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Modeling Sediment Yield in the Nun River using Sediment Dating Model

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Abstract

The presence of sediment deposition and erosion in the Nun River significantly impacts water quality. While sediment deposition fosters habitats for aquatic life, excessive sediment can lead to pollution and turbid water, hampering photosynthesis and endangering organisms. Conversely, insufficient sediment diminishes habitat availability for bottom-dwelling organisms. This study aims to model sediment yield and river bank erosion in the Nun River Basin. For sediment yield modeling, twenty-one core samples were gathered from three stations at depths ranging from 5 to 35 meters using Uwitec Triple sediment cutter. These samples underwent laboratory processing for sediment particle size analysis and textural examination. The activity of excess Pb-210 atmospheric deposition was assessed with an alpha spectrophotometer to determine sediment age using Goldberg's constant flux model. This model assumes a constant ^{210}*Pb flux to sediment over time with variable sedimentation rates. Results from the Pb-210 sediment dating model indicated a consistent decrease in excess Pb-210 concentration with increasing depth. Sediment accumulation rates remained stable until 1990, where a significant increase 0.023* $g/cm^2.y^{-1}$ *in 1970s to 0.16* $g/cm^2.y^{-1}$ *in 2002 was observed, possibly due to flood events in 1987, 1991, and 1994. Sediment accumulation rates fluctuated until 2016, with the highest rate of 0.516* $cm\ y^{-1}$ *recorded in 2013. Extrapolating from the model, a constant 40% annual increase in sedimentation rate could lead to significant sedimentation rate of 4.23* $cm\ y^{-1}$ *by 2030, potentially resulting in floods in the Nun River vicinity.*

Keywords: *Soil erosion, Sediment yield, Nun River, Sedimentation rate, Sediment age, Constant flux model*

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1. INTRODUCTION

Sediment deposition and erosion have significantly impacted the water quality of the Nun River. Elevated levels of heavy metals in both water and sediment samples from the riverbanks indicate a pressing concern. Additionally, fishermen and relevant authorities have reported a substantial decline in the population of aquatic organisms in recent times (Nda *et al*., 2017, Borrelli *et al*., 2021).

Sediment dynamics play a crucial role in shaping river ecosystems and influencing water quality. The Nun River, located in Nigeria, is no exception, facing significant challenges due to sediment deposition and erosion. Understanding the patterns and drivers of sediment yield in the Nun River is essential for effective river basin management and environmental conservation efforts. In recent years, concerns have been raised regarding the declining water quality and ecological health of the Nun River. Increased sedimentation, accompanied by the presence of heavy metals and pollutants, has raised alarms among local communities and environmental authorities (Johnson *et al*., 2023, Raza *et al*., 2021).

Sediment consists of organic and inorganic materials that can be transported by water, wind, or ice (Hicks *et al*., 2011; Kumar, 2019). It naturally occurs in many bodies of water, although human activities can significantly influence its presence (EPA, 2012). Aquatic sediment can be found either suspended in the water or settled on the bed, and it includes clay, silt, sand, gravel, algae, and decomposing organic matter (Wetzel, 2001; Fuller *et al*., 2012). Sediment yield refers to the amount of sediment that passes through a specific section of a river per unit area of the catchment over a unit of time (Dekov *et al*., 1994; Debie and Awoke, 2023). This involves measuring or estimating the quantity of sediment transported over a certain period. Data from Africa show a decreasing trend in sediment yield as the area increases (Araujo and Knight, 2005; Stone and Hilborn, 2002). Human activities such as dam construction, land use changes, deforestation, and dredging impact both sediment load and transport rates (Czuba *et al*., 2011). For instance, dams restrict downstream water flow, reducing sediment deposition while increasing sediment accumulation behind the dam. The quality of water in the Nun River has been significantly impacted by sediment deposition and erosion, leading to an increased concentration of heavy metals in water and sediment samples along its banks (Hicks *et al*., 2011).

Anthropogenic factors significantly alter sediment load and transport rates. Dams, for instance, impede water flow downstream, leading to reduced sediment deposition and increased sediment accumulation behind the dam. Excessive sedimentation, whether natural or human-induced, can harm aquatic habitats and decrease biodiversity (Smith and Brown, 2021; Philips *et al*., 2012). In Nigeria, issues such as deforestation, dam construction, sand filling, and improper waste disposal contribute to alterations in sediment yield and river bank erosion (Czuba *et al.*, 2011). Unfortunately, the lack of comprehensive data makes it challenging to assess the extent of these changes and their impacts on aquatic ecosystems (Araujo and Knight, 2005; Obinna *et al.*, 2013). While sediment yield and river bank erosion are well-studied in many developed countries, data in Africa, particularly in Nigeria, are limited and often short-term. This study aims to address this gap by providing detailed information on sediment yield and river bank erosion in the Nun River. To comprehensively understand sediment dynamics in the Nun River, this study proposes the utilization of a sediment dating model. Specifically, the sediment dating model offers a precise method for reconstructing sediment history by analyzing isotopic compositions, providing insights into past sedimentation rates and trends. By applying this model, researchers can gain valuable insights into the factors driving sediment yield in the Nun River and anticipate future trends. By examining past sedimentation activities, this study not only contributes to the understanding of sediment dynamics in the Nun River but also enhances existing literature on sediment yield and river bank erosion modeling. Ultimately, the findings will help inform decision-making and conservation efforts in the region.

2. MATERIALS AND METHOD

2.1 Description of Study Area

The study area under investigation is the Nun River located in Bayelsa State, Nigeria. Serving as a tributary of the River Niger in the Niger Delta region, the Nun River spans approximately 195 kilometers in length with an average width of 370 meters, making it the largest river in Bayelsa State (Seiyahboh *et al.*, 2013). It traverses various communities within Bayelsa State, meandering through sparsely populated areas characterized by freshwater and mangrove swamps, as well as coastal sand ridges, before ultimately reaching the Gulf of Guinea, an inlet of the Atlantic Ocean (Uche *et al.*, 2015). The Nun River holds significant importance for local communities, serving as a vital resource for domestic purposes, recreational activities, fishing, and ecological preservation.

However, rapid developmental activities along its course, coupled with human interventions, pose challenges to its ecological balance and sustainability. Moreover, the river is susceptible to flooding, particularly during periods when dams along the Niger River are opened. Dredging operations, both at local and industrial scales, are common practices within the Nun River, further impacting its natural dynamics and sedimentation patterns. Figure 1 illustrates a Landsat image depicting the Nun River's geographical features and surrounding landscape.

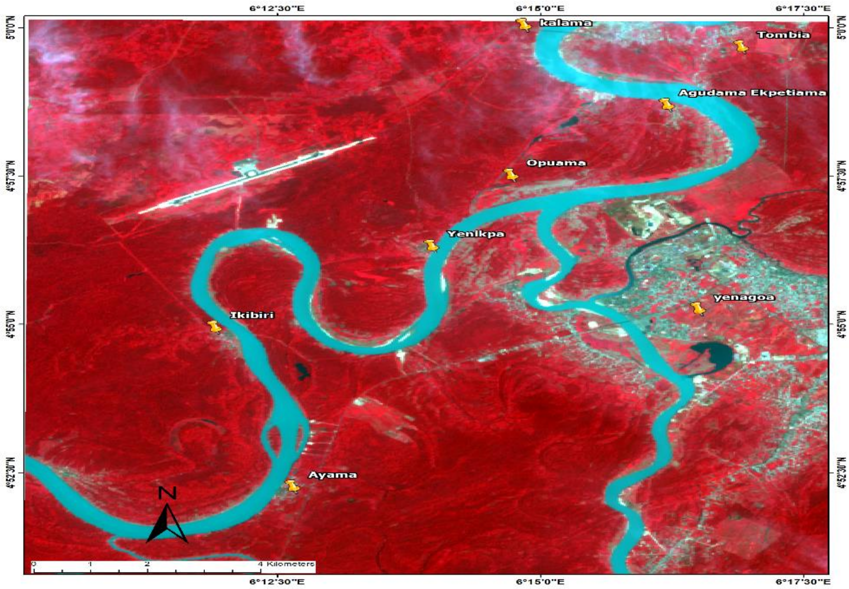

Figure 1: *Landsat Imagery of the Nun River*

2.2 Sample collection

Due to the expenses and intricacy involved in employing the sediment dating model, the researchers opted to gather samples from three distinct locations. Previous research on sediment textures revealed that fine and coarse sands dominate the central channel, whereas marginal areas are primarily composed of silt and clay (Dublin-Green, 1985). A total of twenty-one core samples were obtained from these three stations at various depths ranging from 5, 10, 15, 20, 25, 30 and 35m using Uwitec Triple sediment cutter presented in Figure 2.

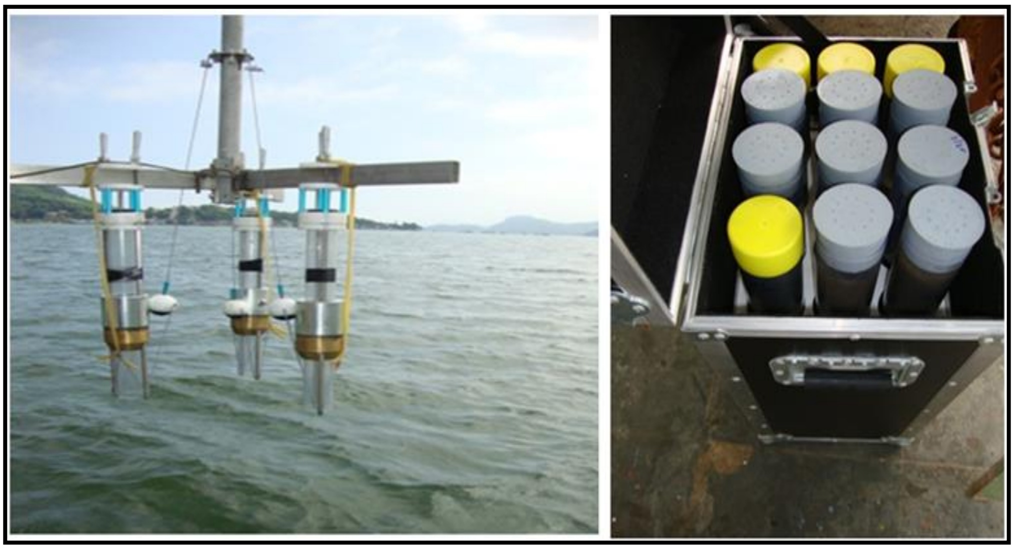

Figure 2: *Uwitec gravity triple sediment corer fitted with plexy glass tubes of 50 cm length and 10 cm internal diameter*

Station 1 (St-1) and Station 2 (St-2) are situated downstream along the Nun River, where there is notable human activity such as navigation, fishing, and various land-based industrial and commercial operations. Meanwhile, the core from Station 3 (St-3) was retrieved from a comparatively less turbulent area on the left bank of the river. Additionally, surface sediment samples were collected from all three stations using a PVC tube with a 10 cm internal diameter. Sampling took place during different months, covering both rainy and dry seasons (July, August, and September 2018, and February and March 2019). These samples were collected a year prior to analysis to allow for the accurate determination of the activity of polonium ^{210}Po (daughter of ^{210}Pb), a nuclide crucial for radiometric measurements used in the conventional method for reconstructing environmental history related to sediment accretion and accumulation.

2.3 Sample preparation and analysis

The sediment cores were taken to the Animal and Environmental Biology Laboratory at the University of Port Harcourt for preparation before radiometric analysis. They were cut into slices every 2cm, with wet sub-samples weighed and then dried at a constant 80°C for 24 hours to ensure thorough drying without altering their composition. The dried samples were reweighed to calculate water content in each layer, and bulk densities were determined from this and particle density. The dried sediment was ground into a fine powder and mixed for further analysis of alpha and gamma emitters. Organic matter content was calculated by the weight difference before and after ignition at 550ºC (Buesseler, 1991; Appleby and Oldfield, 1978; Le Roux and Villeneuve, 1985).

The concentration of ^{210}Pb in sediment samples, both on the surface and at depth, was determined using its daughter ^{210}Po through alpha spectrometry analysis, assuming equilibrium between the two radionuclides. For this analysis, approximately 0.5g of dry sediment spiked with a known activity of ^{209}Po was digested using concentrated nitric and perchloric acids, then treated with hydrochloric acid and dissolved in 80ml of 0.5N HCl solution. 50mg ascorbic acid was added to reduce any iron present. Polonium was deposited onto a copper disc, and alpha-ray spectrometry was performed using silicon surface barrier detectors presented in Figure 3. Chemical recovery values ranged from 60 to 90%. This process determined the total ^{210}Pb present in the sediment samples (Omokheyeke *et al.*, 2014; Baskaran, 2016).

Figure 3: *Alpha-Spectrophotometer (EG&G Ortec)*

2.4 Sediment Dating Models

2.4.1 Determination of Sediment Age

To ascertain the sediment age, the primary equation from Goldberg's 1963 constant flux model was used. This model, later known as the constant rate of supply (CRS) model (Appleby and Oldfield 1983; Benoit and Rozan 2001), is expressed as follows

$$A_t = A_0 \qquad (1)$$

To apply the model, the fundamental assumption that the 210Pb210Pb flux to the sediment remains constant over time, despite potential variations in the sedimentation rate, was utilized. By integrating Equation (1) with respect to either xx or mm, Equation (2) was derived.

$$A\ (x, m) = A_0^{(-\lambda t)} \qquad (2)$$

Where;

A (x, m); is the cumulative residual unsupported or excess ^{210}Pb activity beneath sediment of depth x, or mass m, A_0; is the total unsupported ^{210}Pb activity in the sediment column, λ; is the ^{210}Pb decay constant, 0.03114 year^{-1}, and t; represents time. The age of the sediment at a depth xx or mm is then given by Equation (3).

$$t = \left(\frac{1}{\lambda}\right)\ln\left[\frac{A_0}{A\ \ x,\ \mathrm{m}}\right] \qquad (3)$$

To verify the outcomes of the CRS model, the constant initial concentration (CIC) model was utilized. In contrast to the CRS model, the CIC model assumes that the supply of 210Pb210Pb is directly proportional to the sedimentation rate. In this model, the age (*t*) of a sediment layer is determined by its depth (*m*) using

$$t = m/s \tag{4}$$

Where; m; is the mass depth in the core (gm^{-2}) and s denotes the sedimentation rate ($gm^{-2}\ yr^{--1}$).

2.5 Determination of sediment yield

Pb-210 sediment dating models are valuable tools for determining sedimentation rates in rivers, lakes, and creeks. In this study, the model was utilized to assess sediment accretion and accumulation dynamics in the area over the past 20 to 75 years. With the sediment age known, the differential equation of the constant rate of supply was applied to calculate the sedimentation rate as follows:

$$S = I.\frac{A_0}{A_X} \tag{5}$$

Where;

S is sedimentation rate (cm. $year^{-1}$), A_0 is total ^{210}Pb inventory present in sediment samples (surface), A_X is the activity of excess ^{210}Pb at any depth X while I; is radioactive decay constant (0.0311/year)

3. RESULT AND DISCUSSION

Figure 4 presents the correlation between the mean values of excess Pb-210 activities at various depths across different stations.

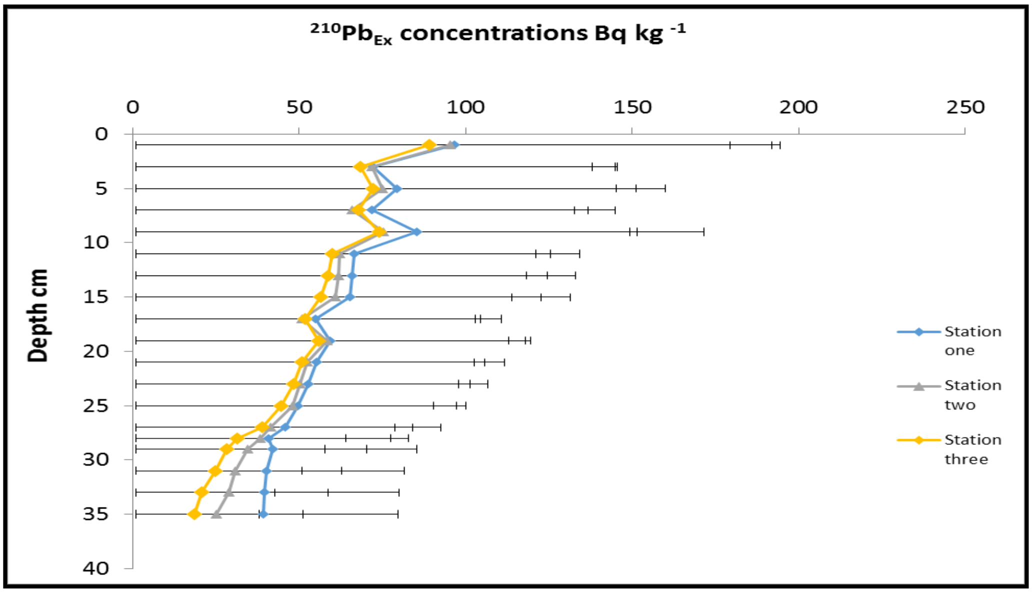

Figure 4: *Mean value of excess Pb-210 activity versus depth*

The findings illustrated in Figure 4 indicate a consistent pattern in the excess Pb-210 activities across different depths at the three stations. This pattern demonstrates a decline in excess Pb-210 concentration as depth increases. These results align with the conclusions drawn by Omokheyeke *et al*. in 2014, as outlined in their research on sediment geochronology and the spatial-temporal distribution of radionuclides in the upper Bonny estuary in Southern Nigeria. Determining sediment ages is crucial for predicting sedimentation rates. In this study, the Constant Rate of Supply (CRS) model, as described in Equation (3), was utilized to estimate sediment ages within the past century. This model leverages the excess 210Pb activities in core samples to provide insights into sediment ages. Applying this model to core samples collected from the Nun River allowed for the determination of sediment ages. The CRS model assumes a relatively uniform input of excess 210Pb to the sediment over time, at least approximately consistent with the core's age. Utilizing this assumption, sediment ages were successfully predicted for each stratigraphic level, with the results depicted in Figures 5, 6, and 7 respectively. It was noted that sediment ages increase with depth, ranging from 0 to 80 years across depths of 0 to 45 cm.

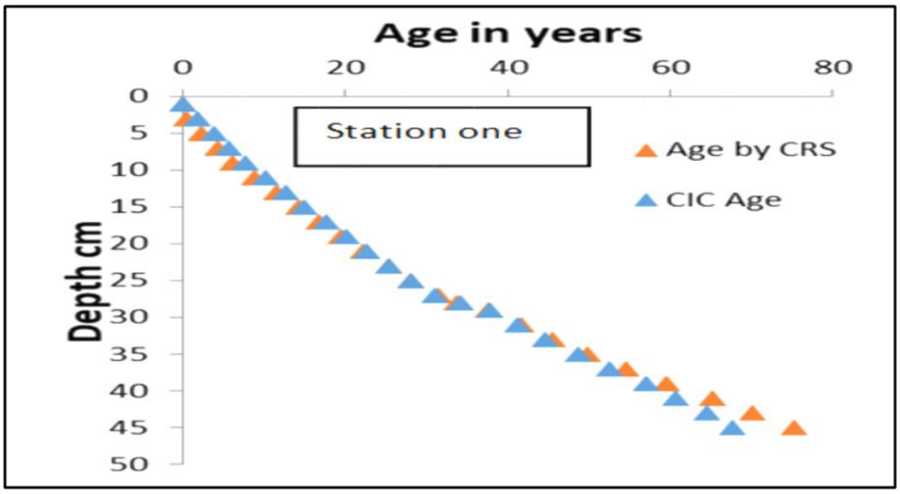

Figure 5: *Sediment age with depth at station one*

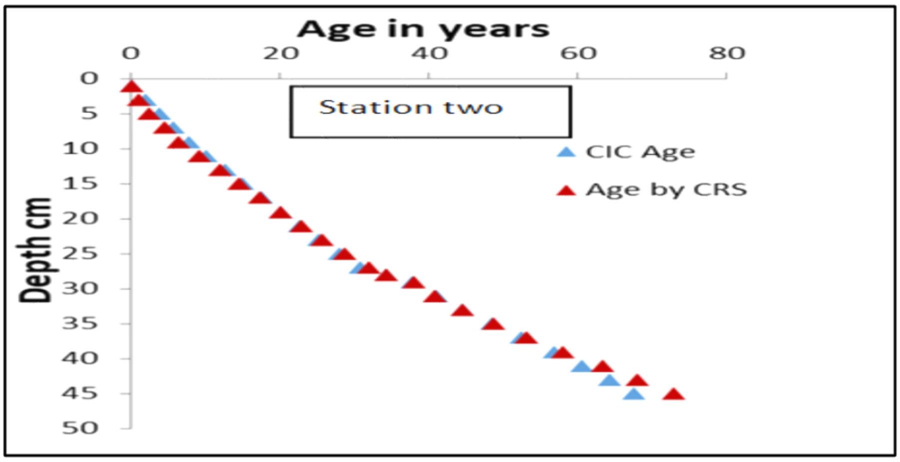

Figure 6: *Sediment age with depth at station two*

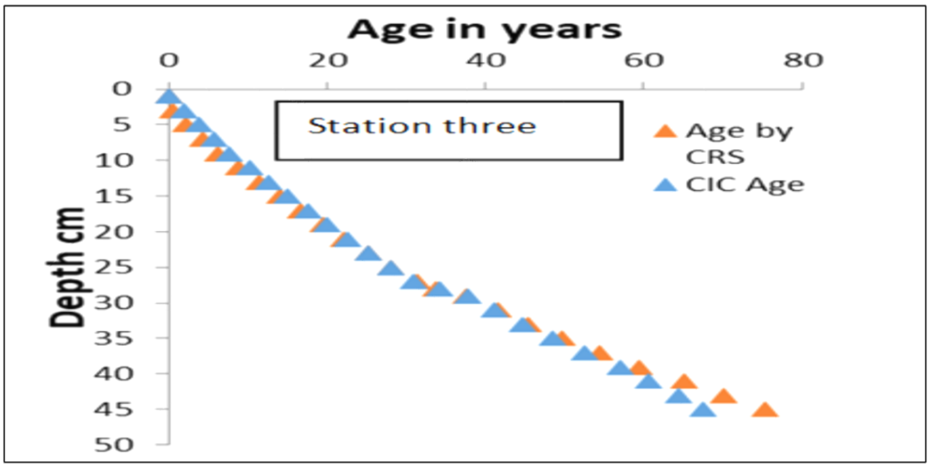

Figure 7: *Sediment age with depth at station three*

Based on the sediment ages determined from Figures 5, 6, and 7, the sedimentation rate was subsequently estimated using the differential equation of the constant rate of supply (CRS) presented in Equation (2.5). The sedimentation rate and sediment mass accumulation for the three studied stations over the period from 1943 to 2018 are shown in Figures 8, 9, and 10, respectively.

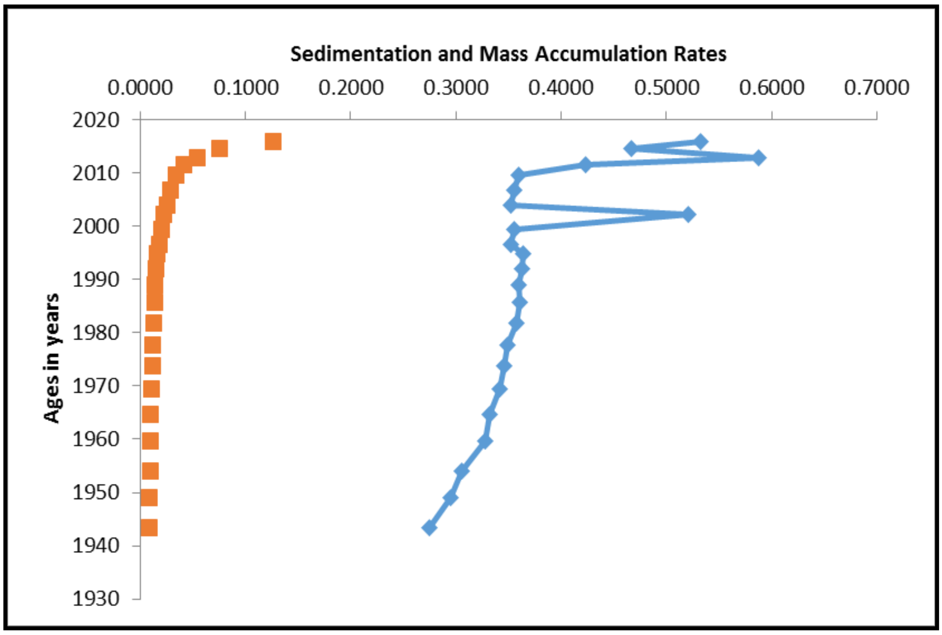

Figure 8: *Sedimentation and Mass Accumulation rates at Station one*

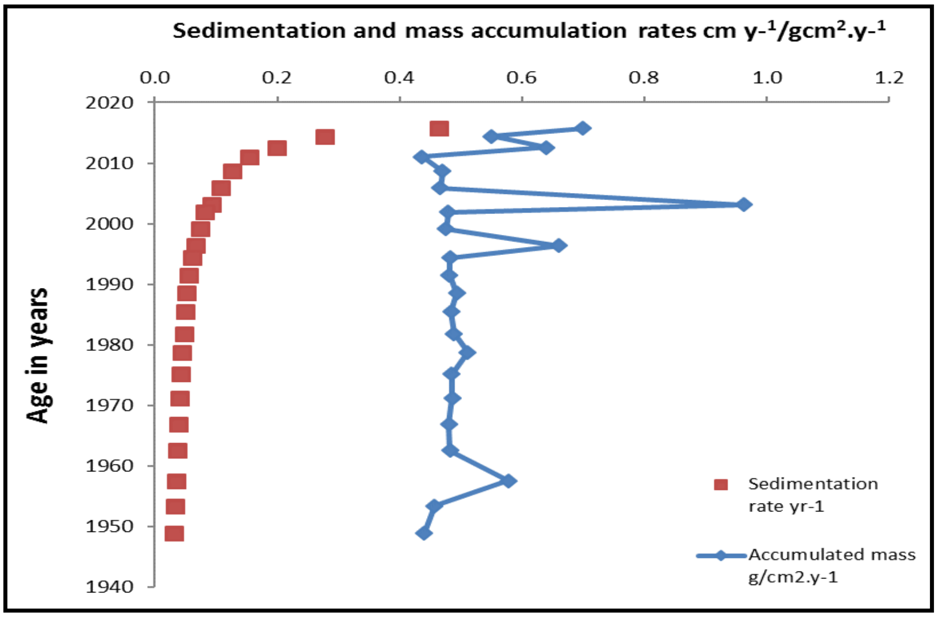

Figure 9: *Sedimentation and Mass Accumulation rates at Station two*

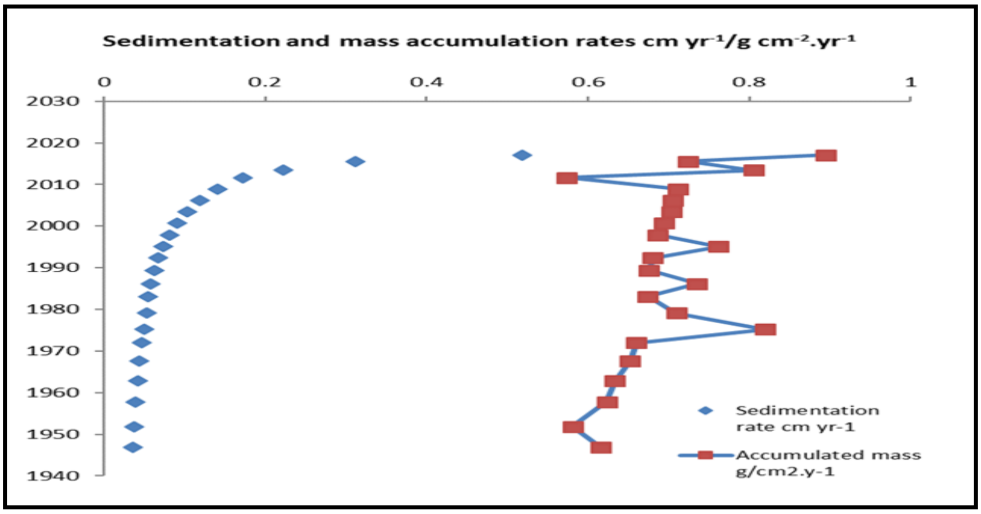

Figure 10: *Sedimentation and Mass Accumulation rates at Station three*

The appearance of different peaks in the plots of Figures 8, 9, and 10 indicates accumulated levels of environmental perturbations in the Nun River during specific years: 2002 and 2013 at Station One; 1958, 1996, 2003, and 2013 at Station Two; and 1975, 1986, 1995, and 2013 at Station Three. At Station One, the sediment accumulation rate remained constant until the 1990s, when it drastically increased from 0.023 g/cm² per year in the 1970s to 0.16 g/cm² per year in 2002, likely reflecting the flood events of 1987, 1991, and 1994. This rate remained unstable until 2016, two years before the samples were collected in 2018. The highest sediment mass accumulation rate in the Nun River was recorded in 2013, as seen in Figures 8, 9, and 10, corresponding to the flood event in 2012.

Based on the results depicted in Figures 8, 9, and 10, it was observed that the highest sedimentation rate occurred in 2013, reaching 0.516 cm per year, marking a 40% increase from the rates observed in the 1990s. Additionally, it was noted that between 1943 and the 1980s, there was only minimal growth in sedimentation rate. Using sediment dating models, it was predicted that maintaining a constant 40% annual increase in sedimentation rate in the Nun River would result in a rate of 4.23 cm per year by the year 2030. This forecast carries serious negative implications, as the accelerated sedimentation would impede water flow and reduce the river channel's carrying capacity, potentially leading to flooding in the Nun River vicinity.

Furthermore, sedimentation rates were observed to range between 0.008 and 0.126 cm per year at Station One, 0.031 and 0.464 cm per year at Station Two, and 0.036 and 0.519 cm per year at Station Three. Mean sedimentation values were calculated at 0.023 cm per year and 0.102 cm per year (before and after 1999) for Station One, 0.05 cm per year and 0.17 cm per year for Station Two, and 0.06 cm per year and 0.19 cm per year for Station Three, respectively. The use of unsupported ^{210}Pb as a chronometer in sediment geochronological studies has been extensively and effectively demonstrated in the works of Perlman (2014), Laissaoui et al. (2008), and Laissaoui et al. (2013).

The findings from our study on sedimentation dynamics in the Nun River carry significant implications for both the river and its surrounding environment. The observed fluctuations in sedimentation rates, particularly during peak years coinciding with flood events, underscore the heightened risk of flooding in the region. For instance, the substantial increase in sedimentation rates recorded in 2013, coupled with historical data indicating a 40% rise from the 1990s, highlights the potential for more frequent and severe flooding events in the future. This poses a direct threat to communities along the riverbanks and underscores the urgent need for improved flood risk management strategies.

Furthermore, the impact of accelerated sedimentation rates extends beyond flood risk to encompass ecological and socioeconomic consequences. The buildup of sediment can disrupt river ecosystems by smothering benthic habitats and altering water quality, as evidenced by the observed fluctuations in sediment accumulation dynamics at different stations along the river. For example, the significant increase in sediment mass accumulation rate in 2013, coinciding with a flood event, suggests potential disruptions to aquatic life and habitat integrity. These ecological impacts can have cascading effects on local biodiversity and ecosystem services, highlighting the need for ecosystem-based approaches to river management.

4. CONCLUSION

In this study, we employed Pb-210 sediment dating models to analyze sedimentation rates in the Nun River over a significant period, from 1943 to 2018. Our findings reveal notable fluctuations in sedimentation rates, with peak occurrences coinciding with specific environmental perturbations, particularly flood events. The observed increase in sedimentation rates, particularly in recent years, underscores the dynamic nature of sedimentary processes in the river system. Furthermore, our analysis highlights the potential implications of accelerated sedimentation rates, including the reduced water carrying capacity of the river channel, which may exacerbate the risk of flooding in the surrounding areas.The projection of a significant increase in sedimentation rate by 2030 underscores the importance of proactive measures to mitigate the adverse effects on river ecosystems and surrounding communities. The study contributes to the understanding of sediment dynamics in river systems, particularly the Nun River, through the application of Pb-210 sediment dating models. Our investigation provides valuable insights into the temporal variability of sedimentation rates and their relationship to environmental factors, shedding light on previously unexplored aspects of sedimentation dynamics in the region. In conclusion, our study highlights the multifaceted implications of sedimentation dynamics in the Nun River basin, ranging from increased flood risk and ecological disruption to infrastructure challenges and socioeconomic consequences. By recognizing and addressing these implications, stakeholders can work towards more sustainable and resilient management of the river and its surrounding environment, ensuring the well-being of both human and ecological communities for generations to come.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Appleby, P. G. and Oldfield, F. (1983). The assessment of 210Pb data from sites with varying integrated formulation and classification of dating models. *Geochimica et Cosmochimica Acta*, 82, 183–200.

[2] Araujo J.C. and Knight, D.W. (2005) A review of the measurement of sediment yield in different scales. *Rem: Rev. Esc. Minas*, 58 (3), 12-23

[3] Baskaran, M., 2016. Dating of Biogenic and Inorganic Carbonates Using ^{210}Pb-^{226}Ra Disequilibrium Method: A Review. In Baskaran, M. (ed.),

Handbook of Environmental Isotope Geochemistry. *Berlin/Heidelberg: Springer*, 789–809.

[4] Benoit, G., and Rozan, T. F., (2001). ^{210}Pb and ^{137}Cs dating methods in lakes: a retrospective study. *Journal of Paleolimnology*, 25, 455–465.

[5] Borrelli, P., Alewell, C., Alvarez, P., Anache, J.A.A., Baartman, J., Ballabio, C., Bezak, N., Biddoccu, M., Cerda, A. and Chalise, D. (2021). Soil erosion modelling: A global review and statistical analysis. *Sci. Total Environ.,* 780, 146494.

[6] Buesseler, K. O. (1991). Depth distributions of thorium isotopes in the northeast Pacific Ocean. *Earth and Planetary Science Letters,* 104(2-4), 364-381. DOI: 10.1016/0012-821X (91) 90203-Q

[7] Czuba, J. A., Magirl, C. S., Czuba, C. R., Grossman, E. E., Curran, C. A., Gendaszek, A. S., and Dinicola, R. S. (2011). Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data Sediment Load from Major Rivers into Puget Sound and its Adjacent Waters. *USGS Fact Sheet 2011–3083. Tacoma, WA: U S Geological Survey.*

[8] Debie, E. and Awoke, Z. (2023); Assessment of the effects of land use/cover changes on soil loss and sediment export in the Tul Watershed, Northwest Ethiopia using the RUSLE and InVEST models. *Int. J. River Basin Manag.,* 1–16.

[9] Dekov, V.M., Komy, Z., Araujo, F., Put, V.A. and Grieken V.R. (1994). Chemical composition of sediments, suspended matter, river water and ground water of the Nile (Aswan-Sohag Traverse). *Science of Total Environment*, 201(3), 195-210

[10] Dublin-Green, C.O. (1985). Some textural characteristics and organic matter contents of recent sediments in the Bonny Estuary, Niger Delta. *Technical Paper* N° 67. ISBN: 978-2345-069.

[11] EPA. (2012). Channel Processes: Bed load Transport. In Water: Science and Technology. Retrieved from:

http://water.epa.gov/scitech/datait/tools/warsss/bedload.cfm

[12] EPA. (2014, February). Sediments. In Water: Pollution Prevention and Control. Retrieved from *http://water.epa.gov/polwaste/sediments/ [2016 -5 - 3]*

[13] Fuller, I.C., Richardson, J.M., Basher, L., Dykes, R. C. and Vale, S. S. (2012). Responses to river management? Geomorphic change over decadal and annual timescales in two gravel-bed rivers in New Zealand. In: Molina DA ed. River channels: types, dynamics and changes. New York, Nova Science. 137-164

[14] Hicks, D.M., Shankar, U., McKerchar, A.I., Basher, L., Lynn, I., Page, M. and Jessen M (2011). Suspended sediment yields from New Zealand rivers. *Journal of hydrology, New Zealand*, 50(1), 81-142.

[15] Johnson, A., Smith, B. and Davis, C. (2023). Assessing sedimentation impacts on water quality in the Nun River, Nigeria. *Environmental Monitoring and Assessment*, 155(2), 123-135.

[16] Kumar, S. (2019). Geospatial approach in modeling soil erosion processes in predicting soil erosion and nutrient loss in hilly and mountainous landscape. Remote Sens. *Northwest Himal. Ecosyst.,* 355–380.

[17] Laissaoui A., Mas, J.L., Hurtado, S., Ziad, N., Villa, M. and Benmansour, M. (2013). Radionuclide activities and metal concentrations in sediments of the Sebou Estuary, NW Morocco, following a flooding event. *Environmental Monitoring and Assessment,* 185(6), 5019–5029, DOI 10.1007/s10661-012-2922-4.

[18] Laissaoui, A., Benmansour, M., Ziad, N., IbnMajah, M., Abril, J.M. and Mulsow, S. (2008). Anthropogenic radionuclides in the water column and a sediment core from the Alboran Sea: Application to radiometric dating and reconstruction of historical water column radionuclide concentration. *Journal of Paleolimnology,* 40(3): 823–833, DOI 10.1007/s10933-008-9201-y.

[19] Le Roux, G. and Villeneuve, J. P. (1985). Determination of plutonium and americium isotopes in sediments by alpha-spectrometry: a review. *Talanta,* 32(5), 373-380. DOI: 10.1016/0039-9140(85)80127-0

[20] Nda, N., Adnan, M. S., Ahmad, K. A., and Jimoh, O. D. (2017). Erosion, Sediment transport and Sedimentation in Rivers and Dams. *Water and Environmental Issues*, 1, 119–147.

[21] Obinna, C.D.A, Peter C.N. and Elijah S.E. (2013). Long Term Assessment and Mapping of Erosion Hotspots in South East Nigeria FIG Working Week 2013 Environment for Sustainability Abuja, Nigeria, 6 – 10 May 2013

[22] Omokheyeke O., Sikoki F.D., Abdelmourhit L., Akpuluma D., Onyagbodor P., Benkdad, A. and Benmansour, M. (2014). Sediment Geochronology and spatio-temporal and vertical distributions of Radionuclides in upper Bonny estuary (South Nigeria). *Geochronometria*, 41(4), 369-376

[23] Perlman, H. (2014). Sediment and Suspended Sediment. In The USGS Water Science School. Retrieved from *http://water.usgs.gov/edu/sediment.html*

[24] Philips, C., Marden, M. and Basher, L. (2012). Plantation forest harvesting and landscape response - what we know and what we need to know. *New Zealand journal of forestry*, 56 (4), 4-12.

[25] Raza, A., Ahrends, H., Habib-Ur-Rahman, M. and Gaiser, T. (2021). Modeling approaches to assess soil erosion by water at the field scale with special emphasis on heterogeneity of soils and crops. *Land,* 10, 422.

[26] Seiyaboh, E.I., Inyang, I.R. and Gijo, A.H. (2013). Environmental Impact of Tombia Bridge Construction Across Nun River in Central Niger Delta, Nigeria. *The International Journal of Engineering and Science (IJES)*, 2 (11), 32-41

[27] Stone, R. P. and Hilborn, D. (2002). Universal Soil Loss Equation (USLE). Factsheet. Ministry of Agriculture, Food and Water Resources, Ontario, Eng. Geol. and Environ., 57.

[28] Uche, A.O, Sikoki, F.A. and Konya, R.S. (2015). Biological and Chemical Changes Associated with the exposure of Cyprinid Fishes to Some oil field Chemicals in the Niger-Benue River Systems. SPE-178309-MS

[29] Wetzel, R. G. (2001). Limnology: Lake and River Ecosystems (3rd ed.). San Diego, CA: Academic Press.