# Erosion Control Using Bermuda Grass-Lined Channels: A Case Study of South Eastern Nigeria

Samuel O. Ihuoma[1], Kevin N. Nwaigwe[2] & Christopher Nzediegwu[1]

[1]Department of Bioresource Engineering, McGill University, Canada.

[2]Mechanical and Industrial Engineering Department, University of South Africa.

ABSTRACT : South eastern Nigeria has several cities that are ravaged by erosion with many others prone to erosion. The use of concrete channels, though recommended, is cost intensive. However, grass lined channels are cheaper and particularly Bermuda grass is locally in abundance and is neither an economic tree nor a food tree. This study is an investigation on the suitability of this particular grass as lining to designed channels for erosion control. Six experimental channels were developed and lined with Bermuda grass at the erosion runoff plot of Federal University of Technology, Owerri, Nigeria. The channels were 15 m long and 0.8 m wide each, with bed slope ranging from 4 - 6 % and side slopes of 3:1 and 4:1. Results showed that mean soil loss for the channel grade 6% was 0.80 ± 0.08 kg and 1.00 ± 0.09 kg for side slopes 3:1 and 4:1 respectively, mean soil loss for channel grade 5% was 0.72 ± 0.08 kg and 0.60 ± 0.08 kg for side slopes 3:1 and 4:1 respectively, and mean soil loss for channel grade 4% was 0.7 ± 0.7 kg and 0.68 ± 0.05 kg for side slopes 3:1 and 4:1 respectively. One-way ANOVA test showed significant difference ($p < 0.05$) for the different channel grades, with the channel grade of 5% and 4:1 being the most stable to handle the natural concentration of runoff. This outcome validates the use of Bermuda grass as an alternative to concrete – lined channels.

**Keywords:** Grass-lined channels, Bermuda grass, erosion, channel grades, soil loss.



## INTRODUCTION

Soil erosion has been identified as a global environmental problem [1], [2], which threatens the soil resources and the sustainability of natural ecosystems [3]. In Nigeria, erosion poses serious ecological challenge, and constitutes a national hazard, which containment is a prerequisite to national development [4]. While many States in the country are currently under the threats of this phenomenal process, the menace is more predominant in the South-eastern part of Nigeria, where it was recognized as the most threatening environmental hazards [5]. Apart from challenging the sustainability of social and environmental security in the locality, soil erosion creates a major problem on the agricultural land, thereby interfering seriously with mass food production [6].

Underlying geology, extreme meteorological conditions, and intensified human activity, coupled with fragile ecosystems, are considered as the main driver of soil erosion in this region [7], [8]. The challenge is further amplified by climate change, uncontrolled grazing practices, deforestation, farming techniques and mining activities.

Soil moved by erosion carries nutrients, pesticides and other harmful chemicals into rivers, streams and ground water resources. Food crops are the most affected by this development due to the shallow roofing systems. Destruction of farm lands and crops by soil erosion creates problem for the population as the farmers cannot find suitable lands on which to cultivate their crops. Extreme fragmentation of remaining farmland may follow, which often results to over-cropping of available land hence, reducing output, unless soils is being improved. Usually, eroded soils are deposited in water systems leading to pollution and siltation [9], which causes drastic reduction of water volume and quantity, drying up of rivers, water reservoirs and dams, and contamination of streams, with adverse effects on aquatic lives. In case of gully erosion, the land may become submerged and not useful for any purpose. Therefore, the protection of soil resources has been acknowledged as a central objective of environmental policy [3].

Figure 1: Devastating impacts of soil erosion in Southeastern Nigeria [10]

Soil erosion can be controlled by reducing the erosive capacity of the flowing water through structural measures (e.g. check dams) or by increasing the resistance of the soil relative the erosive capacity of the flowing water through vegetative lining [11]. Vegetative control measure is preferable in most cases since it offers more permanent and economic control than structural measures. Vegetation plays a major role in intercepting rainfall, increasing water infiltration, providing mechanical protection by reducing raindrop energy and 'splash' effects, and trapping sediments [12]. Adekalu *et al.* [13] observed that proper selection and management of vegetation can increase surface cover and root energy, improve soil property, and reduce soil erosion. Other benefits of vegetal control of rill erosion are its comparatively low initial cost, less skill requirement in its design and construction, ability not to obstruct the movement of farm implements in the farmland, ability to multiply and improve over the years, as well as its aesthetic advantage when used for rural and urban drainage systems.

A wide range of plants recommended as effective cover plants include; Bermuda grass (*cynodon dactylon*), lespedeza sericea, centipede grass, Kentucky blue grass, buffalo grass, star grass, stubborn grass, etc. [11], [14]. The grasses are resistance to drought, and are used to improve the soil structure, and for stabilizing the channel sections, in order to intercept and divert excess surface runoff for the prevention of gully development. Schwab *et al.* [15] stated that providing properly proportioned channels protected by vegetation is frequently a complete solution to the problem of gully formation. Zhu and Zhang [14] investigated the suitability of grasses for soil bioengineering, and recommended that Cynodon Dactylon is effective in reducing the susceptibility of soil erosion, due to its high root mass density.

Unfortunately, data on available grasses needed to stabilize the channel sections are not readily available in southeastern Nigeria where the menace of soil erosion has continued unabated. This study therefore, investigated the suitability of Bermuda grass for lining erosion control channels. Specifically, it assessed the best combination of bed and side slopes suitable for lining a trapezoidal channel with Bermuda grass.

## Materials and Method

### Study Area

The study was conducted at the erosion demonstration plot of Federal University of Technology, Owerri, Imo state, Nigeria. It lies on Latitude 5°25' N and longitude 7°00' E. Vegetation type in the area is lowland rainforest and mean annual rainfall is between 2,250 - 3,000 mm. Rainy season extends from March to November and the distribution is bimodal having two seasons with peaks in July and September. Dry season extends from November to March. Mean relative humidity is between 70-80% during the dry season and 80-90% during the rainy season. The relief is about 61-100 m above sea level. Geology of the area is Coastal Plain Sand, which consists of cross-stratified loose white or yellow pebble sand with grey sandy clay interceptions [16].

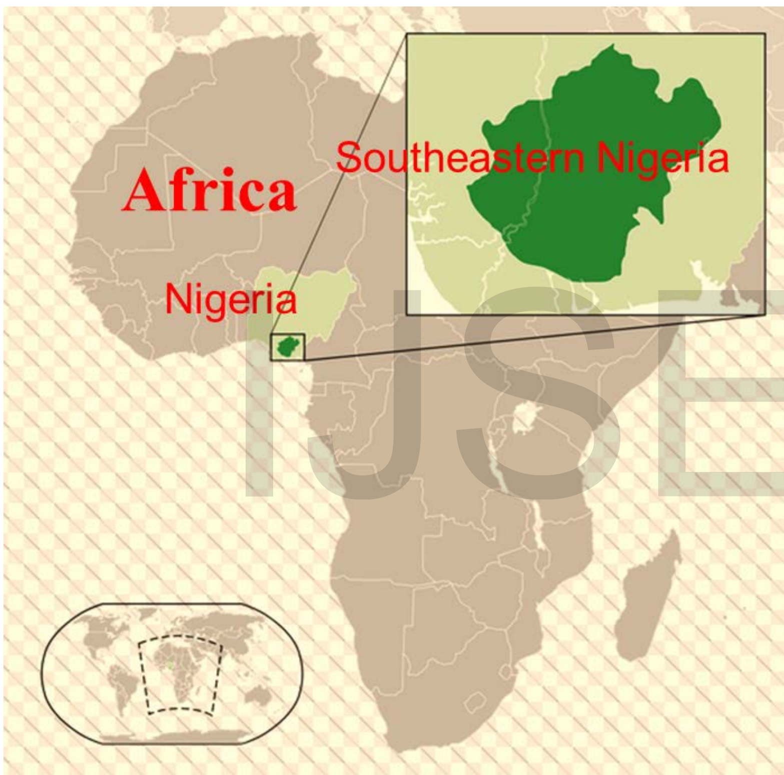




**Figure 2:** Map of Africa showing Southeastern Nigeria.

### Experimental Design

Six (6) trapezoidal channels were designed and constructed along the main land slope and a tail drain provided at the downstream end of the channels. The channels were 15 m long and 0.8 m wide each, with bed slope ranging from 4 - 6 % and side slopes of 1:3 and 1:4. The design of the grass-lined channels was divided into two groups with each group consisting of three (3) different channels, as shown in Table 1. All the channels in group one have the same side slope of 3:1 with bed slope of 4 %, 5 % and 6 %. Similarly, the channels in group two have the same side slope of 4:1 with bed slope of 4 %, 5 % and 6 %. The channels were lined with Bermuda grass, which was chosen because it is abundantly available in the study area.

**Table 1:** Channel groups and dimensions

| Channel dimensions | Group 1 | | | Group 2 | | |
|---|---|---|---|---|---|---|
| Side slopes | | 1:3 | | | 1:4 | |
| Bed slopes | 4% | 5% | 6% | 4% | 5% | 6% |

## Channel Design and Planting details

The factors influencing the selection of Bermuda grass for the study were availability, ease of establishment and suitability to the soil (sandy soil) at the site. Since viable seeds were not available, seedlings (obtained from the agronomy unit of the institution) were used in the experiment. The cross-sectional shape of a vegetated waterway may be trapezoidal, triangular or parabolic. However, broad-bottom trapezoidal channels are preferable because they require less depth of excavation than do parabolic and triangular shapes for the same capacity [17]. Prior to the introduction of the plants into the channels, farmyard manure was incorporated in the soil to enhance fertility. Each of the six channels was independently designed for stability and maximum capacity. The dimensions of the channels were evaluated by method of iteration recommended by Chow [18], Schwab *et al.* [15] and nomographs of United States Soil Conservation Services [19]. Figure 1 shows a cross sectional area of a typical grass-lined channel.

The velocity of flow was obtained from equation (1), while the resistance to flow (Manning roughness coefficient for vegetated waterways) was obtained from equation (2)



$$v = \frac{Q}{A} \quad \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (1)$$

$$n = \frac{R^{3/2} S^{1/2}}{v} \quad \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

Where,

Q is the discharge, $m^3/s$; A is the cross-sectional area of stream flow, $m^2$; V is the velocity of flow, m/s; n is the Manning roughness coefficient; S is the hydraulic slope, m/m; and R is the hydraulic radius [15].

The cross-sectional area, wetted perimeter, hydraulic radius, and top width of the trapezoidal channel were evaluated from equations shown in table 2.

Table 2: Computation of the cross-sections of the channels

ISSN 2229-5518

| Cross-Sectional Area, A ($m^2$) | Wetted Perimeter, P (m) | Hydraulic Radius, R=A/P (m) | Top Width (m) |
|---|---|---|---|
| $bd + md^2$ | $P = b + 2d\sqrt{m^2+1}$ | $\frac{bd + md^2}{P = b + 2d\sqrt{m^2+1}}$ | $t = b + 2dm$ |

Where; b is the width of the channel, m; d = depth of the channel, m; p is the wetted perimeter of the channel, m; and m is the side slopes of the channels [9].

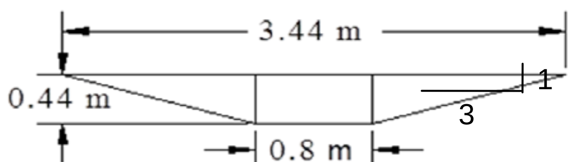

Figure 3: Cross-section of a trapezoidal channel



**Testing of channels and statistics**

The perimeter of the experimental site was fenced after channel construction, to ward off human and animal encroachment. Testing of the channels began when adequate plant cover had been established. This involved discharging water from a water source into the upstream end of the channel until steady state flow was attained. The depths of flow and top width were recorded, and the discharge calculated at the downstream end from the measured volume of water during a given time. The moisture content and bulk density were noted for each experimental run. Then, the soil lost due to the erosive velocity of the flowing water through each of the channels was gathered by means of a sand collector placed at a rectangular outlet constructed at the downstream end of each channel. The sand collected from each of the channels was separately packaged and taken to the laboratory where they were oven dried for 24 hours and weighed. Each channel was tested five times, and the results of the experimental runs were analyzed using SAS PROC GLM and One-way Analysis of Variance (ANOVA) at 95% level of significance.

**Results and Discussion**

The results of the experimental runs are presented in figures 4, 5, and 6. One-way Analysis of Variance (ANOVA) test showed significant difference ($p < 0.05$) for the different channel grades. Figure 4 compares the soil loss from the various channels based on side slopes. The result revealed that the soil loss from channels with side slope of 3:1 ranged from 0.7 – 0.9 kg, with a mean value of 0.75 kg. The channels with side slope of 4:1 recorded soil loss values ranging from 1.1 – 1.9 kg, with an average value of 1.4 kg. The result showed a significant difference between the soil loss values from the 3:1 and 4:1 side slopes. The higher soil loss from the channels with side slope of 4:1 indicates that the soil loss increases with steepness of the slope. This could be attributed to increased velocity of runoff flow arising from the steeper slope.

Michael and Ojha [17] observed that the shape, length, inclination and aspect of channel slope influences the potential extent of erosion.

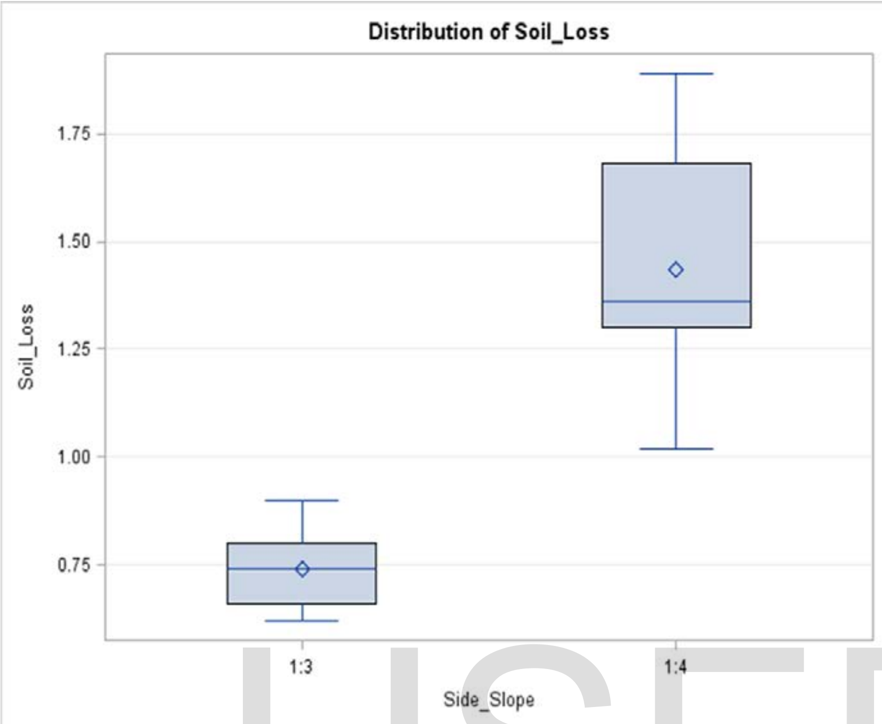


Figure 4: Comparison of soil loss (kg) based on side slopes

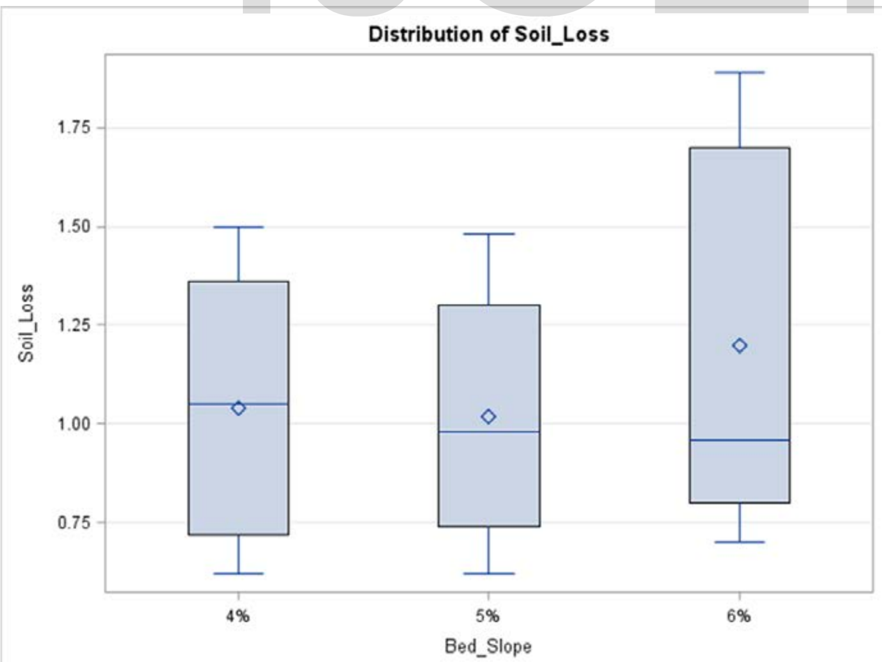


Figure 5: Comparison of soil loss (kg) based on bed slopes

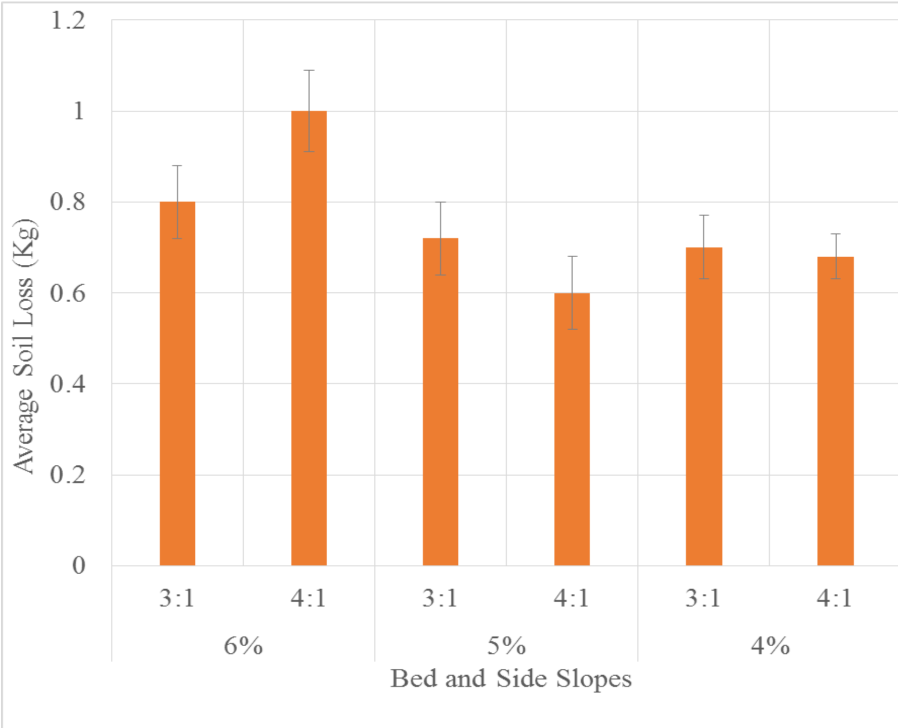


Figure 6: Mean soil loss with channel grades



Figure 5 compares the average soil loss based on the bed slopes of the channels. From the result, there is no significant difference between the channels with bed slopes of 4% and 5%. At these bed slopes, the soil loss ranged from 0.6 - 1.5 kg, with a mean value of 1.0 kg. The channel with bed slope of 6% has a soil loss ranging from 0.7 – 1.9 kg, with mean value of 1.2 kg. This value is significantly different from the soil loss values recorded from the channels with bed slope of 4% and 5%. The higher value of mean soil loss from the channels with 6% bed slope affirms that soil increases with the steepness of the channel slope. Steep bed slopes could lead to increased velocity of flow, which increases scouring of the channel beds, leading to higher soil loss downstream.

The mean soil loss with the various channel grades are shown in figure 6. The channel with bed slope of 6% and side slope of 3:1 had a soil loss ranging from 0.7 – 0.9 kg, with an average value of 0.8 kg. The average soil loss from the channel grade of 6% bed slope and 1:4 side slope ranged between 0.9 – 1.1 kg, with a mean value of 1.0 kg. This is significantly different from the soil loss recorded from the same 6% channel grade when the side slope was 3:1. The higher soil loss could be due to the combined steepness of the side and bed slopes, which increases the velocity of flow in the channel. Schwab *et al*. [15] stated that steeper channels have increased turbulence with localized erosion, due to increased flow velocity. The channel with 5% bed slope and 3:1 side slope had an average soil loss ranging from 0.65 – 0.8 kg, with a mean value of 0.7 kg. This is not significantly different from the channel with 5% bed slope and 4:1 side slope, which has a mean soil loss of 0.6 kg. However, there is significant difference, at 5% significant level, between the average soil loss from the channel grades of 5% and 6%. The 6% bed slope generally recorded more soil loss than the 5% bed slope, which affirms the earlier finding that steeper channels are easily erodible. From the result, there was no significant difference between side slopes of 3:1 and 4:1, when the bed slope was 4%, with soil loss values ranging from 0.65 – 0.75 kg and average value of 0.7 kg. The average soil loss value gotten from channel grade of 4% was not significantly different from the value obtained from the channels with 5% bed slope, but was significantly different from the value obtained from the 6% bed slope.

The result of the study indicated that Bermuda grass was effective in stabilizing the sections of the trapezoidal channels, to minimize erosive capacity of the flowing water, thereby reducing soil erosion. Similar studies on vegetated waterways showed that vegetation plays a key role in soil erosion dynamics [8]. Therefore, grass cover is considered as a sustainable means of controlling soil erosion and enhancing durability of soil slopes [14]. However, analysis of the results revealed that grassed-lined channels with 6% bed slope would be unsuitable for erosion control in the study area, due to increase flow velocity that would lead to localized erosion.

Also, the results revealed that the channel grades of 4% and 5% were effective for erosion control, but the choice of the channel grade to use could depend on the cost, farmer's preference, and ease of crossing with farm implements. However, the minimum average soil loss was recorded from the channel with 5% slope and side slope of 4:1, with a value of 0.6 kg. This gave the best combination of channel grades for erosion control in southeastern Nigeria. It implies that the channel was the most suitable to handle the natural concentration of runoff. The result agrees with the recommendation of Michael and Ojha [17] that channel grade for a vegetated waterway should be kept within 5% bed slope and that side slopes of vegetated waterways should be 4:1, or flatter, to facilitate crossing of farm equipment. Similar study on grasses showed the suitability of grass-lined channels in controlling large-scale erosion in the tropics [11], [12], [13], 20].

## Conclusion

The study involved the design and construction of six trapezoidal channels lined with Bermuda grass, to experimentally determine the best combination of channel grades (6% and 1:3, 6% and 4:1, 5% and 3:1, 5% and 4:1, 4% and 3:1, 4% and 4:1) suitable for the control of soil erosion in south eastern Nigeria. The result of the experimental runs showed that the channel grade of 6% and 4:1 had the highest mean value of soil loss (1.00 ± 0.09 kg), while the channel grade of 5% and 4:1 had the lowest mean value of soil loss (0.60 ± 0.08 kg). The study has revealed the efficacy of grass-lined channels in curbing the perennial problems of soil erosion in south eastern Nigeria. It is recommended that further research be conducted to widen the scope of the work by considering other channel grades and grasses other than Bermuda. This is necessary to generate reliable data bank for modeling and channel design works in the study area.

## Acknowledgements

This work is based on the research supported by the National Research Foundation (NRF). Also, special thanks to Engr. Prof. C. I. Ijioma for his mentorship in this study.

## References

[1] E. Z. Nyakatawa, K. C. Reddy, and J. L. Lemunyon, "Predicting soil erosion in conservation tillage cotton production systems using the revised universal soil loss equation (RUSLE)". Soil and Tillage Res. 57(4): 213-24, 2001.

[2] O. Cerdan, G. Govers, Y. Le Bissonnais, K. Van Oost, J. Poesen, N. Saby, A. Gobin, A. Vacca, J. Quinton, k. Auerswald, A. Klik, J. P. M. Kwaad, D. Raclot, I. Ionita, J. Rejman, S. Rousseva, T. Muxart, M. J. Roxo, and T. Dostal, "Rates and spatial variations of soil erosion in Europe: A study based on erosion plot data". Geomorphology 122: 167–177, 2010.

[3] CEC, "Proposal for a directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC". Brussels, 22.9.2006, COM 232 final, 2006/0086, 2006.

[4] M. O Isikwue, C. Abutu, and S. B. Onoja, "Erodibility of Soils of the South West Benue State, Nigeria". The Pacific Journal of Science and Technology. 13 (2): 437 – 447, 2012.

[5] A. A. Albert, A. A. Samson, O. O. Peter, and A. O. Olufunmilayo, *An Assessment of the Socio-Economic Impacts of Soil Erosion in South-Eastern Nigeria, Shaping the Change,* XXIII FIG Congress Munich, Germany, pp. 12, 2006.

[6] C. C. Egwuonwu and N. A. A. Okereke, "Characterization of Erodibility Using Soil Strength and Stress-Strain Indices for Soils in Some Selected Sites in Imo State." Research Journal of Environmental and Earth Sciences 4(7): 688 – 696, 2012.

[7] I. A. Abdulfatai, I. A. Okunlola, W. G. Akande, L. O. Momoh, and K. O. Ibrahim, *Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions.* Journal of Geosciences and Geomatics, vol. 2, no. 3: 125-129. doi: 10.12691/jgg-2-3-8. 2014.

[8] W. Wei, L. Chen, B. Fu, Y. Lu, and J. Gong, "Responses of water erosion to rainfall extremes and vegetation types in a loess semiarid hilly area, NW China." Hydrol. Process. 23, 1780–1791. Wiley Inter Science (www.interscience.wiley.com), DOI: 10.1002/hyp.7294, 2009.

[9] R. Suresh, "Soil and Water Conservation Engineering." Standard Publishers Distributors, New Delhi, India, 2002.

[10] Imostateblog, Assessed on December, 2015, from https://www.google.ca/search?q=erosion+in+south+east+nigeria&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj6_Ni_rcPRAhVTzGMKHY-FBooQ_AUICCgB&biw=1229&bih=607#imgrc=70JeBrYhp32hGM, 2012.

[11] O. A. Ogunlela and M. B. Makanjuola, Hydraulic Roughness of some African Grasses. Journal of Agricultural Engineering Resources. Volume 75: 221 – 224, 2000.

[12] E. Bochet, J. Poesen, and J. L. Rubio, "Runoff and soil loss under individual plants of a semiarid Mediterranean shrubland: influence of plant morphology and rainfall intensity." Earth Surface Processes and Landforms 31: 536–549, 2006.

[13] K. Q. Adekalu, D. A. Okunada and J. A. Osunbitan, "Compaction and mulching effect on soil loss and runoff from two southwestern Nigeria agricultural soils." Geoderma 137: 226–230, 2006.

[14] H. Zhu and L. M. Zhang, "Field investigation of erosion resistance of common grass pieces for soil bioengineering in Hong Kong." Acta Geotechnica, 11:1047–1059. DOI 10.1007/s11440-015-0408-6, 2016.

[15] G. O. Schwab, D. D. Fangmeier, W. J. Eliot and R. K. Frevert, "Soil and Water Conservation Engineering." John Wiley and Sons, New York, 1993.

[16] G. E. Osuji, M. A. Okon, M. C. Chukwuma and I. Nwarie, "Infiltration Characteristics of soil under Selected Land Use Practices in Owerri, Southeastern Nigeria." World J. Agric. Sci., 6(3): 322-326, 2010.

[17] A. M. Michael and T. P. Ojha, "Principles of Agricultural Engineering." Volume II, Jain Brothers, New Delhi, India, 2005.

[18] V. T. Chow, "Open Channel Hydraulics." McGraw-Hill Inc., New York, 1986.

[19] U. S. Soil Conservation Services (SCS), "Handbook of Channel Design for Soil and Water Conservation." SCS-TP-61., Washington, DC, 1966.

[20] M. M. Shahriar, J. X. Wang, A. Shaurav and W. B. Patterson, "Soil-binding ability of vegetation roots in enhancing erosion resistance of a shallow slope." International Journal of Geotechnical Engineering, 10:4, 409-417, DOI:10.1080/19386362.2016.1168608, 2016.