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STATISTICAL SEDIMENT YIELD FORECAST FOR SELECTED SOILS IN GIDAN KWANO NIGERIA

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Abstract

Soil erosion is a major factor of land degradation in some states in the central part of Nigeria. This results in the loss of nutrient-rich topsoil causing severe agricultural problems for a society like Nigeria. Thus in this study, evaluation of sediment yield was done. To this end, watershed sediment yield data were evaluated for five different types of soil on the irrigation farm site of the Federal University of Technology, Minna Nigeria. A 22.9m by 2m of land was set up in areas where the various types of soil were identified for three rainy seasons during each rainfall event, runoff and sediment load produced were channeled through a collector placed at the lower end of the plot. The statistical mean value for the data collected during the month of July for the three years was 3.58, the forecast mean was 3.80 and the mean absolute percentage error, 20.82%. The mean average value for that of August for the field and forecasted sediment yield, error and percentage error were determined to be 3.47,3.80, -0.33 and 24.03%, respectively. It was concluded that sediment yield increased in some cases which was attributed to the surface runoff with an increase in slope steepness. Total sediment yield for the undisturbed soil surfaces was generally smaller than that for the disturbed surface conditions.

Keywords: *Disturbed soil, Runoff; soil erosion; sediment yield; surface slope; undisturbed soil.*

INTRODUCTION

Intensive use of natural resources calls for detailed inventories of its components and an investigation of the changes which took place in the past. This is particularly important in fast, usually unplanned, changing area, such as agricultural land expansion in many parts of the country. At present, physical expansion of urban area and extensive use of land for agricultural purposes are the main causes of land use change in the developing countries. Land cover change directly affect ecological landscape functions and processes with far-reaching consequences for biodiversity and natural resources. The potential for surface runoff and soil erosion has mostly affected land use and cultivation (Solaimani, et al., 2009).

Soil erosion by water is the detachment of soil particles by the direct action of raindrops and runoff water, and the transport of these particles by splash and very shallow flowing water to small channels or rills (Nikkami and Ghafouri, 2013). Soil erosion is a complex and multifaceted process which involves a host of factors and conditions with combinations, variations, and interactions that substantially affect the observed soil loss (Romkens et al., 2001). One of the basic problem of soil erosion is the accumulation of detached particles that is sediments. Sediment yield and soil across agricultural farm lands in Nigeria has been linked to rainfall impact on soil, impact of surface runoff on the soil surface and the type of soil within the area. Millions of tons of soil are lost through this process thus reducing the available land mass for agriculture (Koulouri and Giourga, 2007). Soil erosion is one of key environmental issues which millions of naira is been spent to control (Pimentel and Kounang, 1998; Lim et al., 2005). This leads to loss of top soil, decrease of soil water capacity, soil fertility, inhibition of vegetation growth and pollution problems (Van Rompaey, et al., 2001; Gregersen, *et al* 2003; Isabirye, et al., 2010; Ghimire, et al., 2013). This leads to sedimentation of reservoirs and increase in suspended sediment concentrations in streams, with consequent effects on ecosystem health (Shrestha, 1997; Le Roux, et al., 2007; Alatorre et al., 2012).

The estimation of suspended sediment yield is a great help to managers and engineers leading to the proper investment in, and design of hydraulic structures (Sadeghi and Mizuyama, 2007; Rahul et. al, 2012)

Sediment yield also provides an important index of land degradation, severity and trends and also reflects the characteristics of a watershed, its history, development use and management. Therefore, the estimation of sediment yield is needed because it does

Figure 1: Upper end of the runoff plot

not only affect reservoir capacity, sediment transport to the oceans, stream water quality and quantity, aquatic life, stream habitat, channel morphology, it is a good indicator for the effectiveness of watershed management conditions (Fazli and Noor, 2013).

Previous researches (Megnounif, et al., 2003; Presbitero, et al., 2005; Polyakov, et al., 2010; Bouchelkia, et al., 2011; Hyuk Pak and Lee, 2012; Gebremicaela, et al., 2013;) indicates that over 70% of most agricultural lands have been affected by varying intensities and types of soil erosion which is a natural process in itself, accelerated by such activities as vegetation clearing or overgrazing.

The objective of this study is to forecast the amount of soil that will be lost and the sediment yield from the disturbed agricultural land area of Gidan Kwano, Minna.

MATERIALS AND METHODOLOGY

Study Site Description:

The Federal University of Technology permanent site has a total land mass of eighteen thousand nine hundred hectares (18,900ha) which is located along kilometer 10Minna Bida road, South East of Minna, lies approximately on longitude $60^{0}28^{1}$E and latitude $09^{0}35^{I}$N. The entire site is drained by river Gwakodna, Wemi nate, Grambuku Legbedna, Tofa and their tributaries. They are all seasonal river and the most prominent features are River Dagga, Garatu Hill and Dan Zaria dam (Musa et al., 2013)

Runoff Plots and Site Set –up

A 22.9m by 2m of land was set up in areas where the various soil types were considered during the rainy season of the years 2009, 2010 and 2011. The slope of each of the plots was also determined using geodetic survey method. Care was taken to avoid sites with special problems such as rills, cracks or gullies crossing the plot. The gradient along the plot was regular and free of local depressions. During construction of the plots, one out of the two plots were undisturbed and the other plot was thoroughly disturbed for each of the soil considered. Similarly, care was taken not to disturb or change the natural conditions of the plots such as destroying the vegetation or compacting the soil for the undisturbed soils while for the disturbed soils, every form of shrubs present on the plots were removed and the plot completely cleared of grasses.

Around the edge of each plot, long plywood which does not have perforation or openings was placed, following the direction of the slope in a rectangular pattern to permit only runoff delivery and sediment within the experimental plot. The plywood extends 20cm above the ground surface and 10cm below the ground surface. A broad collector 1.2m long and 30cm wide was placed at the base of each of the plots to collect all the runoff and sediment produced during the rain event. On the collector were spouts (15cm in diameter) through which runoff delivery empties into a collecting tank (250L) installed in pits just below ground level. Placed over the spout is a mesh to collect the sediment. It is important to note that only short duration rainfall was considered such that the water collecting tank of 250 litre capacity was not over filled (Romenkens et al., 2001).

The plots were categorized into disturbed and undisturbed soils for the various types of soils considered. Records of rainfall depth for each storm were taken using a locally constructed rain-gauge Figure 1 and 2.

Runoff Delivery and Sediment Load

During each rainfall event, runoff and sediment load produced were channeled through the collector placed at the lower end of the plot into the receiving container which was placed inside a hole dug at the end of the plot; the container was then placed inside it. The sediment loads trapped on the collector by the mesh placed over it were scooped off into a soil bag. Sediments channeled into the tank were allowed to settle after which the runoff volume was determined.

This is in line with the works of Flanagan et al., (2002), Ciesiolka et al., (2004), and Folliott et al., (2013). The clear water was collected with a bucket and measured with a graduated container while the

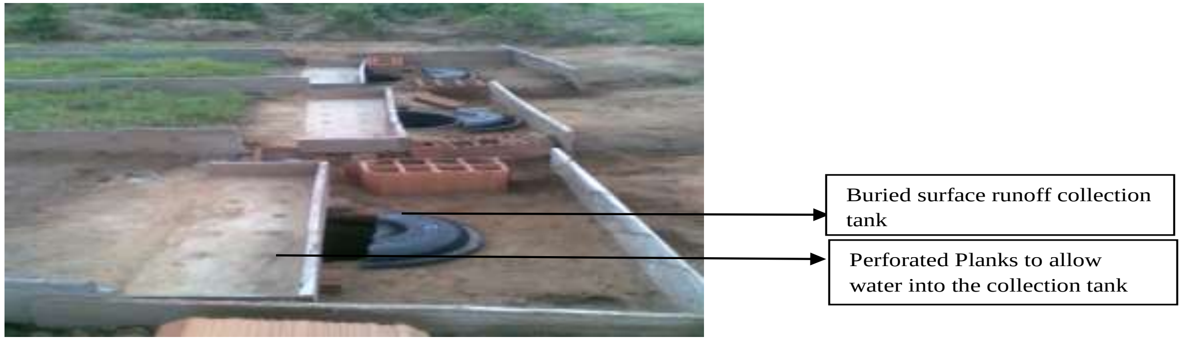

Figure 2: Lower end of the runoff plots

Table 1: Average sediment yield, forecasted and percentage error values for the three months under consideration for three years.

	Condition of Soil	Type of Vegetation	Average Sediment Yield (July)	Forecast sediment Yield (July)	% Error (July)	Average Sediment Yield (August)	Forecast sediment Yield (August)	% Error (August)	Average Sediment Yield (September)	Forecast sediment Yield (September)	% Error (September)
	Undisturbed	Grassed	3.32	3.00	9.73	3.53	3.00	15.01	3.05	3.00	1.53
Sandy	Disturbed	Bare Soil	4.52	3.00	33.58	4.57	3.00	34.35	3.50	3.00	14.20
	Undisturbed	Grassed	3.15	4.00	27.12	2.86	4.00	40.02	2.52	4.00	58.73
Clay	Disturbed	Bare Soil	3.22	4.00	24.10	3.34	4.00	19.64	2.82	4.00	41.84
	Undisturbed	Grassed	3.14	4.00	27.52	3.21	4.00	24.61	2.79	4.00	43.20
Silt	Disturbed	Bare Soil	2.95	4.00	35.75	3.69	4.00	8.50	3.08	4.00	29.87
	Undisturbed	Grassed	3.62	4.00	10.60	3.44	4.00	16.28	3.03	4.00	31.87
Sandy Loam	Disturbed	Bare Soil	4.72	4.00	15.31	4.24	4.00	5.73	3.67	4.00	8.89
	Undisturbed	Grassed	3.30	4.00	21.33	2.68	4.00	49.25	2.65	4.00	50.75
Loam	Disturbed	Bare Soil	3.88	4.00	3.18	3.15	4.00	26.85	3.07	4.00	30.29

sediment collected at the bottom of the tank plus the sediment collected on the collector were taken for oven drying to a constant weight. The sediment weights were determined after oven drying using a weight balance. The sample weight divided by the area of the experimental plot gives the total soil loss from the plot.

RESULTS AND DISCUSSION

The average amount of sediment yield during the study period, resulting from series of rainfalls during the various months of July, August and September, was calculated in all plots over natural slopes and results presented Table 1.

Antecedent soil moisture has a major effect on the amount of sediment yield and soil erosion (Minella, et al., 2009; Nikkami and Ghafouri, 2013), the theoretical calculation of the sediment yield is accomplished by estimating various catchment parameters such as area, land use patterns, runoff, and vegetative cover factor, etc (Rahul et al., 2012).

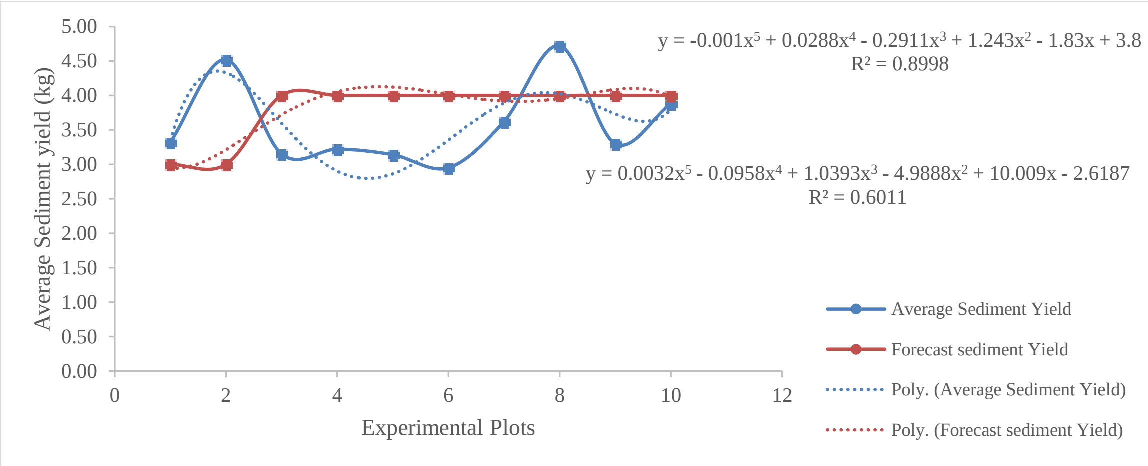

Figure 3: Graph of average and forecasted sediment yield for the month of July

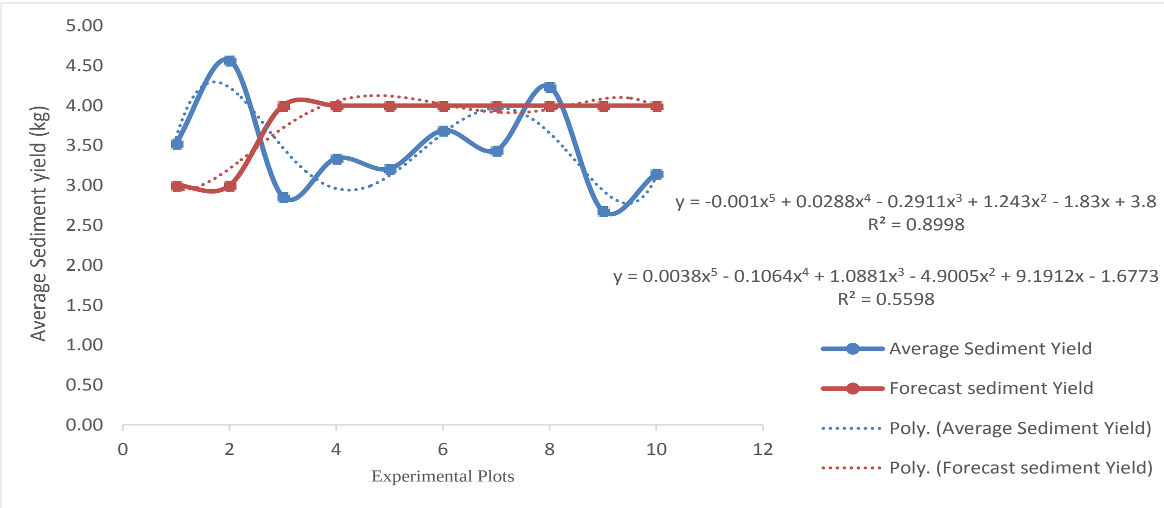

Figure 4: Graph of actual and forecasted sediment yield for the month of August

The results obtained were for averages taken during the months of July, August and September for the years 2009, 2010 and 2011 and the overall average of the three months and three years. Using the polynomial function of the fifth order, the regression analysis for the actual sediment lost within the study period was 60.11% while that of the forecasted sediment yield was 89.98%. It was observed that the disturbed silt had the highest percent error of 35.75. The average quantity of soil that was lost for the month of July over a period of three years was 2.95. Figure 3 shows the graph of average and forecasted sediment yield for the month of July.

Table 1 shows average sediment yield during the month of August alongside the forecasted values, and the percentage error. The mean average value for the actual field and forecasted sediment yield, and percentage error were determined to be 3.47, 3.80, and 24.01% respectively. This result was similar to the works of Mangrio et al., (2011). It can be observed that the average forecasted value was observed to be higher than the actual determined values from the field thus giving room for errors during the course of the experiment which could be as a result of the increased rate of rainfall during the period and the fact most part of the top soil had been removed by earlier rain events. Using the polynomial function of the fifth order, the regression analysis for the actual sediment lost within the study period was determined to be 89.98% with a best fit polynomial equation to the fifth order of $y = -0.001x^5 + 0.0288x^4 - 0.2911x^3 + 1.243x^2 - 1.83x + 3.8$ for the forecasted values while regression value for the actual field value was 55.98% with a best fit polynomial equation of the fifth order of $y = 0.0038x^5 - 0.1064x^4 + 1.0881x^3 - 4.9005x^2 + 9.1912x - 1.6773$. Figure 4 shows the graph of actual and forecasted average sediment yield for the month of August for three years.

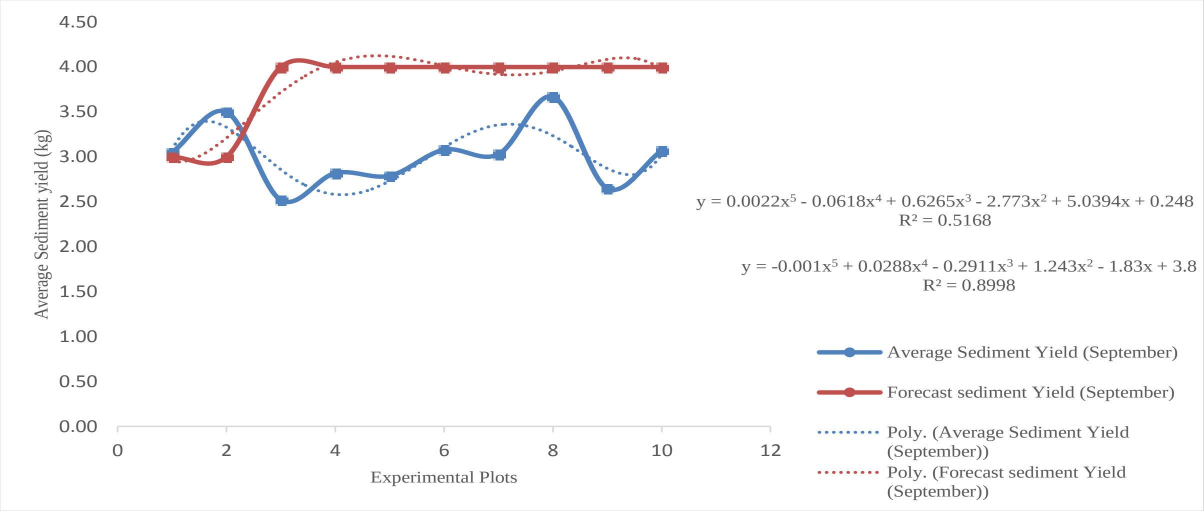

Figure 5: Graph of actual and forecasted average sediment yield for the month of September for three years

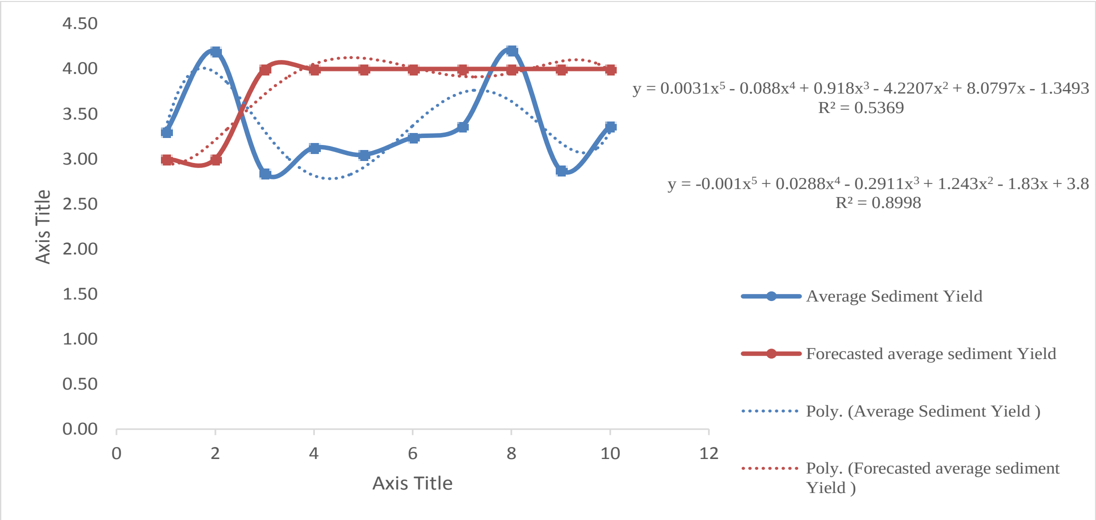

Figure 6: shows the graph of average actual and forecasted sediment yield for the three months for a period of three years.

The actual average and forecasted sediment yield for the month of September for the three years and alongside the forecasted values, and the percentage error as observed in Table 1 shows that the average actual sediment yield was determined to be 3.02; the forecasted mean value was 3.80 while the average percent error was calculated to be 31.12%. It is observed that the month of September had the highest percentage error value when compared with the previous months of July and August. This very month also was observed to have the lowest sediment yield for the three month

which means minimal amount of soil is lost. This may be accounted for as a result of reduction in the amount of rain fall within the study area. Figure 5 shows graph of the actual and the forecasted sediment yield for the month of September. Using the polynomial function of the fifth order, the regression analysis for the actual sediment lost within the study period was determined to be 51.68% with a best fit polynomial equation to the fifth order of $y = 0.0022x^5 - 0.0618x^4 + 0.6265x^3 - 2.773x^2 + 5.0394x + 0.248$ for the average actual sediment yield values while regression value for the forecasted field value was 89.98% with a best fit polynomial equation of the fifth order of $y = -0.001x^5 + 0.0288x^4 - 0.2911x^3 + 1.243x^2 - 1.83x + 3.8$.

The overall average value for the sediment yield within the three months for the years is presented in Table 1. The average mean value for the actual and forecasted sediment yield were 3.36 and 3.80, respectively. The percentage error were calculated to be 31.12%. Figure 6 shows the graph of average actual and forecasted sediment yield for the three months for a period of three years. The forecasted regression value for the average values for the three months during the study period of three years observed to be the same those of the single months of July, August and September. Though the regression analysis determined for this study when compared with the works of Joshi and Tambe (2010) were observed to be lower but the curves were relatively similar. The actual and forecasted sediment yield equations for the three months of study within the three years is obtained as $y = 0.0031x^5 - 0.088x^4 + 0.918x^3 - 4.2207x^2 + 8.0797x - 1.3493$ and $y = -0.001x^5 + 0.0288x^4 - 0.2911x^3 + 1.243x^2 - 1.83x + 3.8$. This is similar to the works of Joshi and Tambe (2010) and Ndomba (2011).

CONCLUSIONS

Soil erodibility in all land uses is expected to be low because of clayey, clay –loamy soil texture and high organic matter content within the study location. It is concluded that the total sediment yield within the study area was relatively stable within the three years of study. Though, in some cases sediment yield increased in some cases which was attributed to the surface runoff with an increase in slope steepness. Total sediment yield for the undisturbed soil surfaces was generally smaller than that for the disturbed surface conditions. Sediment concentration in runoff during prolonged rainfall on an initially dry soil surface first increases rapidly, then decreases gradually. This pattern reflects the dynamic nature of changes in the soil surface conditions with respect to the effect of surface sealing and rill development during rainfall. Subsurface soil water pressures substantially affected the sediment concentration in runoff, but hardly affected the runoff volume. The slope was observed to strongly affect drainage network development and runoff distribution, which in turn enhances soil loss.

It is therefore important to note that considering the actual and forecasted sediment yield equations for the three months of study for three years obtained as $y = 0.0031x^5 - 0.088x^4 + 0.918x^3 - 4.2207x^2 + 8.0797x - 1.3493$ and $y = -0.001x^5 + 0.0288x^4 - 0.2911x^3 + 1.243x^2 - 1.83x + 3.8$ respectively using the polynomial function of order five. Sediment yield results computed here can only be used as preliminary values pre-cursory to a detailed sediment yield study.

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