SPATIOTEMPORAL CHANGES IN THE CHANNEL HYDROMORPHOLOGY OF RIVER YEDZERAM SECTION AND ITS IMPACTS IN SURROUNDINGS, NORTH EAST NIGERIA

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Abstract
The complex structure of rivers and increasing interest in quantitatively representing this complex structure has motivated the study of river dynamics, which has become an important subject in river science. This study analyzed spatiotemporal changes in the channel morphology of River Yedzeram section and its impacts in surroundings, North East Nigeria, Recent changes in the channel morphology of River Yedzeram segment from Wuro-Harde to Tappare Babeti Mubi North; Adamawa State of Nigeria was evaluated using thorough fieldwork and Geographical Information System (GIS) Analysis. Modifications such as channel width, channel depth, channel sinuosity and lateral channel movement processes in the channel segment were examined over the period of 13 years (2006 to 2019). The Results depicted that from 2006 to 2011 the average migration magnitude was 20.51m while the average migration rate was 3.96m/year). From 2011 to 2015 the average migration magnitude was 20.34m while the rate of migration was 4.39m/year. From 2015 to 2019 the average migration magnitude was 19.47m, while the rate of migration rate was 3.89m/year. A short term (2016 to 2019) channel deepening rate of 0.12m/year was also observed within the right bank section of the channel. Riparian buffer zones mapping and restriction policies against encroachment within the zones were recommended and serious need to enlighten and educate the public on the effects of their activities on the environment, which could result to detrimental landscape changes in the area.

Keywords**:** Channel expansion, lateral movement, Channel deepening, Channel Meandering and Riparian land uses.

Introduction
A river channel is an open system which receives and extends matter and energy to external environment (Huang, Chang, and Nanson, 2004, Humphries, 2014 & Bravard, Petit 2009). River has well-defined boundaries (Mick 2018), and is determined by factors such as climate, geology, basin relief, and land use whereas the flow in the defined boundary cannot be stopped from reaching the unwanted user (Gordon, and Lucien, 2019; Oliver *et al*, 2021). Therefore, as a geomorphic feature, the river channel integrates both the cascading and morphologic systems (Aard, 2013), because the forces that determine its dimensions and morphology are mostly those extended by the flowing water. This could be regarded as a component of the process-response

system (Yonanna, 2007). It is being realized that the morphological study of river needs to be properly analyzed and documented. This is because of the man-environment interaction that explains how people adapt to the prevailing environment and also the modifications in the environment to suit their demands.

Changes in the channel morphometric characteristics can occur as a result of natural events such as Floods, hurricanes, tornadoes, fire, lightning; volcanic eruptions, earth-quakes, landslides, temperature extremes, and drought are among the many that disturb structure, and functions of stream corridor (Harvey, 2015; Saurabh, & Chaubey, 2016). On the other hand, Human-induced disturbances brought about by land use activities undoubtedly have the greatest potential for introducing enduring changes to the channel structure and processes on channel morphology (Ortega, Razola & Garzón, 2014). These human induced disturbances can be chemically defined disturbance, biologically defined disturbance and physically defined disturbance (Gregory, 2006).

Gradual lateral channel migration which is most common along meander bends is dependent on the flow conditions within the channel and the ability of the bank to resist erosion by stream flow (Nanson & Croke, 1992). Giardino & Lee (2011) further clarified that lateral channel migration is influenced by a number of variables including land cover, hydrologic regime, and bank composition and underlying geology, among others. Hickin (1983) observed that the rate of progressive migration is generally assumed to increase with channel centerline curvature up to some threshold, as such channel centerline curvature (an indicator of meander intensity) is assumed to be related to the spatial distribution and the magnitude of channel migration (Hooke & Harvey 1983; Johannesson & Parker 1989; Furbish 1991; Larsen 2007).

Furthermore, considering the influence of river hydraulics, the rate at which channels migrate laterally generally increases with stream power (Nanson & Hickin, 1986; Richard *et al*, 2005). Confined streams can also be subjected to channel incision (deepening) and migration if there is a change in geomorphic controls (Yonnana & Oliver 2020). This is capable of destabilizing stream banks and posing threats on buried pipelines, bridge abutments, and road embankments (Legg & Olson 2014). The unique characteristics of each river should be understood so that the responses of the river due to any encroachment in the flood plain and more in the case of future man-made structures may be anticipated and preventive measures as considered necessary may be planned beforehand. People change the river environment by making artificial levees, bridges and barrages. Although, these activities are important for the development but they have adverse effect on natural characteristic of river. Therefore, the reasons stated prompted this study to attempts to examine the nature and pattern of the current movement of the Wuro-Harde/Tappare Babeti section of the Yedzeram River channel and the related implications on the adjacent human activities and land uses.

The Study Area

The channel under study extended from Wuro-Harde along the Yedzeram River to Tappare Babeti Mubi North; Adamawa State of Nigeria at the confluence of River Muvur and River Yedzeram at Wuro-Harde with the total length of approximately 11,426.5m (Figure 1). It is located between latitude 10º 26' 30"N and 10º22' 00" N of the Equator and between Longitude 13º 12' 30" E and 13º13' 30" E of the Prime Meridian (Google Earth, 2020). It has the Sinuosity index value of 1.4 relatively lower than the reach within the channel. One of the important features of this reach is formation of several avulsions and chutes due to massive lateral shifting of the river. Right bank of the river in this reach is a part of Inactive flood plain where right bank is mainly characterized by active floodplain. This area is mostly containing tropical wet and dry climatic type with prominent wet season from May to October and dry season from November to April (Adabayo, Zemba & Tukur, 2020). While the wet seasons contribute to the channel's flow characteristics, the dry season is responsible for its ephemeral nature. As such its fluvial action is mainly limited to the wet seasons.

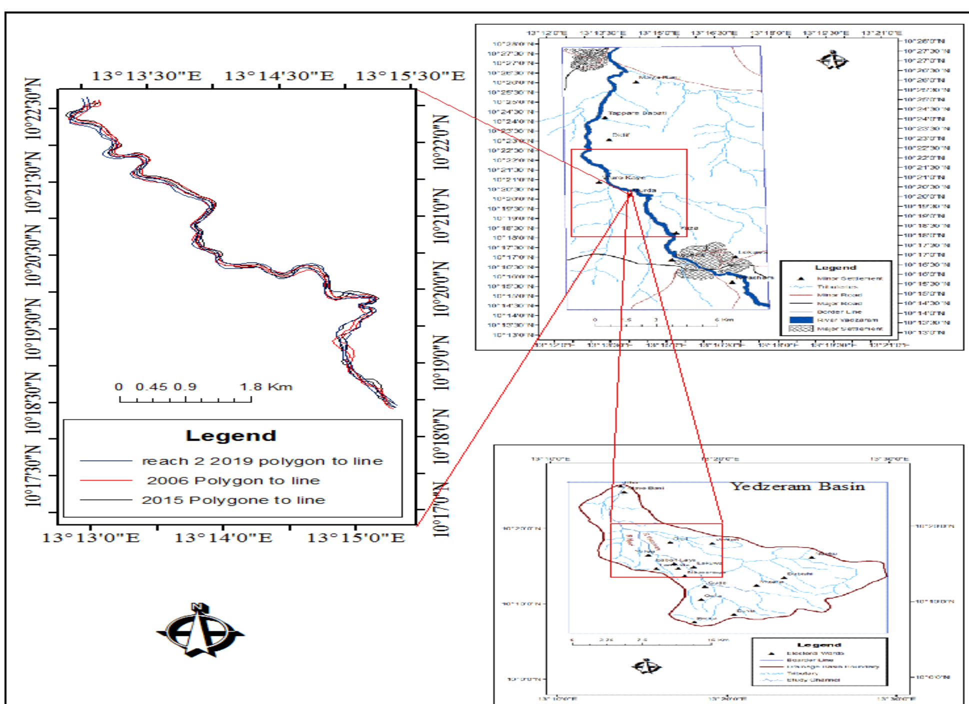

Figure 1: Channel Reach of River Yedzaram from Tappare Babeti to Wuro-Harde.
Source: Researcher Fieldwork, 2019.

Materials and Methods

Geographic Information System (GIS), integrated approach of Remote Sensing (RS), G.P.S., Ranging Pole, Steel Tape and field survey were intensively employed in this study in the rainy season. These helped in the assessment of changes in the channel width, short term channel deepening rate, sinuosity characteristics, channel movement pattern and related effects on human activities and land uses from 2006 to 2019. This short term (13 years) study period was adopted on the basis of availability of required data.

Google Earth Images of the study area for 2006, 2011, 2015 and 2019 with High resolution of 0.5 meters per pixel were captured online and processed in the Arcmap environment of ArcGIS 10.3. In the process, the images were Georeferenced and the studied channel section from each period was digitized to obtain the channel area polygon as well as the left and right bank line shape files. The centerlines of the channel for the four periods were created using the collapse dual lines to centerline tool of Cartography-Generalization components of the Arc toolbox as suggested by Giardino and Rowley (2016). This is because the Centerline Length (*Lc*) also known as the mid channel length serves as a very vital parameter for determining the Active Channel Width (ACW) or simply Average Channel Width (Alcantara, 2014; Kou *et al*, 2017) as well as a more preferable parameter for computing river channel sinuosity (Friend & Sinha, 1993; Larsen, 2007) and the creation of channel migration polygons (Alcantara, 2014; Giardino & Rowley, 2016; Das & Pal, 2016).

The Active Channel Width (ACW) also known as the Average Channel Width or Mid Channel Width (MCW) was expressed as the Channel Area ratio the Channel Length which was also a measure of the Centerline Length.

$MCW = \frac{A_c}{L_c}$ (1), Where MCW is Mid Channel Width, A_C is Channel Area and L_C is Centerline Length.

Changes in channel width were determined by calculating the differences in distances between previous and recent MCWs. In addition, changes in Percentage (P_c) in channel widths from 2006(n1) through 2011(n2) to 2015(n3) and 2019(n4) for the channel section as suggested by Alcantara (2014):

$$P_c = \left[\left(\frac{MCW_{n2}}{MCW_{n1}} \right) - 1 \right] \times 100$$

Where P_c is Percentage Change in channel width, MCW is Mid Channel Width, where n1 was the initial period of measurement and n2 final period of measurement.

Short term channel deepening assessment was conducted mainly by field measurement procedures. In 2018 and 2019, the bed level of the studied river channel section was measured with survey procedure involving the use of leveling staff. The exercise was conducted as an initial routine for assessing the rate of channel deepening at the Tappare Babeti and Wuro-Harde Gauging Stations. The two years channel deepening data obtained was analyzed with respect to section channel width stability over the period.

Discharges (Q) values were computed as the product of cross-sectional Area (A) and mean velocity $\bar{v}$.

River discharges values were obtained from computation of obtained data as follows:

$Q = \bar{v} A$, Where Q is Discharge (m^3s^{-1}); $\bar{v}$ is mean velocity and A is cross sectional area of the river at the sample station.

Plate 1: Methods of determining the width and depth of channel

Source: Fieldwork 2019

Sinuosity Index is the major indicator of the meandering features of the channel at the different study times. $S_n = \frac{L_c}{L_v}$, where S_n is the Sinuosity index, L_c channel length and L_v is the valley length

The level of sinuosity was calculated using the Sinuosity Index Scale (Table 1) as provided by Yong et al., (2018).This served as a comparative analysis tool for the meandering channel and its behavior over the given time (2006 to 2019).

Table 1: Classes of Sinuosity Index

Sinuosity Index	Type of Channel
<1.05	Straight Channel
1.05-1.30	Sinuous Channel
1.30-1.50	Moderate Meandering Channel
>1.50	Meandering Channel

Adopted from Yong, et al., (2018).

The channel migration rate was calculated using the following equation

$R_m = \frac{M_T}{n}$, where R_m represents rate of migration M_T is the Total Migration, *n* is the number of years between sequential channel centerlines (Giardino & Lee, 2011).

Result and Discussion

Based on GIS analysis and intensive field studies, channel opening and gradual lateral movement were noticed as the major processes of channel changes occurring in the channel section studied, although channel avulsion was not observed. However, another channel adjustment activity noticed was short term channel deepening at the bank and middle section of the channel.

The result obtained in Table 2 indicates that the area occupied by the channel was 938,498.74m^2 in 2006, the channel reach occupied about 1,187,601.36m^2 in 2011, 1,079,492.41m^2 in 2015 and 1,676,699.22m^2 in 2019. The difference of area between 2006 and 2011 was 249,102.26m^2, between 2011 and 2015 was 108,108.95m^2, between 2015 and 2019 was 597,206.81m^2. This implies that from 2006 to 2011, the channel reach area decreased by 249,102.26m^2 which indicates that there was channel bank reduction in this section of the channel. From 2011 to 2015, the channel bank width increased by 108,108.95m^2. This indicates that there was degradation that took place in the channel width within the time period. From 2015 to 2019, the channel width experienced bank shrinking because the channel reaches decreased by 108,108.95m^2. This finding indicates instability in the channel width, this result to bank erosion as clearly revealed by Wietse et al, 2010. Based on the channel length changes, there is stability in the channel length changes. This implies that the channel experienced stable meandering in this time period. The Percentage change in the channel width between 2006 and 2011 time period indicates that the channel decreased be 36.10%. Between 2011 and 2015, the channel width increased by 7.20%. Between 2015 and 2019, the channel decreased by 55.58%. Comparing the changes between 2006/2011, and 2011/2015, the channel width generally increased by 28.90%. Between 2011/2015 and 2015/209, the channel decreased by 48.38%. This indicates that channel reclamation has taken place within these recent time period.

Table 2: Tappare Babeti to Wuro-Harde Channel Width Changes

Year	Channel Polygon Area (m^2)	Polygon Length (m)	Mean Channel Width	Percentage Change in Channel Width
2006	938498.74	26395.41	35.56	36.10
2011	1187601.36	24542.62	48.39	-7.20
2015	1079492.41	24039.96	44.90	55.58
2019	1676699.22	24000.00	69.86	

Source: Researcher fieldwork, 2019.

The centerline lengths of the channel reach Wuro Harde to Teppari Babeti of the Yedzeram River channel for 2006, 2011, 2015 and 2019, which were analyzed is provided in Table 4. The total length of the centerline of the channel was 11426m in 2006, 11538m in 2011, 11609m in 2015 and 11133m in 2019. From Table 3, the changes in channel length were 112m between 2006 and 2011, 71m between 2011 and 2015 and 476m between 2015 and 2019. It is clear that the change in the channel lengths between 2015/2019 was greater than the changes that occurred between 2006/2011 and 2011/2015 due to low sinuosity level.

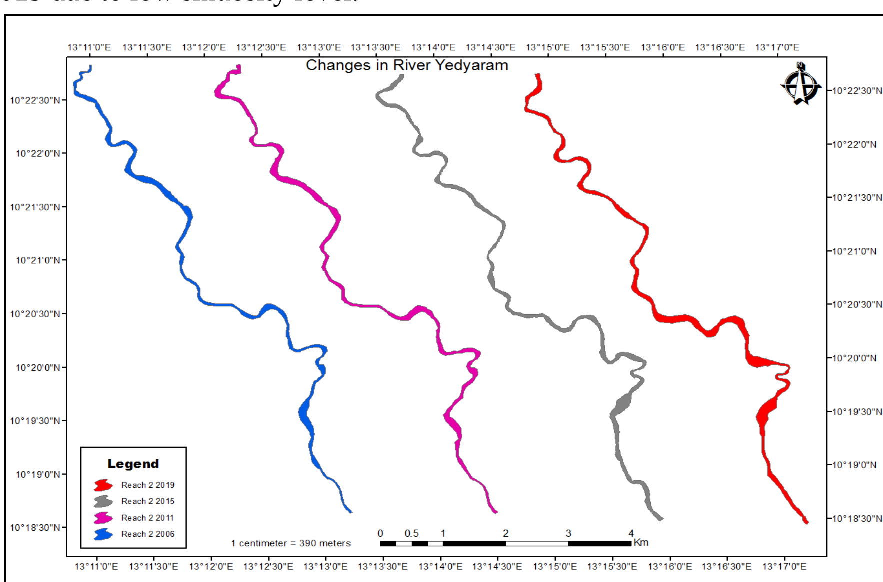

Figure 2: River Yedzeram from Tappare Babeti to Wuro-Harde (2006-2019) channel width changes. Source: Researcher fieldwork 2019.

The main statistical information regarding the sinuosity indexes of the channel reach for 2006, 2011, 2015 and 2019 is presented in Table 3. The highest average sinuosity was observed as 1.38 in 2015 at channel reach. The lowest average sinuosity was observed in the channel reach, with a value of 1.33 in 2019. The lateral migration of river channels and the bank erosion due to lateral shifting is a natural process (Dan, 2013; Leopold et al., 1964; Yang, 1971), but growing intervention of human being has made it semi natural. Lateral migration of river is always associated with bank erosion of the stream bed or channel wall due turbulent flow condition of water (Yang et al. 1999). Migration of river channel organized within a corridor or region (Richard et al, 2005), so it sometimes creates problems to those who living in this region. Sometimes, many people have lost their homes, agricultural land, infrastructure, their livelihoods due to the river channel migration and erosion (Mann, 2013, Mukherjee, 2008; Rudra, 2005).

Table 3: Tappare Babeti to Wuro-Harde channel sinuosity

Year	Centerline Length (m)	Valley Length (m)	Sinuosity
2006	11426	8,375.36	1.364239294
2013	11538	8,375.36	1.377611848
2015	11609	8,375.36	1.386089092
2019	11133	8,375.36	1.329255738

Source: Researcher fieldwork 2019.

The Figure 3 displays sinuosity characteristics by sinuosity index values within different period in the channel reach. The sinuosity index value ranges from 1.39 to 1.33 during 2006 - 2019. Total length of the river reach is 11,609m which is the highest in 2015 whereas it is 11,133m in 2019 which is the lowest. The general trend shows that Sinuosity of the channel decreases from 2007 to 2019. This indicates that the meandering pattern of the channel reach in River Yedzeram is decreasing. Lateral migration of sinuous river channel sometimes creates conflicts between bank erosion and human activities near riverbanks (Larsen and Greco, 2002).Some study suggests that active channel migration also helps to maintain riparian ecosystem Bravard and Gilvear 1996). The trend slope for sinuosity in the equation (y= -0.0096x+1.3884) indicated decrease of sinuosity by -0.0096 within the years of interval.

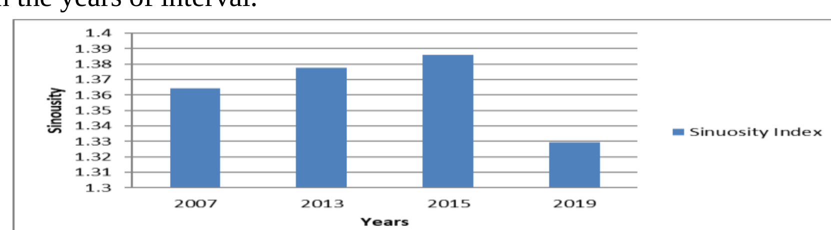

Figure 3: Trend of Sinuosity Index Scores of Yedzeram River from Teppari Babeti to Wuro-Harde (2006 - 2019). Source: Researcher fieldwork 2019.

Table 4 displays the results of the magnitude of migration and migration rates statistics for three distinct time periods (2006-2011, 2013-2015 and 2015-2019). Here time period from 2006 to 2011 is indexed as Phase-1, 2011 to 2015 is termed as Phase-II and from 2015 to 2019 is indicated as phase-III. In Phase-I (2006 to 2011) the average migration magnitude is 20.51m while the average migration rate is 3.96m/year, in Phase –II (2011-2015) the average migration magnitude is 20.34m while the rate of migration is 4.39m/year and in phase-III (2015-2019), the average migration magnitude is 19.47m, while the rate of migration rate is 3.89m/year.

That means there is tendency that lateral migration has increased between phase-I and phase-II, while between phase-II and phase- III the lateral migration has reduced. Fluctuation of channel widths over time because of a short term imbalance between the rate of cut bank erosion and the rate of point-bar sediment accumulation are responsible for variation in migration rate (Nanson & Hickin, 1983). Some study suggests that active channel migration also helps to maintain riparian ecosystem (Bravard & Gilvear 1996).

Total 502122.87Km^2 area was affected by migration during the period 2006 to 2011 (5 years) in phase-I, almost 691790.80Km^2 area has been affected by channel migration over the phase-II which means that there is increase in lateral migration. 691175.62Km^2 area has been affected during the period in phase-III, which is relatively lower than preceding phase-II and higher than phase-I. The variability of migration rate based on area method is 3.96m/year during 2006-2011, 4.39m/year during 2011-2015 and variability of migration rate is 3.89m/year during 2015-2019. Higher value of migration variation of phase 2011-2015 than 2006-2011 and 2015-2019 is showing that the migration rate in 2006-2011 and 2015-2019 is more consistence than time frame of 2011-2015.

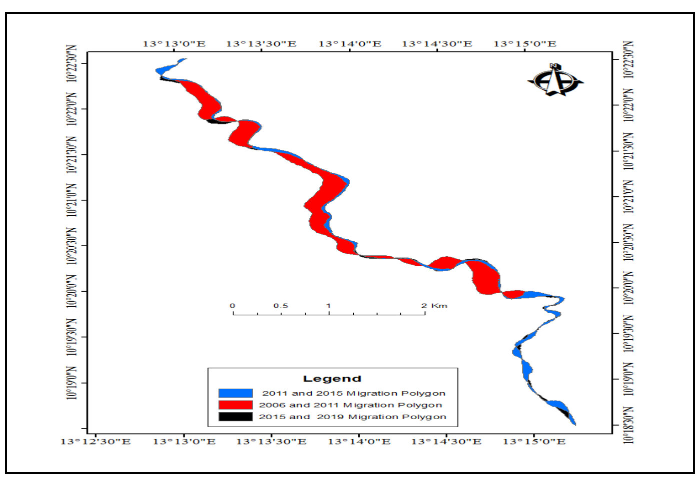

Figure 4: River Yedzeram from Tappare Babeti to Wuro-Harde Lateral Migration (2006-2019)

Table 4: channel Reach Migration rate statistics (Calculated following the polygon area method)

Years interval	No of Polygons	Polygon Area	Polygon Perimeter	Total Migration (Mn)	Rate of Migration (Ry)
2006-2011	19	191984.7092	20445.0000	18.7806	3.756120503
2011-2015	47	236610.8644	22684.76723	20.86077075	4.172154151
2015-2019	52	163014.5695	20353.87438	16.01803829	3.203607657

Source: Researcher fieldwork 2019.

Various anthropogenic activities mainly channel encroachment and sand mining, obstruction of natural flow, lifting of water from the river etc. are the main causes of modification of channel characteristics which includes channel width, depth, discharge and wetted perimeter. The Figures (5) shows the changes that occurred between 2018 and 2019 cross sectional channel width and depth across the Yedzeram River located at Wuro-Bani. The trend slope for depth of the river in the equation (y= -0.112in(x) +550.42) indicated that the channel depth started decreasing by -0.11707m from the depth of 550.42m above the main sea level.

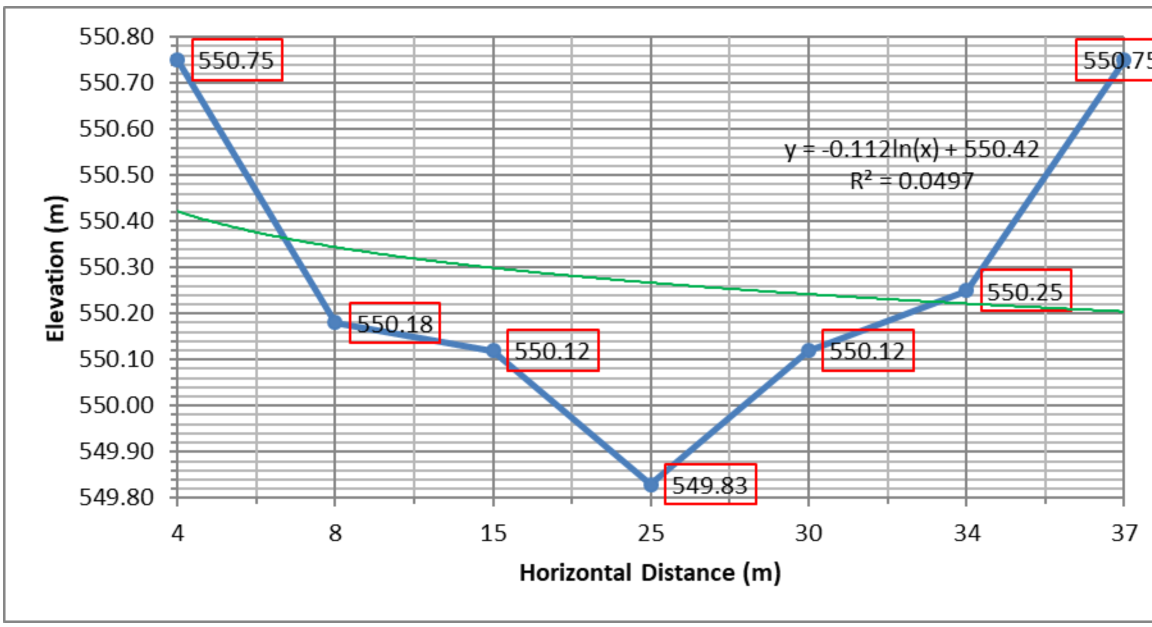

Figure 5: Cross section across the Yedzeram River located at Wuro-Harde (July 2018).
Source: Fieldwork 2019

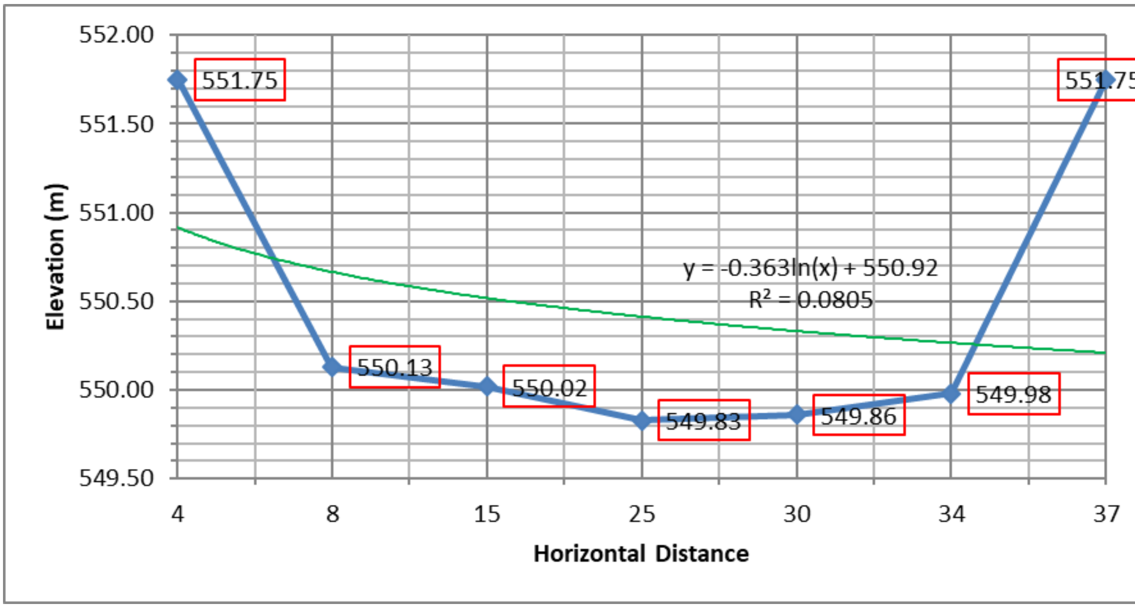

Figure 6: Cross section across the Yedzeram River located at Wuro-Harde (July 2019).
Source: Fieldwork 2019.

In Figure 6, the trend slope for depth of the river in the equation (y=0.363in(x) +550.92) indicated that the channel depth started increasing by 0.363m from the depth of 550.92m above the main sea level.

Table 5 indicates the increasing instability of the river bed and bank site at Wuro-Harde where -2.064% decreases in width of the channel section has been noticed, 1.136% increase in channel depth has been identified and 6.134% increase in channel water discharge has been noticed. Channel encroachment and its associated activities can be responsible for considerable changes in channel morphology, eventually resulting to changes in volume of flows in the channel. Channel encroachment can also disrupt sediment supply and channel form, which can result in a deepening of the channel (incision) as well as sedimentation of habitats and water spillage during excessive rainfall in the upstream, eventually resulting to flooding and destruction of farm produce. Measurable soil properties, natural bank geometry (e.g. channel width, meander length, meander wavelength, amplitude, radius of curvature, arc angle and sinuosity), discharges of various frequencies (Brice 1982; Garcia et al. 1994), distribution of riparian vegetation, and vertical and horizontal heterogeneity of floodplain soils (Motta et al., 2012) etc. are some responsible factors for Channel migration.

Table 5: 2018 and 2019 Variation of Variables at Wuro-Harde channel section

Variables	2018 Data	2019 Data	Percentage change
Average width (m)	34.6m	33.2m	-2.064
Average depth (m)	8.7m	8.9m	1.136
Water discharge (m3/s)	$1739.450m^3s^{-1}$.	$1966.752m^3s^{-1}$.	6.134

Source: Fieldwork 2019

The Impact of Channel Width Changes on the Adjacent Land Use Activities

Careful observation revealed that channel width changes have played vital roles in the production and contribution in the aggradation and degradation of soil in the river channel which affected various land uses (agriculture, transportation and construction of hydraulic structures). A close study of the irrigation agricultural land use zone around the river channel confirmed that the denuded areas of the zone resulted from intense annual volume of water which resulted to crop destruction with little or no soil conservation measures, (plate 2 and 3).

Plate 2 and 3: Effects of channel width changes on rice farm

Source: Fieldwork 2019.

Conclusion

Based on the results of the study and discussion presented, it was discovered that the studied channel section is under serious natural and anthropogenic disturbances. For that reason, it triggered some forms of landform changes and adjustments such as channel drifting channel deepening, channel sinuosity and lateral channel movement processes in the channel section resulting to persistent channel shrinking, gradual deepening, sinuosity and temporal meander bend lateral movement. The impacts of the landform changes on riparian land uses are gigantic and decimating, and that no efforts made towards managing the changes effective and adequate.

Based on the findings of the study, the following recommendations are made;

i. Adverse human activities Such as channel reclamation, dumping of solid waste within the channel, and over-cultivation practices within river channel should be minimized.
ii. In addition, clearing of riverbank vegetal cover, in-stream sand mining and bricks industrial activities within the riparian zones of the channel deserve adequate monitoring and regulation.
iii. There is an urgent need to map out and reclaim the stream channel's flow corridors through such procedures as infrastructure relocation and setback, conservation easements, vegetation buffer zones, longitudinal bank lowering, and addition of side channels among others.
iv.

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