature from erosion and impact of indiscriminate waste dumps blocking this very important drainage channel. This will hence inform decision and policy makers to emphasize creating awareness on the importance of conserving this natural resource. Stream restoration cannot be underestimated because stream recharge is very expensive just as the menace of the Lake Chad Basin in West Africa which is almost lost. The case of urbanization must be controlled to reduce population and deforestation practices. The Mini Piti stream has a poor physical water quality status from the research studies and this could be improved by channel expansion and improved navigation status by embankment.

The need to extend this impact to other water bodies in the study area cannot be ignored because the Mini Piti stream is interconnected to so many others in the city of Port Port Harcourt. The impact of streambank erosion and pollution of the water body is a threat to the adjoining streams, channels and rivers which can lead to the dangers of draught in the future. There are so many grey areas in the study that requires urgent attention such as;

- i) Determining the status of the stream which includes original width and depth upto fifty years ago
- ii) Investigating the short and long-term impacts and effects of erosion on the stream ecology and biodiversity
- iii) Evaluating the trend in some selected water and dredge water quality
- iv) Effectiveness of different erosion control measures and their suitability in the Mini Piti Stream Scenario.
- v) Determination of the water quality status of the Mini Piti stream due to erosion vulnerability

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

- 1.
- 2.
- 3.

REFERENCES

Abam, T. K. S. (1993). *Criteria for Bank Erosion Design in the Niger Delta*. IFERT, RSUST, Port-Harcourt, Rivers State.

Abam, T. K. S. (1995). *Coastal Zone Management Strategy for the Niger Delta; State of Erosion and Flooding*. Report for the World Bank, 56.

Abam, T. K. S. (1997). Aspects of Alluvial Riverbank Recession: Some examples from the Niger Delta. *Environmental Geology*, 31, 3-11.

- Abam, T. & Fubara, D. (2022) Analysis of Hydrological Characteristics: A Case Review of the Niger Delta. *Journal of Water Resource and Protection*, **14**, 611-631. doi: [10.4236/jwarp.2022.149032](https://doi.org/10.4236/jwarp.2022.149032)
- Abam, T. K. S. & Nwankwoala H. O., (2020). Characteristics of some sand deposits in some parts of Bayelsa State, Eastern Niger Delta Nigeria. *Environmental Science Geology*, 1-9.
- Abam, T. K. S. & Okagbue, C. O. (1986). Construction and Performance of Riverbank Erosion Protection Structure in the Niger Delta. *Bulletin of the Association of Engineering Geologists*.
- Abbas, G., Jomaa, S., Bronstert, A. & Michael Rode, M. (2023). Downstream changes in riverbank sediment sources and the effect of catchment size. *Journal of Hydrology: Regional Studies* Volume 46, 101340.
- Aktara, M.N. (2013). Impact of Climate Change on Riverbank Erosion Most. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, **7** (1), 36-42.
- Ali, A.W.A., Ariffin, J., Razi, M.M. & Jazuri, A. (2017). Environmental Degradation: A Review on the Potential Impact of River Morphology. *MATEC Web of Conferences* 103, 04001 (2017) DOI: [10.1051/mateconf/20171030](https://doi.org/10.1051/mateconf/20171030) ISCEE 2016 4001.
- Andrew C. K., Satish C. G., & Melinda K. B. (2013). Assessment of riverbank erosion in Southern Minnesota rivers post-European settlement. *Geomorphology* 201, 312-322.
- Arora, K. R. (2009). *Irrigation, Water Power and Water Resources*. Engineering. Publisher – Jain A.K for Standard Publishers Distributions, 1705-B.
- Arora, S. & Kumar, B. (2024). Effect of emergent vegetation on riverbank erosion with sediment mining. *Sci Rep* **14**, 11193 (2024). <https://doi.org/10.1038/s41598-024-61315-9>.
- Bolan, S., Padhye, L.P., Jasemizad, T., Govarthan, M., Karmegam, N., Wijesekara, H., Amarasiri, D., Hou, D., Zhou, P., Biswal, B.K., Balasubramanian, R., Wang, H., Siddique, K.H.M., Rinklebe, J., Kirkham, M.B. & Nanthi Bolan, N. (2014). Impacts of climate change on the fate of contaminants through extreme weather events. *Science of the Total Environment*, 909, 168388
- Box, J. E., Colgan, W. T., Wouters, B., Burgess, D. O., O'Neel, S., Thomson, L. I., & Mernild, S. H. (2018). Global sea-level contribution from Arctic land ice: 1971-2017. *Environmental Research Letters*, **13**(12), 125012. Doi: [10.1088/1748-9326/aaf2ed](https://doi.org/10.1088/1748-9326/aaf2ed).
- Brown, D.R.N., Brinkman, T.J., Bolton, W.R., Brown, C.L., Cold, H.S., Hollingsworth, T.N. & Verbyla, D.L. (2020). Implications of climate variability and changing seasonal hydrology for subarctic riverbank erosion. *Climatic Change* **162**, 1–20 (2020). <https://doi.org/10.1007/s10584-020-02748-9>.
- Dehkordi, A.K., Nafchi R.F., Samadi-Boroujeni, H., Boroujeni, M.K., & Ostad-Ali-Askari, K. (2024). Assessment of morphological changes of river bank erosion using landsat satellite time-series images. *Ain Shams Engineering Journal*, **15**(3), 102455.
- Eze, C.L. (2004). *Alternative Energy Resources (With Comments on Nigeria's Position)*. Macmillan Nigeria Publishers.
- Garanaik, A. & Sholtes J. (2013). Riverbank Protection GIVE 717. In Grove, A. T. (1951). "Soil Erosion and Population Problems in South East Nigeria. *Nigeria Geographic Journal*, **17**, 3, 291-306.

- Gobo, A.E. & Abam, T.K.S. (2006). Return Period Analysis as a Tool for Urban Flood Prediction in the Niger Delta: A Case Study of Port Harcourt City, Nigeria. *Journal of Environmental Hydrology*, 14, 1-9. <http://www.hydroweb.com>.
- Gobo, A. E. & Ngah, S. (2021). Environmental impacts on sand mining in some coastal communities in Port Harcourt Metropolis. *Journal of Applied Life Science International*, 1– 40.
- Hagerty, D. J., Spoor M. F. & Unrich, C. R. (1981). Bank Failure and Erosion on the Ohio River. *Engineering Geology*, 17,141-158. <http://www.surfrider.org/structures/erosion.asp>.
- Hoomehr, S., Akinola, A.L., Wynn-Thompson, T., Garnand, W. & Eick, M. (2018). Water Temperature, pH, and Road Salt Impacts on the Fluvial Erosion of Cohesive Streambanks. *Water*, 10(3), 302; <https://doi.org/10.3390/w10030302>
- Iyama, W.A., Amakiri, S., Itonyio, B. &Uzor.L. (2017). Assessment of Dredge Water Quality Status of the Ntawogba Creek, Port Harcourt using Selected Water Quality Parameters. *Journal of Health, Applied Sciences and Management JOHASAM*, 1 (3), 21-28.
- Iyama, W.A. &Edori, O.S. (2014a). Seasonal Variations in Water Quality during Dredging of a Typical Freshwater in the Niger Delta, Nigeria. *International Journal of Advanced Science and Engineering Technology*, 4(2), 407-417.
- Iyama, W.A. &Edori, O.S. (2014b). Seasonal Variation in Water Quality during Dredging of Brackish Water Habitat in the Niger Delta, Nigeria. *Trends in Applied Sciences Research*, 9(3), 153-159.
- Kabirul, M. D., Numal, A. K. & Manil, M. D., (2019). Impact Analysis of Sand Dredging from Alluvial Tidal River. *Department of Environmental, Water Resources and Coastal Engineering, Military Institute of Science and Technology Bangladesh*. 10-30.
- Ohaeri, M.C.A., Ogbonna, D.N., Gobo, A.E. & Ngah, S.A. (2021). Environmental Impacts of Sand Mining in SomeCoastal Communities in Port Harcourt Metropolis, Nigeria. *Journal of Applied Life Sciences International*, 24(10), 31-43.
- Ohimain, E., Bamidele, J.F. & Omisore, O.O. (2010). The Impacts of Micro-Topographic Changes on Mangroves in the Lower Reaches of the Benin River, Niger Delta. *Environmental Research Journal* 4(1),167-172. DOI: 10.3923/erj.2010.167.172
- Okeke, C.A.U. & Ede, A.N. (2019). Mechanisms of riverbank failure and channel instability on the Nkisi River, Southeast Nigeria. *IOP Conference Series: Materials Science and Engineering*, 640 012104DOI 10.1088/1757-899X/640/1/012104.
- Rahman, M.R. (2010). Impact of Riverbank Erosion Hazards in the Jamuna Floodplain Areas in Bangladesh. *Journal of Science Foundation*, 8 (1 & 2), 55-65.
- Rentier, E. S. &Cammeraat, L. H. (2022). The environmental impacts of river sand mining. *Science of the Total Environment*, 838. 155877. <https://doi.org/10.1016/j.scitotenv.2022.155877>.
- Rooijen, E. &Lotsari, E. (2024). The spatiotemporal distribution of river bank erosion events and their drivers in seasonally frozen regions. *Geomorphology*,454, 109140.
- Rutherford, I. (2000). Some human impacts on Australian stream channel morphology. In: *River Management: The AustralasianExperience* (ed. by S. Brizga& B Finlayson), John Wiley & Sons.
- Sargar, G.S., Thakare, B.G. &Hasekar, A.S.S. (2024). Review of permissible limits of physicochemical parameters drinking water. *International Journal of Research and Analytical Reviews (IJRAR)*, 11 (1), www.ijrar.org (E-ISSN 2348-1269, P- ISSN 2349-5138)
- Tha, P.T., Piman, T., Kittipongvises, S. &Ruangrassamee, P. (2024). Riverbank erosion vulnerability assessment and coping strategies: A case study of the riparian communities in the Mekong River Basin in Cambodia. *Heliyon*, 10(3), e25418.

Tripathy, B. & Mondal, T. (2020). Riverbank Erosion and Environmental Degradation. *International Journal of Research*, 7(7), 305-316.

Tuhin, K. D., Sushil, K. H., Ivy, D. G. & Sayanti, S. (2014). "River Bank Erosion Induced Human Displacement and Its Consequences", *Living Rev. Landscape Research*, 8, (2014), 3. URL (accessed): <http://www.livingreviews.org/lrlr-2014-3>.

WHO (2017). World Health Organization. *Guidelines for Drinking Water Quality*: Geneva, Switzerland.

Yamani, M., Goorabi, A. & Dowlati, J. (2011). The Effect of Human Activities on River Bank Stability. *American Journal of Environmental Sciences*, 7, (3), 244-247. (2011).

Yeole, S. (2021). Physico-chemical Properties and Microfaunal Diversity of Masoli Reservoir, Parbhani(MS), India. *Int. Res. J. of Science & Engineering*, 9 (2), 61-66.