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Determination of Hydraulic Roughness Coefficients of Some Vegetated Species in Awka, Nigeria

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In this study, selected types of grasses were studied to determine their hydraulic roughness coefficient and to select the most suitable grass for erosion control. The experiments were performed in twelve trapezoidal open channels measuring 5 m x 0.12 m x 0.03 m at different flow depths (0.001m, 0.002m, 0.003m, 0.004m and 0.005m) and at varying bed slope (0.2%, 0.3%, and 0.4%). Overall, Bahama grass showed the highest Manning's n-value due to its deep root system and creeping nature. For each slope, the degree of submergence, Reynolds number, and flow depth increases as Manning's n decreases. As the flow depth increases, the Reynolds number increased while the drag coefficient, Cd decreases.

Keywords: Hydraulic Roughness Coefficient (n); Erosion; Discharge; Channel; Vegetation

I. INTRODUCTION

Soil erosion is known to be the major cause of environmental degradation in most developing countries. It appears to be the worst among the natural disasters especially in Nigeria (Onwuka *et al.,* 2012). According to Ogunlela and Makonjuola (2000), soil erosion is simply the process of detachment, transportation, and deposition of soil particles (sediments) by erosion agents such as water and wind. It can be caused by both natural factors (water and wind) and human factors (e.g., man's removal of the protective cover of vegetation). It causes continuing destruction of the fertile topsoil (contains plant nutrients and organic matter), thereby reducing agricultural productivity (Mahmoudzadeh, 2007). Vegetation can be used to control erosion due to its buttress and sprawling root systems that are responsible for increasing their resistance to erosion.

Manning's roughness coefficient (retardance co-efficient) n, is the property responsible for the flow resistance of vegetation. Vegetation roughness coefficients are the major parameters used to determine the flow characteristics which depend on the flow conditions (depth and velocity) and vegetation condition (type and density) (Ebrahimi *et al.,* 2008). The vegetation in the channel influences channel flows and its extent of influence is based on the characteristics of the vegetation and the flow characteristics. The vegetation characteristics include; the vegetation species, degree of submergence (submerged or unsubmerged), density, distribution, and flexibility. The flow characteristics include; flow area, depth, and sidewalls of the channel. The velocity of flow is the main effect of vegetation in the channel, vegetation tends to increase the roughness or flow resistance or retardance (Fischenich, 2000). Rodney *et al.* (2011) stated that the roughness coefficient varies for different vegetation from season to season.

In addition, the drag on the vegetation is known to be another important parameter that is related to flow resistance. Therefore, the main objective of this study is to evaluate the vegetation resistance in terms of Manning's

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roughness coefficient and drag coefficient to determine the suitability of the selected vegetation in controlling erosion.

II. MATERIALS AND METHODS

A. Study Area

This study was carried out during the rainy season of 2017 at the Department of Agricultural and Bio-resources Engineering experimental site in Nnamdi Azikiwe University, Awka Anambra State Nigeria (latitudes of 6°15'11.8 N to 6°15'5.3E and longitudes 7°7'118 N to 7°7'183 N and altitude of 142m).

B. Determination of the Hydraulic Roughness Coefficient (n) of the Selected Vegetated Species

The value of the hydraulic roughness coefficient was determined using Manning's equation (Rodney *et al.,* 2011) expressed in equation 1. Manning's equation is the most widely used formula for calculating overland flow and was used in this research (Hessel *et al.,* 2003).

$$n = \frac{r^{2/3} s^{1/2}}{V} = \frac{A\, r^{2/3} s^{1/2}}{Q} \qquad (1)$$

Where: n = Manning's roughness coefficient ($s/m^{1/3}$) ; r = Hydraulic radius, A/P (m); S = Slope (m/m); V = Velocity of flow (m/s); A= Cross-sectional area (m^2); Q = Discharge of flow or flow rate (m^3/s)

C. Experimental Layout

These three different vegetations - Spear grass (*Imperatacylindrica*), Guinea grass (*Panicum maximum*), and Bahama grass (*Cynodondactylon*) were studied. Four experimental treatments were set up as shown in Table 1.

Table 1. Experimental layout

Treatment	Grass	Slope of channel (%)		
		A	B	C
I	Bahama *(Cynodon dactylon)*	0.2	0.3	0.4
II	Guinea *(Panicum maximum)*	0.2	0.3	0.4
III	Spear *(Imperata cylindrica)*	0.2	0.3	0.4
IV	Control	0.2	0.3	0.4

Twelve (12) channels were constructed to represent four (4) treatments by three (3) slopes by one (1) replication (4×3×1) randomised design. The four treatments were Bahama grass, Guinea grass, Spear grass, and the control (no vegetation). Three different levels of slope for each of the vegetation and the control are 0.2%, 0.3%, and 0.4%, respectively.

D. Experimental Procedures

The experimental channels were constructed at the experimental site of the Agricultural and Bio-resources Engineering Department (Figure 1). Minimum tillage was carried out and farmyard manure was mixed inside each of the channels to enhance the fertility of the soil before the establishment of the vegetation (this is necessary because if the soil is erodible, most of the nutrients may be depleted). Selected grasses were obtained from Nnamdi Azikiwe University, Awka botanical garden.

When adequate vegetation cover had been established, the stem height was measured and the experimental runs commenced. The discharge was determined using the timed gravimetric method. Flow discharge was collected in a container for a fixed length of time (30 seconds), then the content of the container was measured (using a measuring cylinder) to determine its volume of water. Discharge was obtained by dividing the obtained volume of water by the fixed length of time. During the experimental runs, depths of flow were recorded at each time interval. This experiment was carried out at different flow depths for different vegetation heights in different sloped channels.

Figure 1. Construction of trapezoidal channels in Agricultural and Bio-resources Engineering experimental site

E. Determination of Channel Slope

The level or slope of the channels was obtained using automatic level survey equipment to ensure a constant slope along the channel bed.

F. Determination of Velocity of Flow

In this experiment, a timed gravimetric method was used to obtain flow discharge. The complete flow was collected in a container for a duration of time (30 seconds). The contents of the container was weighed (using a measuring cylinder) to determine the volume of water. Discharge was determined by dividing the obtained volume of water by the fixed length of time. The velocity of flow was determined using Equation 1.

G. Determination of Drag Coefficient of the Vegetation

The value of the Drag coefficient of each of the vegetation was determined using Equation 2 for unsubmerged conditions as reported in Wu *et al.* (1999). These authors stated that the drag coefficient for the unsubmerged vegetation is given as Equation (2):

$$C_D = \frac{2gs}{V^2} \quad (2)$$

Wu *et al.* (1999) also determined the drag coefficient for submerged vegetation as Equation (3):

$$C_D = \left(\frac{D}{T}\right)\frac{2gs}{V^2} \quad (3)$$

Where: g = Gravity constant (m/s2); s = Channel slope (m/m); V = Flow velocity (m/s); D = Depth of flow (m); T = Height of vegetation (m)

H. Determination of Reynolds Number of the Selected Vegetation

The value of the Reynolds number of each of the vegetation was determined using Equation (4).

$$R_e = VY/v \quad (4)$$

Where: R_e is the Reynolds number, Y = Height of the inundated part of the vegetation; v = Kinematic viscosity of water (m^2/sec).

III. RESULTS AND DISCUSSION

A. Relationship between Manning's n and Degree of Submergence (Y/H)

The graph of Manning's n plotted against the degree of submergence (Y/H) for Spear grass (*Imperata cylindrica*), Guinea grass (*Panicum maximum*), and Bahama grass (*Cynodondactylon*) at 0.2%, 0.3%, and 0.4% slope are shown in Figures 2, 3 and 4, respectively. For all the grasses, the degree of submergence increases as the Manning's n decreases with respect to the stem height (low stem height has a higher Y/H value than that of a high stem height). The n value decreases as the Y/H value increases at a reduced stem height. Therefore, the lower the hydraulic roughness coefficient, the higher the degree of submergence.

These three (3) grasses were all unsubmerged; this is because of the low flow depths used. The results of this study agreed with Abood *et al.* (2006) that noted that when the values of Y/H is less than one (Y/H < 1), it indicates that the plants were unsubmerged.

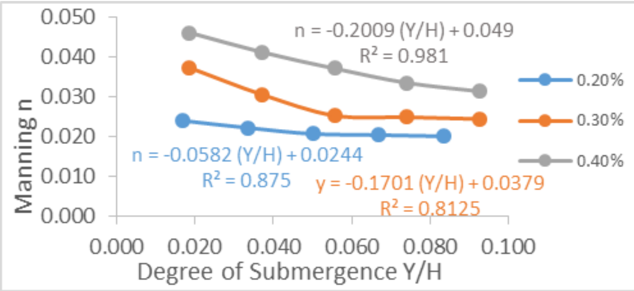

Figure 2. Manning's n versus Degree of submergence (Y/H) at 0.2%, 0.3%, and 0.4% respectively for Spear grass (*Imperata cylindrica*)

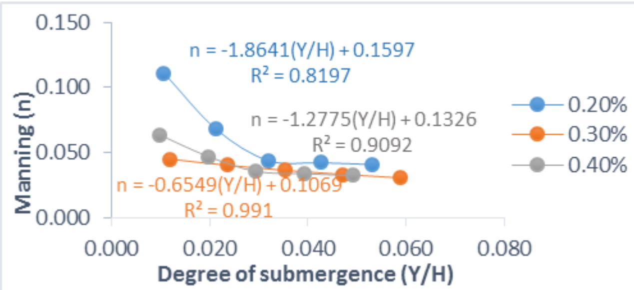

Figure 3. Manning's n versus Degree of submergence (Y/H) at 0.2%, 0.3%, and 0.4%, respectively for Guinea grass (*Panicum maximum*)

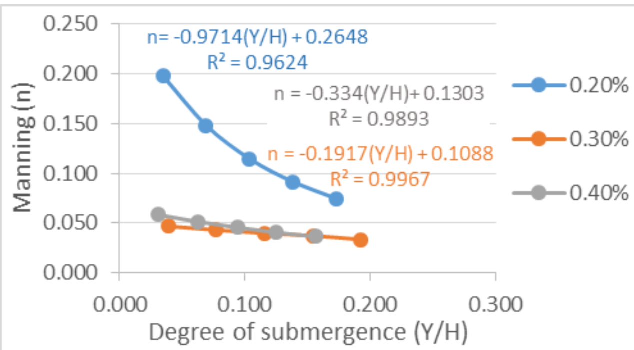

Figure 4. Manning's n versus Degree of submergence (Y/H) at 0.2%, 0.3%, and 0.4% respectively for Bahama grass (*Cynodondactylon*)

B. Relationship between Manning's n and Reynolds Number R_e

The graphs of Reynolds number Re plotted against Manning's n and Manning's n versus VR of Spear grass (*Imperata cylindrica*), Guinea grass (*Panicum maximum*), Bahama grass (*Cynodondactylon*), and Control (without vegetal lining) are shown in Figures 5, 6, 7, 8 respectively.

In general, it was noticed that Reynolds number Re increases as the Manning's n decreases and this is the same for VR and Manning's n, both at an increasing flow depth for 0.2%, 0.3%, and 0.4% sloped trapezoidal channel of varying stem height. This occurred for unsubmerged flow conditions. The n-Re relationship is similar to the n-VR relationship because Re is proportional to the product VR. Manning's n value decreases as VR increases, the decrease in n is as a result of an increase in plant bending and submergence, that is to say, the minimum Manning's n value occurs when the product VR is large enough to force the grasses to be entirely flattened (Rhee *et al.,* 2008). The results of the present study were in agreement with the results obtained by Abood *et al.* (2006) that an increase in the values of Re leads to a decrease in the values of Manning's n for both submerged and unsubmerged flow conditions.

The values of the Reynolds number Re indicates the type of flow in the channel and it also agrees with Rajput *et al.* (2008) that stated that flow in an open channel depends on the Reynolds number. This shows that the flow is laminar in Bahama grass than in the other grasses. Therefore, Bahama grass retards flow better than Guinea grass and Spear grass. For the Control (without vegetation), the Reynolds number Re is higher than that of the grasses and the flow tends to be either transitional or turbulent. These prove that vegetation possesses a hydraulic roughness property that helps to retard flow, thus reduce reducing the rate of erosion/flooding.

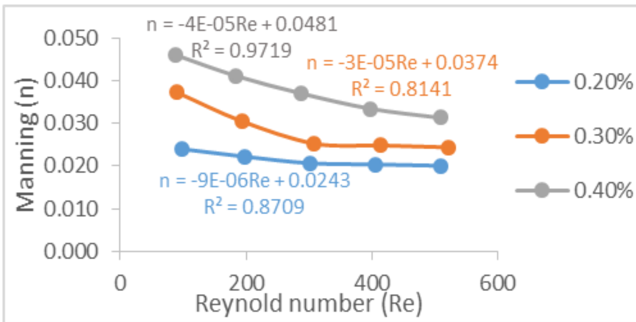

Figure 5(i). Manning's n versus Reynolds number for Spear grass (*Imperata cylindrica*)

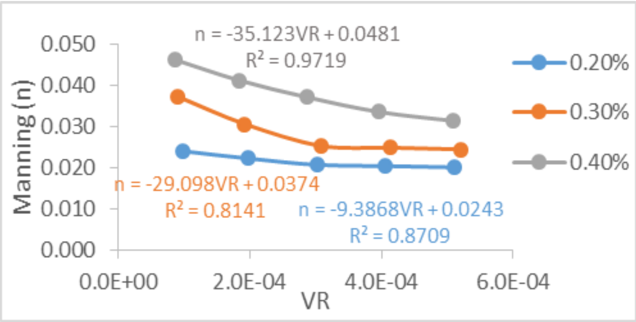

Figure 5(ii). Manning's n versus VR for Spear grass (*Imperata cylindrica*)

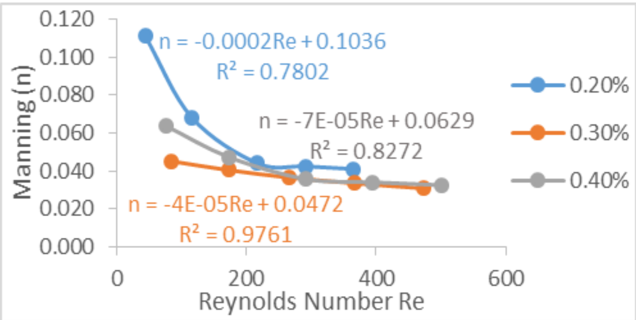

Figure 6(i). Manning's n versus Reynolds number for Guinea grass (*Panicum maximum*)

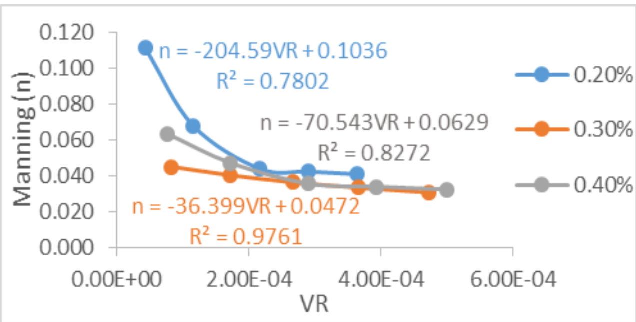

Figure 6(ii). Manning's n versus VR for Guinea grass (*Panicum maximum*)

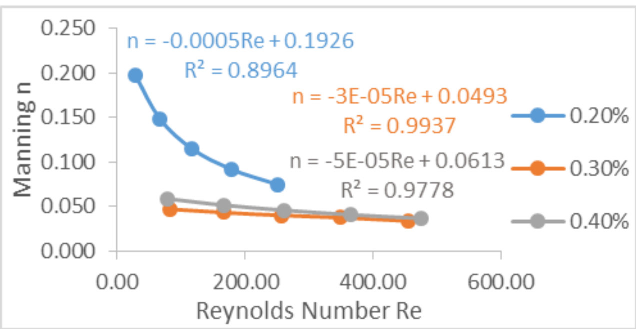

Figure 7(i). Manning's n versus Reynolds number for Bahama grass

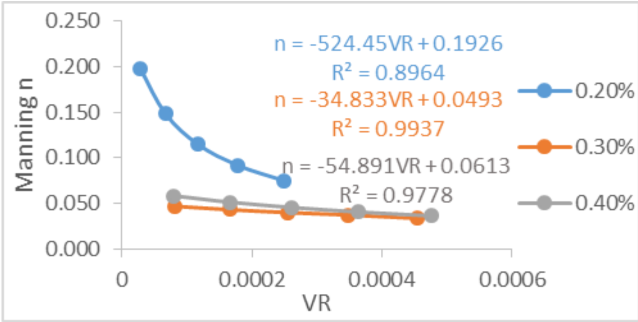

Figure 7(ii). Manning's n versus VR for Bahama grass

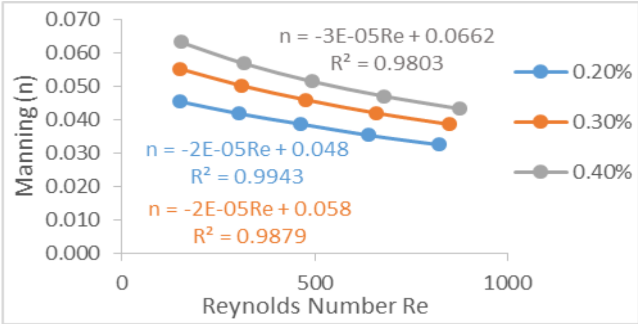

Figure 8(i). Manning's n versus Reynolds number for Control (without vegetation)

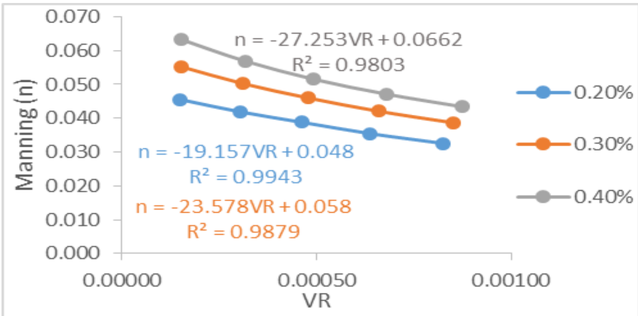

Figure 8(ii). Manning's n versus VR for Control (without vegetation)

C. Relationship between Manning's n and Vegetation Density

The linear graph showing the relationship between Vegetation Densities and Manning's n for Speargrass, Guinea grass, and Bahama grass is shown in Figures 9, 10, 11, respectively.

It was noticed that the Manning's n increases as the vegetation density increases except for Bahama grass and guinea grass at constant flow depth. The result of this study for Spear grass (for unsubmerged flow condition) agreed with the result obtained by Abood *et al.* (2006) for Napier grass and Cattail grass in both submerged and submerged flow conditions.

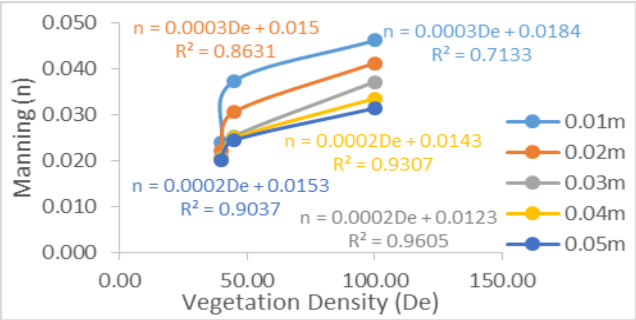

Figure 9. Manning's n versus Density (De) for Spear grass (*Imperata cylindrica*)

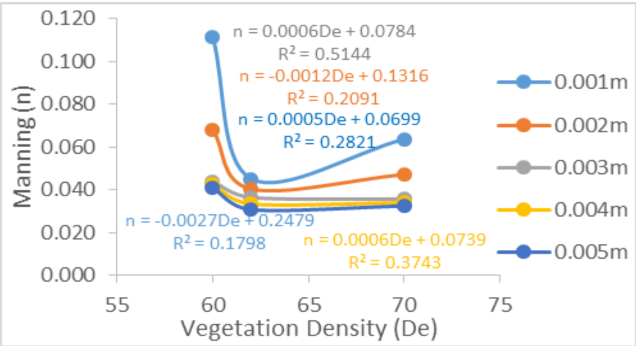

Figure 10. Manning's n versus Density (De) for Guinea grass (*Panicum maximum*)

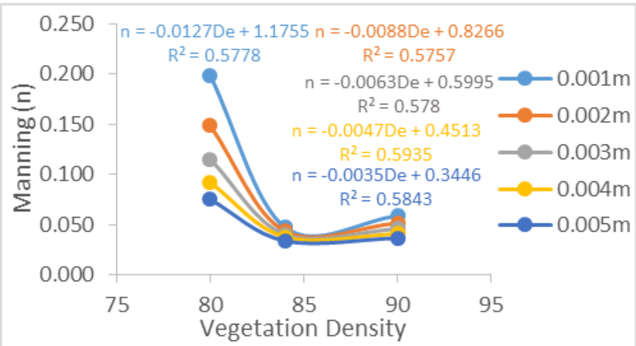

Figure 11. Manning's n versus Vegetation Density (De) for Bahama grass (*Cynodondactylon*)

D. Relationship between Manning's n and Flow Depth (d)

It was found out that the Manning's n decreases as the flow depth increases for all grasses at a constant slope. As the channel becomes steeper, the Manning's n increases at a constant flow depth except for Guinea grass and Bahama grass, which proves that the bed slope affects the value of Manning's n. The graphical representations and their linear relationships of Spear grass (*Imperata cylindrica*), Guinea grass (*Panicum maximum*), Bahama grass (*Cynodondactylon*), and Control (without vegetation) are shown in Figures 12, 13, 14, and 15, respectively.

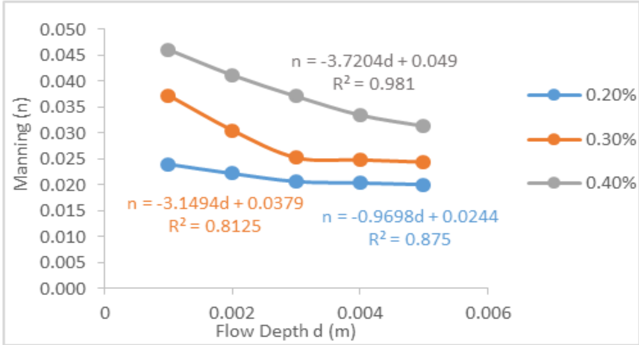

Figure 12. Manning's n versus Flow depth for Spear grass (*Imperatacylindrica*)

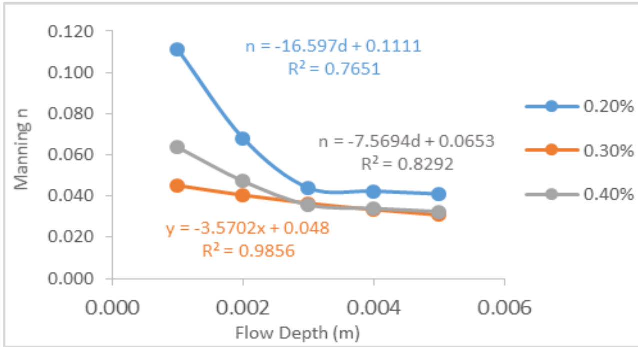

Figure 13. Manning's n versus Flow depth for Guinea grass (*Panicum maximum*)

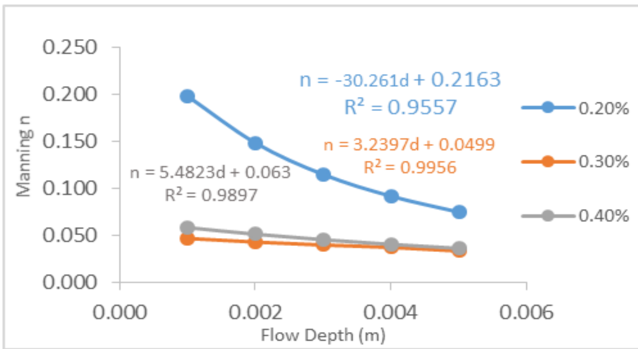

Figure 14. Manning's n versus Flow depth for Bahama grass (*Cynodondactylon*)

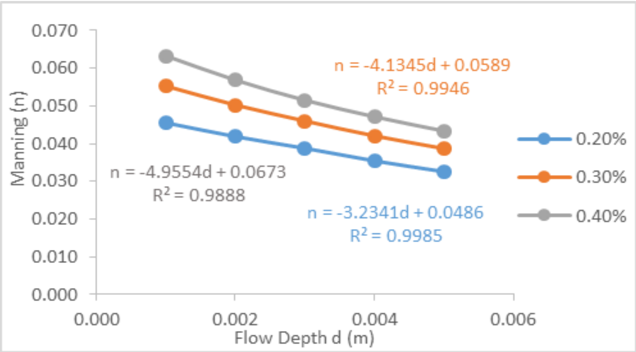

Figure 15. Manning's n versus Flow depth for Control (without vegetation)

E. Relationship between Drag Coefficient (Cd) and Reynolds Number (Re)

For all grasses, it was noticed that as the Re value increases, the drag coefficient decreases, at a constant bed slope as the flow depth increases. Bahama grass has the highest drag coefficient values followed by Guinea grass and Spear grass. This means that the Bahama grass possesses more drag or resistance to flow than the other two types of grass. These results are expressed graphically in Figures 16, 17, and 18, respectively. The linear relationships are shown in the graph with their coefficient of determination, R^2 for the relationships of the three types of grass at different bed slopes.

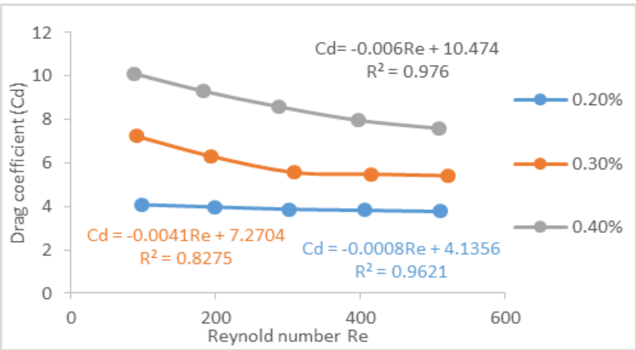

Figure 16. Reynolds number (Re) and Drag coefficient (Cd) for Spear grass (*Imperata cylindrica*)

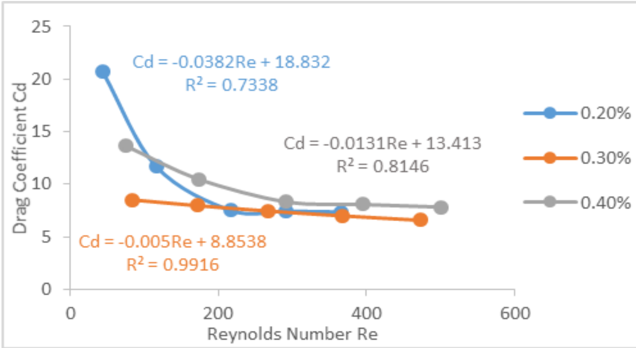

Figure 17. Reynolds number (Re) and Drag coefficient (Cd) for Guinea grass (*Panicum maximum*)

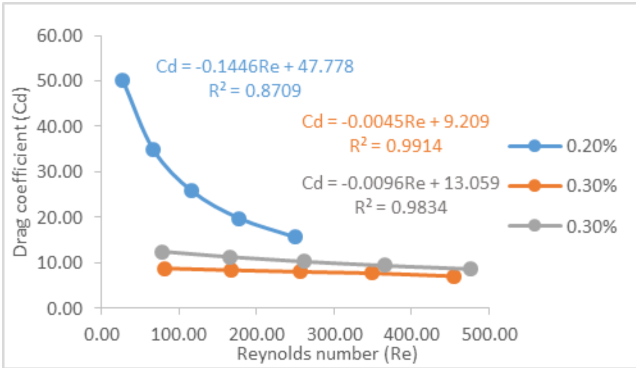

Figure 18. Reynolds number (Re) and Drag coefficient (Cd) for Bahama grass (*Cynodondactylon*)

Statistically, at 0.2% slope, the values of the Mannings roughness coefficient for the four vegetations were not significant at $P \leq 0.05$. The same trend was also observed in the four vegetations for 0.3% slope, apart from the Mannings roughness coefficient of guinea grass and Bahama grass, which were statistically significant ($P \leq 0.05$). For 0.4% slope, the Mannings roughness coefficient of the four vegetations was also not significant at $P \leq 0.05$, apart from the values of Bahama grass and control, which were statistically significant at $P \leq 0.05$.

IV. CONCLUSION

This study presents the effect of the selected vegetation Spear grass (Imperata cylindrica), Guinea grass (Panicum maximum), and Bahama grass (Cynodon dactylon)) on the hydraulic roughness coefficient, n in a trapezoidal open channel. Generally, conclusions were drawn as follows:

a) Bahama grass was found to have a higher value of manning's n when the bed slope, flow depth, and stem height were constant, same as guinea grass and spear grass, respectively.

b) The results from this study has provided data that can be used in hydrologic modelling, channel design works on the grasses and control of erosion in areas that are prone to erosion.

c) The results from this study will guide the farmers to choose the best resisting vegetation that is within their reach for erosion control.

d) Bed slope affects Manning's n. Therefore, it is a factor affecting the hydraulic roughness coefficient. As the bed slope becomes steeper, Manning's roughness coefficient (n) decreases.

V. ACKNOWLEDGEMENT

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