Analyses of Trends in Stream Flow Behaviour of Mubi Section of River Yedzeram, Northeastern Nigeria

[1]Ezekiel Yonnana, [1]Samuel Hyellamada Jerry, [1]Thomas James, [1]Kadmiel Oliver and [2]Alheri Jacob

[1]Department of Geography, Adamawa State University Mubi, Adamawa State, Nigeria
[2]Department of Civil Engineering, Federal Polytechnic Mubi Adamawa State, Nigeria
Email: ezekiel97@adsu.edu.ng

Abstract

The understanding of trends in the flow characteristics of a stream is of hydrologic and geomorphologic significance in terms of channel morphology changes and management of stream water resources for sustainable uses. In this study, attempts have been made to analyse the short-term trends in behaviour of selected Mubi section of River Yedzeram. The study was based on 14 years (2005 through 2019) direct field measurements and stream flow available data. The variables of interest in the study included Annual Total Rainfall, Mean Flow Velocity, Annual Mean Discharge, Flow Pattern, Stream Bed Shear Stress and Specific Stream Power. Result of the findings showed considerable increase in trends of all the variables over the period of study. This indicates the occurrence of significant hydrologic and channel morphologic changes in the stream section as well as the possibilities of further changes in the future. Continual hydro-morphologic monitoring, data collection and development of strong policies on in-stream and riparian land disturbances within the entire Mubi section of the stream are recommended.

Keywords: Hydraulic Geometry, Hydro-Morphologic Monitoring, River Yedzeram, Short-term Trend Analysis and Stream Flow Behaviour.

Introduction

Streams are vital features of both natural and cultural landscapes. Beside their aesthetic beauty, they serve as very important life sustaining components of the ecological system in terms of habitat for aquatic lives and water supply for terrestrial flora and fauna. As a matter of fact, the importance of streams to man as sources of water for consumption, domestic, industrial, transportation, recreation and agriculture uses among others, cannot be under estimated. However, as dynamic features of the fluvial systems, streams are subject to vast changes in their morphological (form) and cascading (process) components, which could result to either excesses or deficits in their water contents; deformations in their channel morphologies or complete extinction. Such changes can only be ascertained if the flow behaviour of the river system is well understood. In this case, the application of the concept of hydraulic geometry is key and inevitable. Pitlick and Cress (2002) noted that changes in stream channel geometry are determined both by changes in water discharge (Leopold and Maddock, 1953), and by changes in sediment load and bank properties (Schumm, 1960). The quantitative relationship between stream discharge and the hydraulic geometric parameters of the stream is expressed in the widely used discharge equation (Knighton, 1998; Huggett, 2007; Charlton, 2008):

$$Q = wdv \qquad (1)$$

Where Q is stream discharge, w is wetted width, d is flow depth and v is flow velocity.

Therefore, the concept of hydraulic geometry provides a vital platform for understanding the flow behaviour of any river system taking into consideration such parameters as flow depth, wetted width, channel slope and roughness, flow velocity, and water density which in turn determine flow properties as discharge, flow pattern (turbulence), stream power and competence; the key determinants of sediment load transport in the fluvial system. It is also important to note that any form of excessive changes in the flow characteristics of the stream tends to pose considerable destructive or constructive impacts on its channel morphology on one hand and its dependents on the other hand.

In most tropical scenarios where torrential stream flow behaviour is influenced by both natural factors as intensive rainfall events alongside anthropogenic factors as land use changes, episodic over-flows (floods), strong hydraulic in-channel flows and channel scours are not far-fetched. These result in deformations of stream channel morphologies in forms of channel banks failure and erosion, meander bends migration and avulsion, as well as stream channel incision, which in turn often pose devastating effects on structures and riparian ecosystems (Leopold *et al,* 1995; Walling *et al,* 2003; Giardino & Lee, 2011; Legg & Olson, 2014; Das & Pal, 2016). However, with proper monitoring and good management approaches, such devastating impacts of stream flow can be checked. Therefore, in a notion similar to that of Williamson *et al* (2015), one can equally opine that a good activity of stream or river management is based on informed decisions that are underpinned by the fundamental principles of hydraulics and fluvial geomorphology, taking into account the multiple functions and services that a stream delivers. This informs the need for continual monitoring of stream flow trends for the purposes of management and sustainable use of river resources.

Trend analysis is a suitable statistical tool used in the assessment and monitoring of environmental changes over period of time. Its relevance in water resources studies have been acknowledged (Hirsch *et al,* 1982; Lettenmaier *et al,* 1982; Hirsch *et al,* 1991; Helsel & Hirsh, 1991; Aroner, 2000).

The Yedzeram river channel which cuts across Mubi town is the consequent stream of the Yedzeram fluvial sub-stream network. The river channel is significant in understanding to a greater extent, the stream flow behaviour of the entire Yedzeram River System. The Mubi section of the Yedzeram River serves as a major source of livelihood (water) to a large population of riparian human communities (both rural and urban). It also supports a substantial riparian vegetation community and serves as a source of groundwater recharge in the area. Made of an alluvial river channel by nature, it supplies large quantities of gravel and sand that meet the construction needs of the area, most especially the rapidly growing Mubi (urban) settlement.

Although, cursory observations and preliminary studies have highlighted the possibilities of variations in the flow behaviour of the river over the years, little or no past hydro-morphologic monitoring and data collection have been carried out for the river section over the years, until 2005 following the establishment of the Department of Geography, Adamawa State University Mubi and the studies of Yonnana (2007), Yonnana *et al* (2008), Yonnana and Adebayo (2009). Since then, some published and unpublished studies have been conducted on the river section but not from a trend perspective. This informs the need for the current study which attempts to analyse the river section's flow characteristics trends from the year 2005 through 2019.

Materials and Methods

Description of the Study Area

The Yedzeram Sub-basin is located between latitudes 10°06'N and 10°19'N of the Equator and between longitudes 13°14'E and 13°26'E of the Prime Meridian, covering a total area of 1.50Km^2. River Yedzeram forms the consequent stream of the sub-basin and runs across Mubi town. However, this study focused mainly on the section of the river that cuts across the town, located between latitudes 10°16'N and 10°19'N of the Equator and between longitudes 13°14'E and 13°16'E of the Prime Meridian, covering about 8.5Km^2 from Lokuwa bridge to Yaza (Figure 1). The stream channel is ephemeral by nature and characterized by gravel to sand bed material with small areal floodplains which support some irrigation agricultural activities in the area.

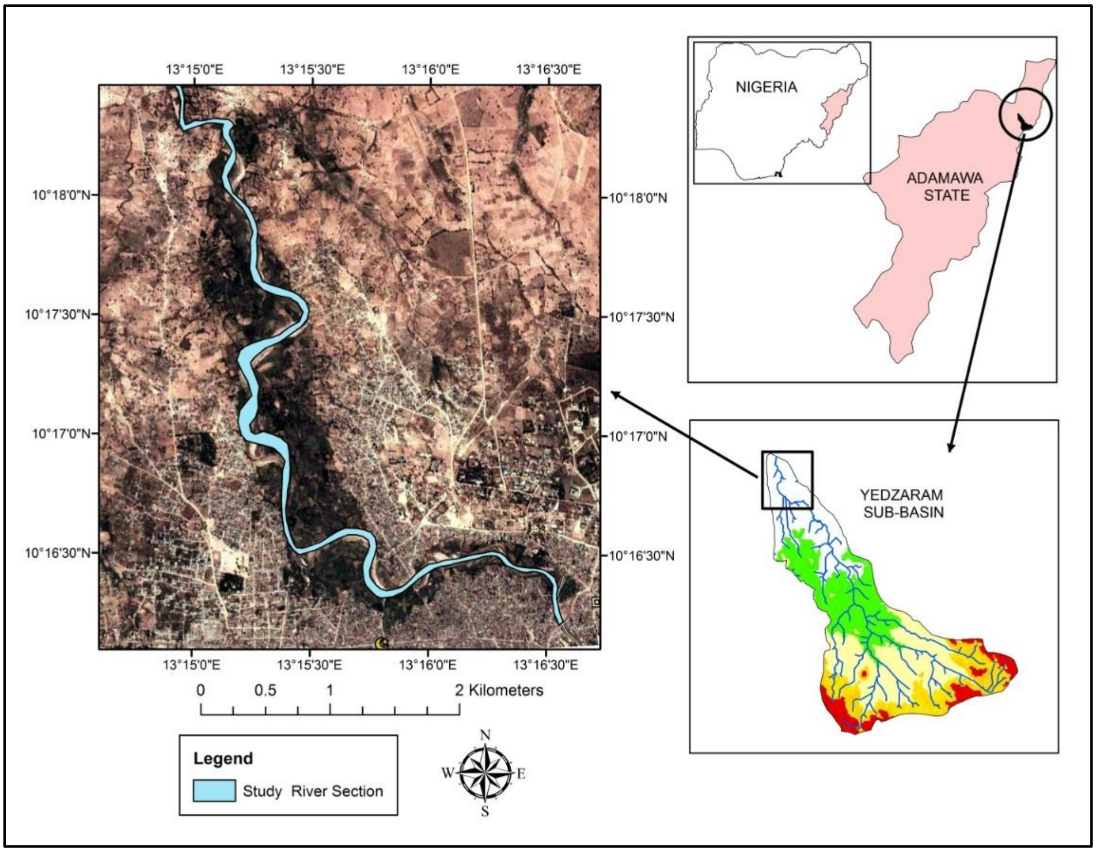

Figure 1: Study Area

The study area is of tropical wet and dry climate type, coded ***Aw*** in the Koppen's climate classification scheme. The temperature regime of the area is warm to hot throughout the year owing to high radiation income with a slight cool period from November to February. The area experiences gradual increase in temperature from January (33.9°C) to April (39.6°C) with annual maximum occurring in April. The wet season which runs from June to October yields annual rainfall amounts of 970mm to 1200mm (Adebayo, 2004). However, greater amounts have been recorded in recent times. These rainfall amounts contribute immensely to the area's stream flow characteristics owing to the influences of its geology (Basement complex rock types) and shallow to moderately deep soils over a rugged relief.

Data Collection and Computations

Data for the study were generated mainly by field measurements-based procedures provided by Harrelson *et al* (1994) and the use of empirical formulae. In April 2005 (dry season), the bed level of the channel and a gauge height station were established at the Lokuwa bridge. This involved the use of automatic leveling instruments (Sun Jikson

Automatic level, leveling staff, measuring tape and eTrex Global Positioning System) following standard leveling survey procedure. Owing to seasonality and the ephemeral nature of the river channel, gauge readings and discharge measurements were obtained at the peak of rainy seasons (August and September) from 2005 to 2018. Channel slope data were also obtained using the surveying procedures described by Harrelson *et al* (1994). Hydraulic radius and flow velocity data were generated using the empirical formulae provided in equations (2) and (3) as suggested by Nagle (2000).

$$R = A/W_p \qquad (2)$$

Where R is Hydraulic Radius, A is channel cross sectional Area (w x d), and W_p is the wetted perimeter ($2d + w$).

$$v = \frac{R^{0.67} S^{0.5}}{n} \qquad (3)$$

Where v is stream cross sectional velocity, R is hydraulic radius, S is water surface slope and n is Manning's channel roughness coefficient as provided by Charlton (2008).

Stream discharge (Q) which is the amount of water that flows pass a unit cross section of a stream channel at a unit time measured in m^3s^{-1} was computed as with annual mean values and computed as averages:

$$Q = Av \qquad (4)$$

However, this study was confined mainly to discharge values obtained from the computations involving records of the stream wetted width and means of flow depths and velocity at the gauge station.

Froude number was used to determine the pattern of the stream flow as to whether tranquil (subcritical) or rapid (supercritical). The number is a dimensionless ratio (Fr) of inertial to gravity forces in flowing water (Charlton, 2008; Thomas, 2016) expressed as:

$$Fr = \frac{v}{\sqrt{gd}} \qquad (5)$$

Where v is stream cross sectional velocity, g is gravitational acceleration and d is flow depth. The term $\sqrt{gd}$ is the velocity of a small gravity wave (a surface ripple). In situations where $Fr < 1$, the flow is tranquil or subcritical and when $Fr > 1$, the flow is rapid or supercritical. The supercritical pattern of stream flow can be highly erosive (Charlton, 2008) and as such is connected with intense scouring action on channel bed and banks (Scheidegger, 1987) which eventually result to channel migration processes.

Another important parameter that characterizes the flow behaviour of a stream is its bed shear stress (τ_o) expressed in Newton per square meter (Nm^{-2}). As the stream flows down slope, it exerts a shearing force, or shear stress per unit area of the bed which tends to increase with increase in flow depth and channel steepness (Charlton, 2008). The stream bed shear stress which is a function of the water density ***(ρ)***, gravitational acceleration **(*g*)**, flow depth ***(d)*** and the channel slope ***(S)*** is described by the Du Boy's equation:

$$\tau_o = \rho g d S \qquad (6)$$

The stream bed shear stress is responsible for triggering the entrainment of channel bed sediment and thus plays an active role in shaping the channel (Wilcock *et al*, 2009) by erosion. It is also a very significant determinant of stream bed load transport.

Work is involved in the flow of streams because materials of various kinds (dissolved load, suspended load and bed load) are entrained and transported. A stream flow parameter that measures the rate at which such work is done is the Stream Power ***(Ω)*** expressed in Watts per unit length of the channel (Wm^{-1}) or power per unit area of the channel bed ***(ω)*** expressed in (Wm^{-2}). Charlton (2008) further noted that the available stream power is related to the water surface slope **(*S*)**, stream discharge **(*Q*)**, gravitational acceleration **(*g*)** and the mass density ***(ρ)*** of water (1,000 kg m^{-3}) such that:

$$\Omega = \rho g Q S \qquad (7)$$

$$\omega = \frac{\Omega}{w} = \frac{\rho g w d v S}{w} = \rho g d v S \quad (8)$$

Where ***w*** is the channel wetted width, ***d*** is flow depth and ***v*** is cross sectional velocity.

Generally, stream power determines the capacity of a given flow to transport sediment (Charlton, 2008). However, since the study involved only cross sectional measurements, stream power computations were restricted mainly to power per unit area (specific stream power).

Data Analysis

Means and standard deviations of the channel and hydraulic geometry variables were analysed to ascertain their nature of central tendencies. Trend analysis involving the use of graphical representations, correlation and linear regression statistical tools were employed in assessing the pattern of changes in the area's rainfall regime and the stream hydraulic geometry for the 14 years period of study.

Result of the Findings

The channel and hydraulic geometry characteristics of the studied stream section are presented in Appendix 1. However, over the 14 years (2005 through 2019) period of study, means and standard deviations of the variables are presented on Table 1. Most of the hydraulic variables exhibited high standard deviation values (Table 1) owing to fluctuating flows, mostly characterized by episodic events.

Table 1: Channel and Hydraulic Geometric variables of Mubi subsection of River Yedzaram (2005 - 2019).

Flow variable	**Mean**	**St. Dev.**
Mean wetted width	32.41	2.96
Mean flow depth	0.84	0.13
Mean width/depth ratio	39.24	5.73
Mean wetted perimeter	34.09	3.06
Mean cross sectional area	27.36	5.75
Mean Hydraulic Radius	0.80	0.11
Mean Flow Velocity (ms^{-1})	1.65	0.22
Mean Discharge (m^{3}s^{-1})	46.24	17.02
Mean Froude Number	0.57	0.04
Mean Stream Bed Shear Stress (Nm^{-2})	27.56	6.56
Mean Specific Stream Power (Nm^{-2})	46.86	19.05

The graphical representation in figure 2 showed some up trends in both annual total rainfall and annual mean discharge over the 14 years period. The trend slope for annual total rainfall in the regression equation (y=35.566x-705.35) indicated a yearly increase of rainfall by 35.566mm, while that of annual mean discharge (y=1.1705x-3395.2) indicated yearly increase of mean flow discharge by 1.1705m^{3}s-^{1}.

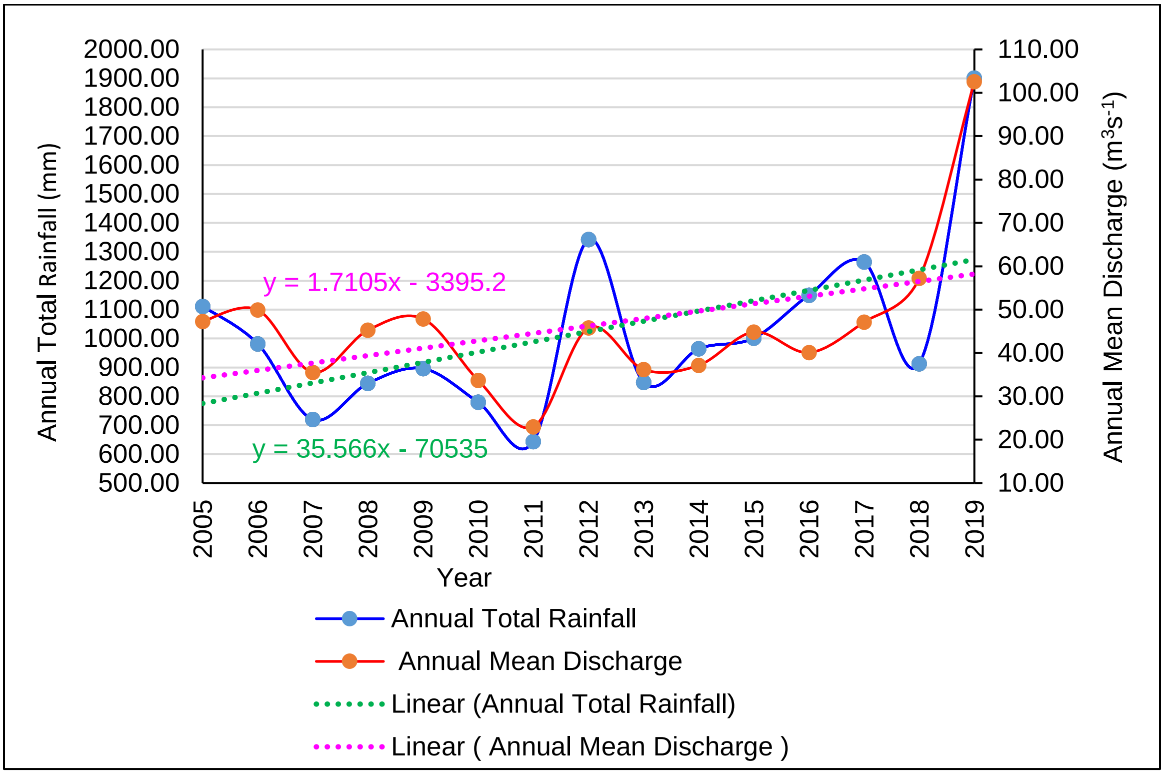

Figure 2: Trend of Annual Total Rainfall and Annual Mean Discharge

Some form of positive relationships was also observed between the area's rainfall and the stream flow regimes. Statistical analysis revealed a strong positive correlation coefficient *(r=0.80)* between the area's annual total rainfall and the stream annual mean discharge over the 14 years period. To further confirm the extent of this relationship, results of trend analysis and linear regression (Figure 3) showed a positive trend in which the annual mean discharge increased by 0.0482m^3s^{-1} for every 250mm increase in Annual Total Rainfall. In addition, r^2 value (0.64) signified that 64% of the variation in Annual Mean Discharge was accounted for by its regression on Total Annual Rainfall. The establishment of the relationship between the area's Total Annual Rainfall and Annual Mean Discharge implies that the ephemeral flow characteristic exhibited by the stream section is strongly tied to area's rainfall regime (seven months dry season and five months wet season) alongside other climatic and anthropogenic factors such as high evaporation rates and excessive water withdrawals for municipal uses.

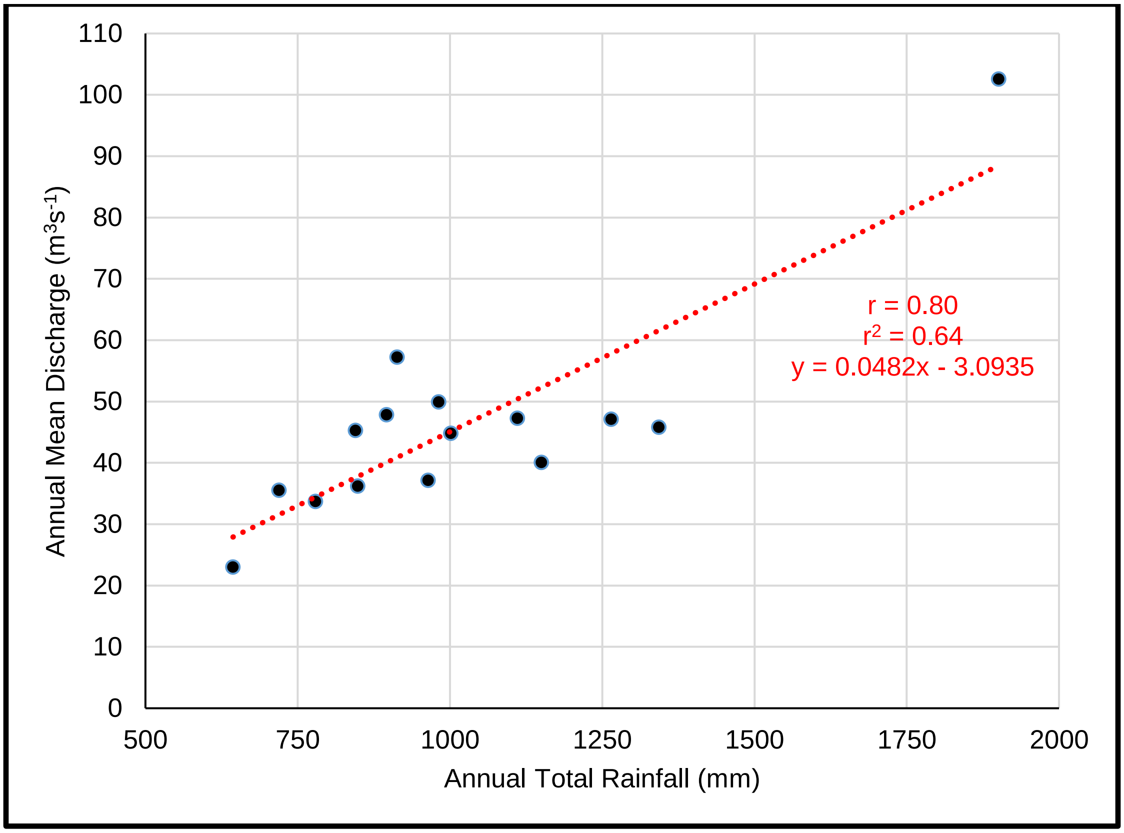

Figure 3: Relationship between Annual Total Rainfall and Annual Mean Discharge

On average, the flow pattern of the stream section was subcritical as defined by a Froude number of 0.57, indicating the dominance of gravitational forces over the flowing water at most times as noted by Charlton (2008). The tranquil pattern of flow observed was an indication of less channel roughness and low flow velocities of the stream section. This observation tallies with the assertion of Nagle (2000) that stream turbulence is a product of channel roughness and flow velocity. Though characteristically subcritical by turbulence, the flow pattern of the stream section apparently influences substantial bed load transport (James, 2018), channel banks erosion, meandering behaviour and lateral channel migration at several times (Yonnana *et al*, 2020).

Both stream bed shear stress and specific stream power are hydraulic parameters that define the work capability of a stream, most especially in terms of sediment detachment, entrainment and transportation. In other words, the parameters determine the erodibility tendencies of the stream. Results showed similarities in the trend patterns of the two parameters, yet with varied trend slopes (Figure 4). While the mean stream bed shear stress was increasing at 0.4155 Nm^{-2} $year^{-1}$, the rate of increase of mean specific stream power was higher at 1.3789 Nm^{-2} $year^{-1}$. At these rates substantial erosional and bed load transport processes were possible.

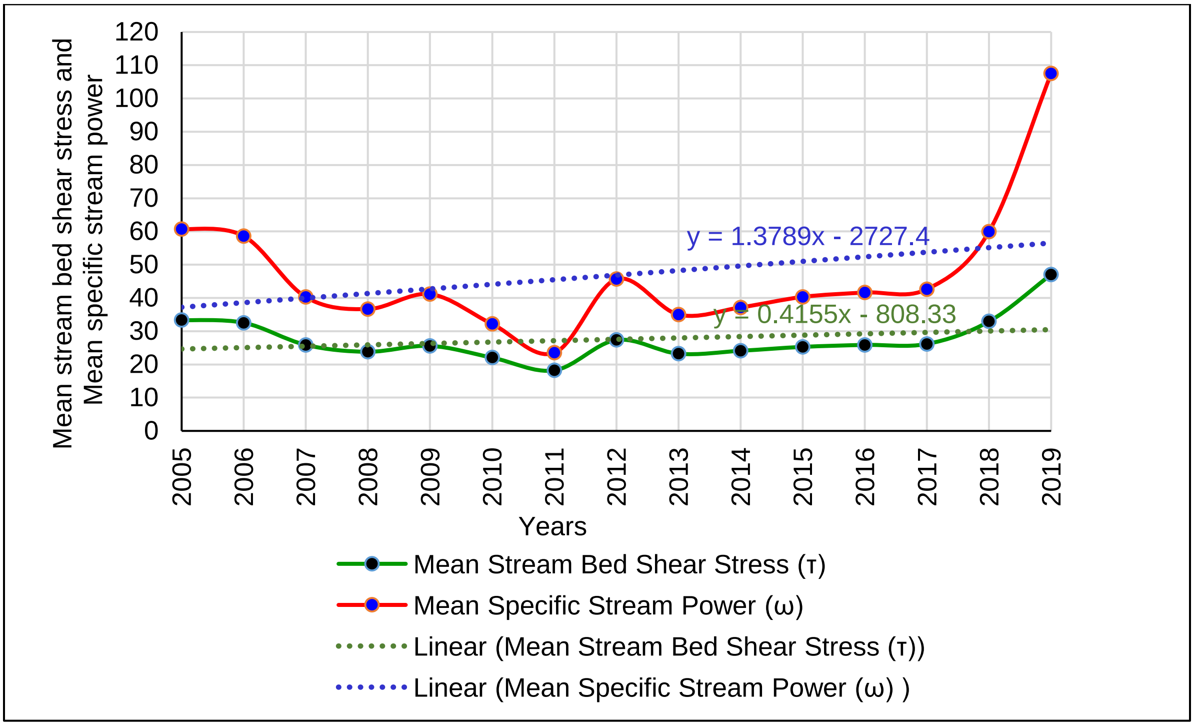

Figure 4: Trends of mean stream bed shear stress and mean specific stream power

Conclusion

This study has analysed the trends in stream flow behaviour of the Mubi subsection of River Yedzeram in Northeastern Nigeria. The study was restricted to a short-term period of 14 years due to inadequacy of relevant data. The findings of the study revealed some considerable positive changes in the hydraulic regime of the Mubi section of River Yedzeram over the last 14 years (2005 through 2019) owing the gradual changes in both climatic and hydraulic variables. Anthropogenic activities such as construction of pavements, urbanization and increasing land cultivation were noted as additional pointers towards increasing runoffs/discharges and sediment load contribution to the stream channel. The resulting effects lead to changes in the hydro-morphologic characteristics of the river section through sediment transport, river bed and banks erosion, stream meandering, channel widening and lateral migration. The implications of these changes include the destruction of riparian land uses as well as the disturbance and pollution of in-stream ecosystems.

Recommendations

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

i. Continual monitoring and data generation are immensely required for long term and more reliable assessment of the stream flow behaviour.
ii. Further studies on the implications of the stream behaviour on its hydro-morphology and effects on adjacent land uses are also required
iii. Standing policies on anthropogenic disturbances of the stream should be established by the appropriate authorities.

References

Aroner, E.R. (2000). WQHYDRO Environmental Data Analysis Technical Appendix.

Charlton, R. (2008). *Fundamentals of Fluvial Geomorphology.* New York, Routledge.

Das, S. & Pal, S. (2016). Character and Cardinality of Channel Migration of Kalindri River, West Bengal, India. *International Research Journal of Earth Science,* 4(1); 13-26.

Giardino, J.R. & Lee, A.A. (2011). Rates of Channel Migration on the Brazos River. Final Report Submitted to the Texas Water Development Board.

Harrelson, C.C., Rawlins, C.L. & Potyondy, J.P. (1994). Stream Channel Reference Sites: An Illustrated Guide to Field Technique. *General Technical Report* RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Helsel, D.R. & Hirsh, R.M. (1991). Statistical Methods in Water Resources. *Techniques of Water-Resources Investigations of the USGS* Book 4. Chapter A3.

Hirsch R.M., Slack, J.R. & Smith, R.A. (1982). Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Research*, 18(1); 107-121

Hirsch, R.M., Alexander, R.B. & Smith, R.A. (1991). Selection of Methods for the Detection and Estimation of Trends in Water Quality. *Water Resources Research,* 27(5); 803-813

Huggett, R.J. (2007). *Fundamentals of Geomorphology.* London, Rutledge Francis Taylor Group.

James, T. (2018). Assessment of Bed Load Sediment Transport in the Middle Reaches of River Yedzeram, Mubi, Adamawa State, Nigeria. An unpublished MSc Thesis submitted to the Department of Geography, Adamawa State University Mubi, Adamawa State Nigeria.

Knighton, D. (1998). *Fluvial forms and processes: a new perspective*: Arnold, Hodder Headline, PLC.

Legg, N.T. & Olson, P.L. (2014). Channel Migration Processes and Patterns in Western Washington: A Synthesis for Floodplain Management and Restoration. *Shorelands and Environmental Assistance Program Report, State Department of Ecology publication.* No.14-06-028. https://fortress.wa.gov/ecy/publications/SummaryPages/1406028.html

Lettenmaier, D.P., Conquest, L.L. & Hughes, J.P. (1982). Routine Streams and Rivers Water Quality Trend Monitoring Review. C.W. Harris Hydraulics Laboratory, *Technical Report* No. 75, Seattle, WA.

Leopold, L.B. & Maddock, T. (1953). The hydraulic geometry of stream channels and some physiographic implications, *U.S. Geol. Surv. Prof. Pap*. 252,

Leopold, L.B., Wolman, M.G. & Miller, J.P. (1995). *Fluvial processes in geomorphology*: Courier Dover Publications

Nagle, G. (2000). *Advanced Geography.* Oxford. Oxford University Press.

Pitlick, J. & Cress, R. (2002). Downstream changes in the channel geometry of a large gravel bed river, *Water Resour. Res.,*38(10), 1216, doi:10.1029/2001WR000898,

Scheidegger, A.E. (1987). *Systematic Geomorphology.* New York, Springer-Verlag Wien. Pp133.

Schumm, S.A. (1960). The shape of alluvial channels in relation to sediment type, *U.S. Geol. Surv. Prof. Pap.,* 352B.

Thomas, D.S.G. (2016). *The Dictionary of Physical Geography* (4th Edition). UK, John Willey and Sons Ltd.

Walling, D.E., Owens, P.N., Carter, J., Leeks, G.J.L., Lewis, S., Meharg, A.A. & Wright, J. (2003). Storage of sediment-associated nutrients and contaminants in river channel and floodplain systems: *Applied Geochemistry,* 18; 195–220.

Wilcock, P., Pitlick, J. & Cui, Y. (2009). Sediment transport primer: Estimating bed-material transport in gravel-bed rivers. *General Technical Report. RMRS-GTR-226. Fort Collins. CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station*. pp. 78.

Williamson, P., Ogunyoye, F., Dennis, I., Douglas, J., Hardwick, M., Sayers, P. Fisher, K., Thorne, C. & Holmes, N. (2015). *Channel Management Handbook, Report – SC110002*. Bristol, Environment Agency, www.environment-agency.gov.uk.

Yonnana, E. (2007). Assessment of Channel Morphologic Characteristics of the Middle Course of River Yedzeram, Mubi Northeastern Nigeria. An MSc Geomorphology Thesis submitted to the Department of Geography, Federal University of Technology Yola, Adamawa State Nigeria.

Yonnana, E., Adebayo, A.A. & Mahmud, H. (2008). Assessment of channel banks stability in the middle course of river Yedzeram, Mubi, Adamawa State. *Nigerian Journal of Research and Production.* Enugu; Nigerian Researchers Forum. 13(2); 144-152.

Yonnana, E. & Adebayo, A.A. (2009). A Survey of human activities and their effects on the channel bank-full width of river Yedzeram in North-eastern Nigeria. *Journal of Environmental Sciences*. 13(1); 27-35.

Yonnana, E., Dzarma, M.S. & Oliver, K. (2020). Assessment of Channel Planform Adjustments in the Mubi Section of River Yedzeram, Adamawa State, Northeastern Nigeria. *Jalingo Journal of Social and Management Sciences,* 2(3); 176-193.

Appendix 1: Channel and Hydraulic Geometric characteristics of the studied river section

Manning's n =0.03; Gravitational Acceleration (g)=9.8ms^{-2}; Density of water (ρ)=1000kgm^{-3}

Year	Annual Total Rainfall (mm)	Mean Flow Cross Sectional Depth (m)	Mean Wetted Width (m)	Stream Channel Slope (mm^{-1})	Mean Wetted Perimeter (m)	Mean Cross Sectional Area (m^2)	Mean Hydraulic Radius (m)	Mean Flow Velocity (ms^{-1})	Annual Mean Discharge (m^{3}s^{-1})	Flow Pattern/ Froude Number (F_R)	Mean Stream Bed Shear Stress (Nm^{-2})	Mean Specific Stream Power (Nm^{-2})
2005	1111.00	0.85	30.50	0.004	32.20	25.93	0.81	1.82	47.27	0.63	33.32	60.75
2006	981.80	0.83	33.40	0.004	35.06	27.72	0.79	1.80	49.93	0.63	32.54	58.61
2007	719.60	0.66	34.60	0.004	35.92	22.84	0.64	1.56	35.54	0.61	25.87	40.27
2008	845.00	0.81	36.30	0.003	37.92	29.40	0.78	1.54	45.27	0.55	23.81	36.67
2009	896.00	0.87	34.20	0.003	35.94	29.75	0.83	1.61	47.87	0.55	25.58	41.15
2010	779.50	0.75	30.80	0.003	32.30	23.10	0.72	1.46	33.69	0.54	22.05	32.16
2011	643.80	0.62	28.80	0.003	30.04	17.86	0.59	1.29	23.01	0.52	18.23	23.49
2012	1342.90	0.93	29.50	0.003	31.36	27.44	0.87	1.67	45.80	0.55	27.34	45.64
2013	848.80	0.79	30.40	0.003	31.98	24.02	0.75	1.51	36.19	0.54	23.23	35.00
2014	964.40	0.82	29.40	0.003	31.04	24.11	0.78	1.54	37.16	0.54	24.11	37.16
2015	1001.60	0.86	32.70	0.003	34.42	28.12	0.82	1.59	44.84	0.55	25.28	40.32
2016	1150.40	0.88	28.30	0.003	30.06	24.90	0.83	1.61	40.08	0.55	25.87	41.64
2017	1265.00	0.89	32.50	0.003	34.28	28.93	0.84	1.63	47.13	0.55	26.17	42.63
2018	913.30	0.84	37.40	0.004	39.08	31.42	0.80	1.82	57.22	0.63	32.93	59.97
2019	1900.90	1.20	37.40	0.004	39.80	44.88	1.13	2.28	102.55	0.67	47.04	107.48