Application and Assessment of Nature-Based Solution (Bamboo) as a Low-Cost Management Strategy for Gully-Impacted Sites in Anambra State, Nigeria

[1*]Samuel Oji Iheukwumere, [2]David C. Onuoha, [2]Chinomso Ukah

*[1]Department of Geography and Meteorology, Nnamdi Azikiwe University, Nigeria.
[2]Department of Environmental Management, Nnamdi Azikiwe University, Nigeria.
*Corresponding author: so.iheukwumere@unizik.edu.ng
*Orcid: 0000-0002-5563-6175
DOI: https://doi.org/10.5281/zenodo.20464763

Abstract

Gully erosion represents one of the most severe environmental challenges in southeastern Nigeria, particularly in Anambra State, where intense rainfall, fragile soil structure, and anthropogenic activities accelerate land degradation. Conventional erosion control measures such as concrete retaining walls and engineered drainage systems are often expensive and difficult to implement in rural communities. This study evaluates the effectiveness of bamboo as a low-cost and locally available material for stabilizing gully-impacted sites. Using an experimental method, bamboo was applied in two forms: as infiltration pipes to channel surface runoff into the soil and as crib/retaining walls to reduce channel expansion and erosive force. Field measurements were conducted at the control point and the bamboo-installed point (treatment) to determine changes in rainwater runoff flow rate, infiltration capacity, and gully channel expansion rate. Statistical analysis using paired sample comparison indicated a significant reduction in runoff flow rate (32.7% reduction) after the introduction of bamboo infiltration pipes, while infiltration rates increased considerably (124.7% increase). Similarly, the installation of bamboo crib walls resulted in a measurable reduction of 53.2% in channel expansion and erosivity. The results demonstrate that bamboo-based interventions can effectively reduce surface runoff, enhance infiltration, and stabilize gully walls. The study concludes that bamboo offers a sustainable, affordable, and environmentally friendly strategy for gully erosion control in vulnerable areas of Anambra State and similar tropical environments. Government agencies and affected communities should promote bamboo-based erosion control methods in erosion-prone areas of the state. Bamboo is easily sourced, and early implementation of control measures would forestall further damage and destruction usually associated with gully-impacted sites.

Keywords: *Gully management, bioengineering, bamboo application, bamboo crib wall, soil stabilization.*

INTRODUCTION

Gully erosion is a major environmental and socio-economic problem in southeastern Nigeria. The phenomenon has led to severe land degradation, destruction of infrastructure, displacement of communities, and loss of agricultural land. Among the states most affected is Anambra State, where high rainfall intensity, sandy soils, and poor land management practices contribute significantly to gully formation and expansion. The region experiences intense rainfall associated with the West African monsoon system, resulting in high surface runoff that accelerates soil detachment and channel incision. Egbuna, Unachukwu and Alom (2024), noted the most common cause of erosion in the area is the relatively uniform loss of the soil surface by excess runoff. Traditional engineering solutions such as concrete retaining walls, drainage channels, and gabion structures are commonly used to stabilize gullies. However, these approaches are often costly and difficult to maintain in many developing regions. In Anambra State, gully erosion presents a serious environmental challenge. One that has defied several solutions, gulping millions of naira which could have been used for other economic, environmental, and health concerns. In addition to the huge property loss and environmental impact, lives have been reportedly lost. The devastating impact of gully erosion in Anambra State has been reported by Eleke (2016); Obi and Okekeogbu (2017); Obianeri (2023); Egbuna, Unachukwu, and Alom (2024).

Obianeri (2023) reported that several buildings, structures, and roads have been destroyed, while over 100,000 persons have been displaced by the menace of gully erosion ravaging communities in Anambra State. This may not stop soon without low-cost measures to halt the rapid growth of gullies in the State. Onuchukwu and Odesa (2024) observed that the average gully progression rate within Agulu-Nanka-Oko erosion sites in the rainy season is 6.55 and 4.5 meters for the dry season. The Sun (2022, October 2) reported that gullies and areas exposed to erosion in the South East tripled from about 1.33 per cent (1,021square km) in 1976 to about 3,7 per cent (2,820 square km) in 2006. Ogbuefi and Ijeomah (2018) revealed that gully erosion in the State has seriously led to loss of farmland, soil fertility and agricultural productivity (38.8%), loss of building and fenced properties (16.5%), involuntary human migration (11.2%), traffic congestion (8.9%), siltation of water bodies (8.0%), ground water pollution (6.2%) and loss of lives (5.4%). In simple terms, the earlier a low-cost, community-implementable solution is discovered, the better. This will stem the losses incurred by government, organizations, and individuals as a result of the gullies. This research will tend towards finding a solution rather than the myriad of works which focused on causes, quantification, impact assessment and lithology.

Though Onwuka and Onuoha (2020) and Okoye et al (2022) applied a chemical stabilization approach in their studies in order to establish its effectiveness and applicability in gully management in the study area. They excluded bioremediation or nature-based measures which have been severely recommended by researchers including Obi and Okekeogbu (2017); Ezeobi, Okolo and Odoh (2023) and Egbuna, Unachukwu, and Alom (2024). Nature-based solutions are increasingly recognized as sustainable alternatives for erosion control. One promising material is bamboo, a fast-growing plant widely available in tropical regions. Bamboo possesses high tensile strength, flexibility, and resistance to environmental stress, making it suitable for structural and soil stabilization purposes. Bamboo has been used in slope stabilization, bioengineering structures, and water control systems in various parts of Asia and Africa, as seen in the works of Puno and Marin (2017) and Tardio et al (2018). However, limited empirical studies exist on its application in controlling gully erosion in southeastern Nigeria. This study, therefore, investigates the effectiveness of bamboo as a low-cost erosion control strategy in gully-impacted sites in Anambra State.

MATERIALS AND METHODS

Study Area

Anambra State lies between latitude 5˚ 42′ N and 6˚ 47′N and longitude 6˚ 37′ E and 7˚ 23′ E. The state has 21 local government areas. The study area lies within the tropical region, and its boundaries are formed by Delta State and Edo State to the west, Imo State and Rivers State to the south, Enugu State to the east, and Kogi

State to the north. The area is influenced by two climatic seasons: the dry and wet seasons. The wet season starts around April and ends in November, with a break in August, and the average annual rainfall is about 1800 mm. The dry season lasts from November to April. Anambra State is underlain by sedimentary formations of varying types and ages. Vegetation cover in many affected areas has been reduced due to urban expansion, agricultural activities, and infrastructure development, thereby increasing susceptibility to erosion. Aguleri, a town in Anambra East LGA, is located on Latitude: 6° 19' 60.00" N Longitude: 6° 52' 59.99" E (Figure 1).

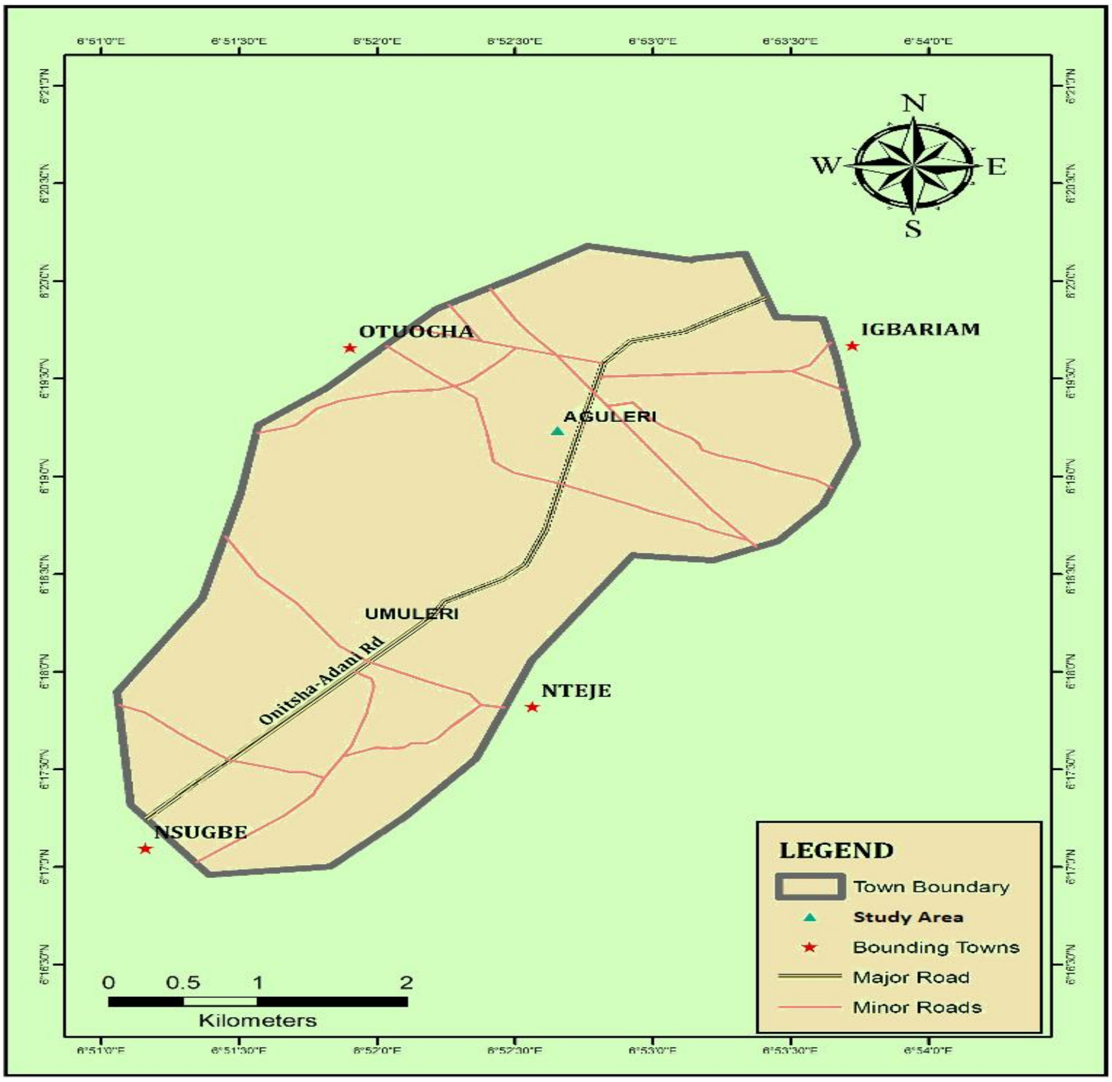

Figure 1: Study Area Map
Adapted from Onyeka, Ezezim, and Okpoko (2021)

This study adopted the experimental method of research involving two major bamboo applications over a period of three months from August to October. First, the insertion of perforated 30 to 40cm long bamboo hollow culms into the soil. The length was considered long enough to convey runoff water into the subsoil. The bamboo culms were inserted vertically into the soil along runoff pathways to redirect surface water into subsurface layers. Second, the construction of crib walls. Bamboo poles were arranged in crib wall formations along gully walls and channels to reduce erosive forces and stabilize soil. Monitoring and collection of data covered data on surface runoff flow rate, soil infiltration rate, channel width, channel depth, and channel expansion rate. Measurements were taken before and after bamboo insertion points for runoff rate and at the insertion point for infiltration rate. Measurements for the crib wall section were taken at the bamboo installation point and after the bamboo installation point (used as control). Data collected were analysed using descriptive and inferential statistics such as mean, standard deviation, percentage reduction analysis and Paired sample t-test.

RESULTS AND DISCUSSION

Runoff Flow Rate Reduction

In consideration of the contribution of runoff flow rate to the formation of gullies, the first objective was based on assessing the effectiveness of bamboo infiltration pipes in reducing rainwater runoff flow rate. From the dataset and percentage reduction analysis (Tables 1 and 2), there was a noticeable decrease in runoff flow rate after the installation of bamboo infiltration pipes. Bamboo pipes redirected surface water into subsurface layers, thereby reducing the amount of water flowing across the gully surface. This reduction in runoff significantly lowered the erosive energy of flowing water.

Table 1: Runoff Flow Rate

Rainfall Event	*Runoff Flow Rate Before installation point (m^3/s)*	*Runoff Flow Rate After installation point (m^3/s)*
1	0.46	0.31
2	0.52	0.36
3	0.49	0.33
4	0.55	0.38
5	0.51	0.34
6	0.58	0.40
7	0.47	0.30
8	0.53	0.35
9	0.50	0.34
10	0.56	0.37

Source: Authors' field Analyses

Table 2: Percentage Reduction in Runoff Flow Rate

Parameter	*Before*	*After*
Mean	0.517	0.348
Standard Deviation	0.038	0.032
Percentage Reduction	—	**32.7%**

Source: Authors' field Analyses

The paired t-test result for runoff flow rate (Table 3) shows a t-value of 9.21 with a p-value less than 0.001, indicating a highly statistically significant difference between the runoff flow rates measured before and after the installation of bamboo infiltration pipes. A t-value of 9.21 suggests that the difference between the two sets of measurements is very large relative to the variability within the data. The p-value (<0.001) means that the probability that this difference occurred by random chance is less than 0.1%. Since this value is far below the commonly accepted significance level of 0.05, there is a difference in runoff flow rate before and after the bamboo intervention.

Table 3: Runoff Reduction

Variable	*df*	*t-value*	*p-value*
Runoff flow rate	9	9.21	<0.001

Source: Authors' field Analyses

This result indicates that the installation of bamboo infiltration pipes significantly reduced the runoff flow rate at the study site. The bamboo structures functioned by channelling excess surface water into the soil, thereby reducing the volume and velocity of water flowing into the gully channel. From an erosion control perspective, the reduction in runoff flow rate is important because lower runoff velocity reduces the erosive power of flowing water, which helps prevent soil detachment, sediment transport, and further expansion of gully channels.

Increase in Soil Infiltration

Objective two evaluates the changes in infiltration rates at the treatment (bamboo installation) point and control points. Table 4 shows the measurements and visibly higher figures for the treatment point. The percentage increase in Table 5 shows a remarkable 124.7% improvement in soil infiltration.

Table 4: Soil infiltration measurement

Measurements	*Control (mm/hr)*	*Treatment (mm/hr)*
1	18	42
2	21	46
3	19	44
4	17	40
5	22	48
6	20	45
7	18	41
8	23	49
9	21	47
10	19	43

Source: Authors' field Analyses

Table 5: Percentage Increase for Soil Infiltration

Parameter	*Control*	*Treatment*
Mean	19.8 mm/hr	44.5 mm/hr
Standard Deviation	1.87	3.02
Percentage Increase	—	**124.7%**

Source: Authors' field Analyses

Table 6: Infiltration Increase

Variable	*df*	*t-value*	*p-value*
Infiltration rate	9	12.87	<0.001

Source: Authors' field Analyses

The paired t-test result (Table 6) for infiltration rate shows a t-value of 12.87 with a p-value less than 0.001. This indicates that there is a highly statistically significant difference between the infiltration rates measured at the control and treatment points. A t-value of 12.87 is very large, meaning that the difference between the two sets of measurements is far greater than what would be expected by random variation alone. The p-value (<0.001) means that the probability that this observed difference occurred by chance is less than 0.1%. Since this value is far below the conventional significance level of 0.05, there is an evident difference in infiltration rates, with the treatment point boosting a higher figure. This result therefore confirms that the installation of bamboo infiltration pipes significantly increased the soil infiltration rate at the study site. The bamboo pipes created vertical channels that allowed runoff water to penetrate deeper into the soil profile rather than flowing over the surface. By implication, more water infiltrated into the soil through the bamboo. Thereby reducing the quantity of surface overflow.

Reduction in Channel Expansion

Objective three was to determine the effect of bamboo crib walls on gully channel expansion and erosivity. Table 7 shows a mean of 0.425 and 0.199 (m/month), translating into 53.2% reduction in the rate of erosivity and expansion. Further analysis using a paired t-test (Table 8) reveals a t-value of 10.44 and a p-value less than 0.001, indicating that there is a highly statistically significant difference between the channel expansion rates measured at the crib wall point and the control point.

Table 7: Channel Expansion Measurements

Measurements	***Control point (m/month)***	***Crib wall Point (m/month)***
1	0.42	0.18
2	0.38	0.17
3	0.45	0.21
4	0.40	0.19
5	0.47	0.23
6	0.41	0.20
7	0.44	0.21
8	0.39	0.18
9	0.46	0.22
10	0.43	0.20
Total	**4.25**	**1.99**
Mean	0.425 m/month	0.199 m/month
Standard Deviation	0.030	0.019
Reduction	—	**53.2%**

Table 8: Channel Expansion

Variable	***df***	***t-value***	***p-value***
Channel expansion	9	10.44	<0.001

Source: Authors' field Analyses

A t-value of 10.44 indicates that the observed difference between the two conditions is very large relative to the variability within the data. The p-value (<0.001) means that the likelihood that this difference occurred due to random chance is less than 0.1%. Since this value is below the standard significance level of 0.05, it can be concluded that there was a difference in channel expansion between the crib wall installation point and the control point. This result therefore demonstrates that the application of bamboo crib walls significantly reduced the rate of gully channel expansion at the study site. The bamboo structures acted as stabilizing barriers, reducing water velocity, trapping transported sediments, and reinforcing the gully walls against further erosion.

DISCUSSION

The observed reduction in runoff flow rate following the installation of bamboo infiltration pipes supports findings that infiltration-based erosion control systems can significantly reduce surface water velocity and sediment transport (Morgan, 2009). As surface runoff travels over the soil, it exerts shear stress on the soil surface, detaching and carrying away soil particles. The erosive power of runoff is significantly amplified as it accumulates more soil particles. This not only increases the volume of sediment being transported but also the abrasive force of the runoff, enabling it to erode the soil more efficiently. Empirical data from the Ethiopian Highlands indicate that surface runoff on steep lands can result in erosion rates exceeding 200 tons per hectare annually, underscoring the critical need for effective soil conservation measures to reduce soil detachment, runoff velocity and increase infiltration capacity of the soil in such regions (Onet et al, 2019; Wang et al, 2024 and Firoozi & Firoozi, 2024). Increased infiltration rates also indicate improved soil permeability and groundwater recharge potential.

Bamboo crib wall structures function similarly to bioengineering stabilization techniques widely used in slope management. The flexibility and tensile strength of bamboo allow it to absorb hydraulic pressure while reinforcing soil structure (Ghavami, 2005). Studies on gully erosion in southeastern Nigeria show that intense rainfall and unconsolidated sandy soils are major drivers of channel expansion (Adetona and Ezezika, 2011). The significant reduction in channel expansion rate recorded in this study suggests that bamboo crib walls effectively reduce erosive energy and trap sediments. Acharya (2020) stated that the introduction of plants inside the bamboo crib wall will not only increase the life of such a wall but also increase the stability of the whole slope in the long run. According to Tardio (2018), bamboo is of high interest for nature and biodiversity protection (and therefore ecosystem restoration) as well as for slope protection and stabilization. Nature-based solutions such as bamboo stabilization are increasingly recommended for sustainable land management because they combine ecological restoration with engineering stability (Liu and Dou, 2022). These approaches are particularly valuable in developing regions where high-cost engineering solutions may be impractical.

CONCLUSION

This study assessed the application of bamboo as a low-cost erosion control strategy in gully-impacted areas of Anambra State, Nigeria. The findings indicate that bamboo infiltration pipes significantly reduce surface runoff and increase soil infiltration rates, while bamboo crib walls effectively limit gully channel expansion. The results demonstrate that bamboo is a practical, affordable, and sustainable alternative to conventional erosion control structures. Adoption of bamboo-based stabilization techniques can help communities mitigate gully erosion while promoting environmentally friendly land management practices. Based on the findings of the study, it is recommended that:

1. Government agencies and affected communities should promote bamboo-based erosion control methods in erosion-prone areas of the state. Bamboo is easily sourced and early implementation of control measure would forestall further damages and destruction usually associated with gully-impacted sites.

2. Community participation should be encouraged in bamboo planting and maintenance. This will make the sourcing of bamboo easy and readily available when needed.
3. Further studies should evaluate long-term durability and structural performance of bamboo stabilization systems.
4. Integration of bamboo bioengineering techniques with other nature-based solutions should be explored.

Acknowledgement

The authors express their gratitude and do declare that this research was funded by Tertiary Education Trust Fund (TETFund), Nigeria.

References

Acharya, M. (2020). Bamboo Crib Wall: A Sustainable Soil Bioengineering Method to Stabilize Slopes in Nepal. *Journal of Development Innovations*, 4(1). 99-118.

Adetona, O., and Ezezika, O. (2011). Environmental impacts of gully erosion in southeastern Nigeria. *Journal of Soil and Water Conservation*, 66(3), 162–172.

Egbuna, O. K., Unachukwu, S. S., and Alom, A. C. (2024). Gully Erosion Assessment and Management in Anambra State Nigeria. Iconic Research and Engineering Journals, 7(12), 48-55

Eleke, D.C. (2016, October 24). The Menace of Erosion in Anambra. ThisDay news online. Retrieved from: https://www.thisdaylive.com/index.php/2016/10/24/the-menace-of-erosion-in-anambra/

Ezeobi J. U., Okolo N.V., and Odoh C.C. (2023). Extent And Volume of Soil Loss Using RUSLE Model in Agulu – Nanka – Oko and Ekwulobia Gully Erosion Complexes of Anambra State, South Eastern Nigeria. *Environmental Review, Volume 9(2),* 19-33.

Firoozi, A.A., and Firoozi, A.A. (2024). Water erosion processes: Mechanisms, impact, and management strategies. *Results in Engineering*, 24(2024), 103237. https://doi.org/10.1016/j.rineng.2024.103237.

Ghavami, K. (2005). Bamboo as reinforcement in structural concrete elements. *Cement and Concrete Composites*, 27(6), 637–649.

Liu, J., and Dou, Y. (2022). Good Practices on Vulnerable Ecosystem Restoration in China. In *Southern University of Science and Technology* (47-52). Article 10 United Nations Environment Programme.

Morgan, R. P. C. (2009). *Soil Erosion and Conservation*. Wiley-Blackwell, Hoboken.

Nwajide, C. S. (2013). *Geology of Nigeria's Sedimentary Basins*. CSS Press, Lagos Nigeria.

Obi, N.I., and Okekeogbu, C.J. (2017). Erosion Problems and Their Impacts in Anambra State of Nigeria: (A Case of Nanka Community). *International Journal of Environment and Pollution Research*, 5(1), 24-37

Obiadi, I., Nwosu. C.M., Ajaegwu, N., Anakwuba, E., Onuigbo, E., Akpunonu, O. & Ezim, E.O. (2011). Gully Erosion in Anambra State, South East Nigeria: Issues and Solution. *International Journal of Environmental Sciences,* 2(2). 795-805

Obianeri, I. (2023, December 21) Residents lament as erosion ravages 169 Anambra communities. Punch news online. Retrieved from: https://punchng.com/residents-lament-as-erosion-ravages-169-anambra-communities/

Ogbuefi, L.I. and Ijeomah, O.K. (2018). Gully Erosion in Anambra State: Causes, Effects and Management Approach. *Journal of Environmental Sciences and Resources Management*, 10(1). 64-85.

Okagbue, C. O., and Uma, K. O. (1987). Performance of gully erosion control measures in southeastern Nigeria. *Catena*, 14(2), 201–215.

Okoye, O. N. N. Ugbede, F. O., Oli, C. C., Onwukeme, V. I., and Onwuka, S. U. (2022). Chemical Stabilization of Gullies of Nanka and Oko in Anambra State, South-Eastern Nigeria. Journal of Chemical Society of Nigeria, 47(5) 1141 - 1147

Onet, A., Dinca, L.C., Grenni, P., Laslo, V., Teusdea, A.C., Vasile, D.L., Enescu, R.E., and Crisan, V.E. (2019). Biological indicators for evaluating soil quality improvement in a soil degraded by erosion processes. *Journal of Soils and Sediments*, 19(5), 2393-2404, 10.1007/s11368-018-02236-9

Onuchukwu, E. E., and Odesa, G. E. (2024). Investigation of gully progression rate and causes of failed gully control projects in parts of Anambra State, Nigeria. *Tropical Journal of Science and Technology*, 5(1), 1 – 13. DOI: http://doi.org/10.47524/tjst.v5i1.2

Onwuka, S. U. and Onuoha, D. C. (2020). Evaluation of the pre-grouting and postgrouting erodibilities of nanka sand geologic unit causing gully in Anambra state, Nigeria. British journal of environmental sciences, 8(2), 10-17.

Onyeka, A., Ezezim, H., and Okpoko, P. (2021). Impact of Developmental Activities on Archaeological and Cultural Resources in Aguleri and Umueri Anambra-State. Journal of Tourism and Heritage Studies, 8(2), 69-82. 10.33281/JTHS20129.2019.2.4.Puno, G. R., and Marin, R. A. (2017). Soil erosion analysis in bamboo-planted sites using paired catchment approach. *Journal of Biodiversity and Environmental Sciences*, 11(5). 415-422.

Tardio, G., Mickovski, S., Fernandes, J., Rauch, H. P, and Acharya, M. (2018). The Use of Bamboo for Erosion Control and Slope Stabilization: Soil Bioengineering Works. DOI: 10.5772/intechopen.75626.

The Sun (2022, October 2). Combating erosion in Anambra. Retrieved from: https://thesun.ng/combating-erosion-in-anambra/

Wang,C., Fu, X., Zhang, X. Wang, X., Zhang, G., and Gong, Z. (2024). Modelling soil erosion dynamic processes along hillslopes with vegetation impact across different land uses on the Loess Plateau of China. *Catena*, 243(2024), Article 108202, 10.1016/j.catena.2024.108202