THE EFFECT OF DRAINAGE BASIN MANAGEMENT ON SEDIMENT DELIVERY BY THE MALMO STREAM, KUBANNI DRAINAGE BASIN, ZARIA, NIGERIA

By

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ABSTRACT

The Ahmadu Bello University (ABU) dam receives water and sediments from the upstream catchment area of River Kubanni, which is made up of four tributaries. An earlier assessment of the magnitude of sediment produced by the northernmost tributary of the river was made for one year with data on sediment concentration and stream discharge collected from the gauging station made up of a 120^{o} V-notch weir and a stage used to estimate the discharges. Suspended sediment samples were collected using the USDH 48 sampler for onward analysis in the laboratory to determine the suspended sediment concentration. The rating curve was used to allow a reasonable estimate of suspended sediment yield. A Channel Sediment Yield (CSY) value of 482 tons/yr was derived for the catchment area. This value is high and the information thus provided presents the need for immediate measures to control sediment yield into the ABU reservoir. Owing to the continuous effort of the ABU administration in afforestation with yearly tree planting campaign and reduction of farming activities, the author carried out the same study five years after to observe if there is a significant reduction in the sediment yield of the sub-basin and derived a CSY value of 248 tons/yr indicating a reduction of about 50% which can be said to be statistically significant thus making the efforts of the administration positive and commendable.

Key Words: Discharge, Suspended Sediment Concentration, Suspended Sediment Discharge and Channel Sediment Yield

INTRODUCTION

Water is an essential commodity to all life forms in general and man in particular. Water is needed for domestic and industrial uses, irrigation, hydro-electric power generation and recreation, to mention but a few. In most cases, he turns to rivers for water supply. As a result of extreme fluctuations in river discharges in some climatic regions, dams are constructed across rivers to serve as water reservoirs. When a dam is constructed across a river, it receives water and sediments from the catchment area of the river network. The sediments are transported and deposited into the dam and this becomes worrisome if the dam is not designed to flush out such sediments as they will continue to settle at the bottom of the lake and over time increase in thickness. This tendency ultimately reduces the actual depth of the lake, and the volume of water that can be retained in the reservoir (Ward, 1975; Young, 2006).

Sediment yield is the total amount of sediments, including bedload, dissolved load and suspended sediments which are generated within the catchment area of the river and subsequently moved from a drainage basin to be deposited on flood plains, in storage reservoirs, or carried off to the seas. The greater part of which is made up of suspended sediment load especially in reservoir sedimentation (Vanoni, 1975; Oyebande and Martins, 1978; Strahler and Strahler, 2006). Sediment yield in drainage basins is a function of many variables including the geology and soil, relief characteristics, vegetation cover, drainage characteristics, climate, time and land use pattern within the drainage basin (Chorley, 1969; Gregory and Walling, 1973).

Sediment yield has been identified as the major cause of reservoir sedimentation. Glymph (1973) for instance, reported that some small reservoirs in the United States incure up to 25% storage loss annually as a result of sediment yield into them. Dasma, Mitan and Freeman (1973) identified a similar phenomenon for dams downstream of mining areas while Platt (1971) reported similar occurrence in reservoirs downstream of logged areas. Similar phenomenon has also been extensively reported across Nigeria. Imevore, Ogunkoya and Sagua (1988) reported that some dams in Nigeria which include the one near Ile-Ife at Oke Odo, had become totally silted up and turned into weed-infested marshes due to rapid urban development and farming activities at the headwaters of the lake. Another one is that of Effon Alaye dam in Ondo State, which would have completely silted up, but for perennial dredging. Adedeji and Jeje (2004) have also observed significant channel erosion of the Opa basin in southwestern Nigeria. Similar situation exists in northern Nigeria where there is marked seasonality in rainfall.

Prior to 1973, Ahmadu Bello University (ABU) water demand had always been met, though inadequate and irregularly, by the Zaria water treatment plant, located some 25km south-east of the University. The desire to achieve balance between water supply and demand led the Ahmadu Bello University (ABU) authority, in 1973, to start the construction of a small earth dam across River Kubanni in order to retain water that would meet the community's present and future needs. At the completion of the dam, in 1974, it had a storage capacity of 2.6 x 10^6m^3, maximum depth of about 8.5m, a catchment area of $57km^2$, a lake surface area of 83.4ha with a supply capacity of 13.64 million litres per day, to cater for about 50,000 people. The dam was designed to have a hollow spillway, such that excess water over the storage capacity of the lake spills into this spillway and is evacuated through pipes under the embankment. However, the facility for flushing out sediments was not provided. Consequently, sediments have been accumulating in the dam over the years (Committee on Water Resources and Supply, 2004).

In a study during the 1997 dry season in March, Iguisi (1997) recorded a reservoir depth of 5.2m as against the initial 8.5m which indicate that the dam has an average annual loss of depth of about 14.3cm which represents a loss of about 3.3m (i.e about 30% loss in storage capacity) in 23 years. This is a result of erodible materials transported and deposited on the floor of the reservoir. Thus, sediment production within the basin is very high. However, the study of Iguisi (1997) did not address the issue of sources and nature of sediment delivery into the dam; the primary concern was the net accumulation of sediments in the dam. It is then invariably important to find out the relative sources of sediments and their nature for the purpose of designing strategies for controlling sedimentation of the dam.

The accumulated sediment in the reservoir is expected to come from the catchment area of the river network composed of four tributaries. Out of the four tributaries, the northern (Malmo) tributary drains a semi-urban area, with most of it forming part of the ABU campus, while the rest drain cultivated areas. Generally, the Malmo tributary is expected to produce greater amount of sediments than the other tributaries because of reduced vegetation cover and widespread bare surfaces in its catchment area.

Yusuf (2006) assessed the magnitude of suspended sediment produced by the Malmo tributary of the Kubanni River. A Channel Sediment Yield (CSY) value of 482 tons/yr and a Specific Sediment Yield (SSY) value of 92 tons/km^2/yr were derived for the catchment area of the tributary and the recommendation for the protection and upgrading of the environment was made. In 2008, the report of the ABU committee on protection of the Kubanni reservoir surmised that from year 2023, as a result of siltation, rationing of water will start; first during dry season, later in both seasons. From year 2039, there will be no more water in the reservoir during dry season. In year 2059, the reservoir will be completely silted up and will have disappeared from maps (Committee on the Protection of Kubanni Dam, 2008).

This led to further proactive efforts by the University to reduce the rate of sediment delivery into the reservoir by enforcing the ban on farming, mining and grazing with a conscious effort of afforestation. The aim of this study was to evaluate the success made so far by re-assessing the magnitude of the sediment produced by the Malmo stream.

STUDY AREA

The study area is in Zaria, Kaduna State, Nigeria. It is one of the provinces that make up the Central High plains of Northern Nigeria and it is approximately 670m above mean sea level. It is located on latitude 11^{0}03'N and longitude 7^{0}42'E about 664km away from the sea (Arowolo, 2000). The study site is located in the upper Kubanni drainage basin, in Zaria 11^{0}08'58"-11^{0}10'25" N and 7^{0}36'45" - 7^{0}38'28"E: Federal Survey Topographical Sheet 102, Zaria S.W. The Kubanni river has its source from the Kampagi Hill, in Shika, near Zaria. It flows in southeast direction through Ahmadu Bello University. It has four tributaries. The Malmo tributary of the river is the focus of this study (Fig. 1)

Zaria belongs to the tropical continental type of climate corresponding to Koppen's tropical savannah or tropical wet and dry climate zone (AW), characterized by strong seasonality in rainfall and temperature distributions. It has two distinct seasons: the dry or harmattan season (October to March) and wet season (April to September). The seasons generally coincide with the southward and northward movement of the surface transition between the hot, moist tropical maritime southeasterly air-mass (MTS) of southern hemisphere of Atlantic ocean origin and the cold, drier tropical continental air-mass (CTS) blowing out of the Sahara Desert known as Inter-Tropical Discontinuity (ITD). Mean annual rainfall is about 1,000mm, but inter-annual fluctuations may be high. Mean monthly temperature is about 27^{0}C but it is highest between the months of March and May, which represent the hot dry period. It is lowest in December/January reaching about 22^{0}C (Kowal and Kassam, 1978).

The soil type is highly leached ferruginous tropical soils, developed on weathered regolith overlain by a thin deposit of windblown silt from the Sahara desert during many decades of the propagation of the tropical continental air mass into the area (Wright and McCurry, 1970). Natural vegetation of the study area is the northern Guinea Savannah with shrubs and a few scattered trees. The dominant shrub around the area is *Isoberlina doka* with an average height of 0.5m. The common grass communities are mostly *Andropogon spp.* (Kwabe, 1987). Grasses sprout during the raining season, shrubs grow very rapidly, but no sooner than the raining season ceased than they become dry (Jaiyeoba, 1995).

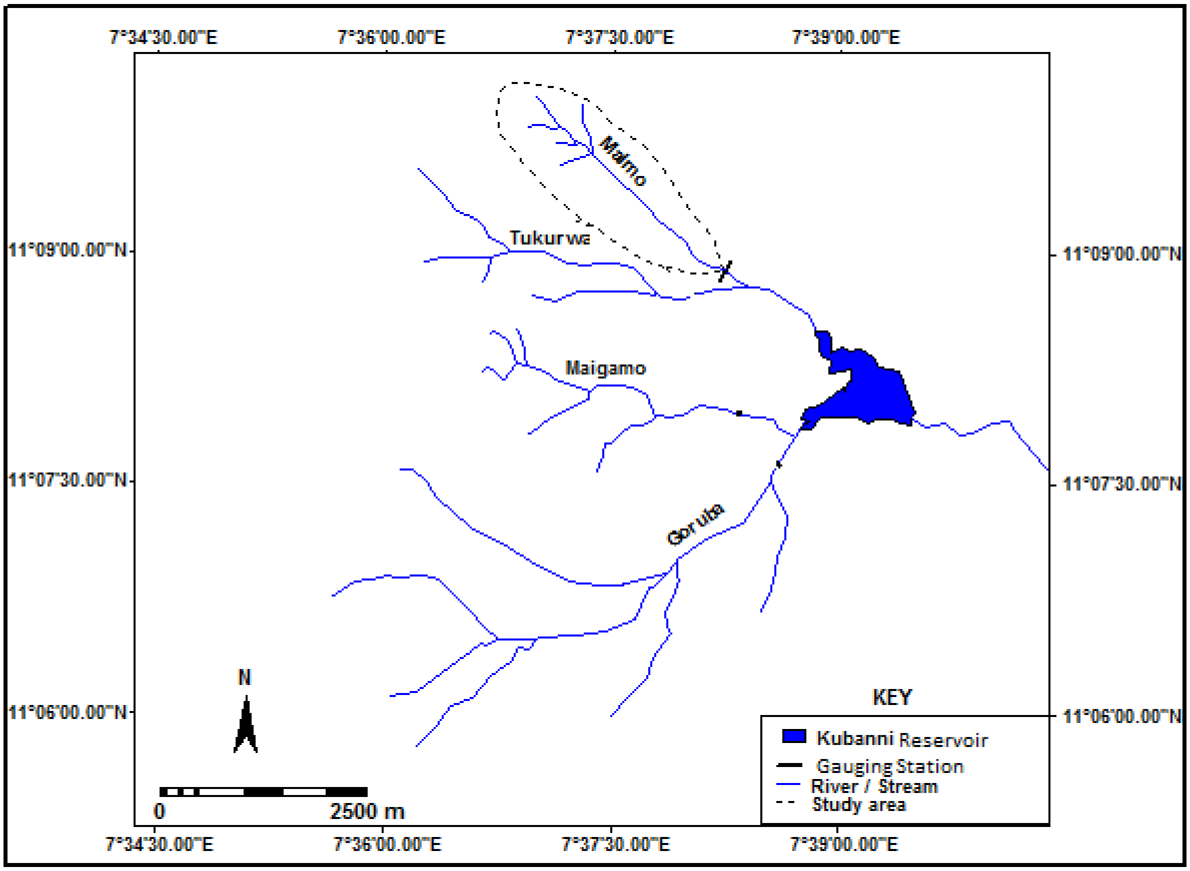

Fig.1: The Kubanni Reservoir and the Study Gauging Station Upstream
Source: Adapted and Modified from Zaria SW Topographic Map

MATERIALS AND METHODS

In order to achieve the aim of this study, data on sediment concentration and stream discharge were collected from the gauging station indicated in Fig.1 during the study period (May, 2011 to February, 2012) which marked the flow period of the Malmo stream.

Stream Discharge

The measurement of stream discharge usually involves consideration of both stage and velocity. There are a number of ways in which river discharge can be measured. These include velocity-area technique, dilution gauging, volumetric gauging, the slope area technique, weirs and flumes (control structure method) and the rated section. For consistency, control structure method used by Yusuf (2006) was adopted. Measurements were observed after rainfall events and twice a day; in the morning (around 7.00am) and in the evening (around 6.00pm) everyday, which represent instantaneous and regular interval monitoring (Ogunkoya, 2000). Subsequently, the daily average readings were calculated in order to obtain the stream discharge.

Sediment Concentration

Suspended sediment samples were collected at the gauging station using the USDH 48 sediment sampler designed by the United States Federal Inter-Agency Sedimentation Project after rainfall events during discharge measurements. The samples were stored in clean plastic bottles, labelled and taken to the laboratory for analyses following the procedure of Douglas (1971) and Matthes, Scholar and George (1991).

Estimation of Suspended Sediment Yield

As suspended sediment measurements are rarely continuous, temporal extrapolation is often required to enable a reasonable estimate of suspended sediment yield to be made. This is usually achieved through the sediment rating curve which relates suspended sediment concentration, suspended sediment load; a product of suspended sediment concentration and discharge to stream discharge, on the basis of a limited number of sediment measurements (Ferguson, 1987; Walling and Webb, 1992; Richards, 1993; Yusuf, 2006).

Statistical Analyses

The significance and reliability of the results obtained were tested by the use of appropriate statistical parameters including the correlation coefficient (r) to measure the strength of the linear correlation between variables and the ratio of explained variation to the total variation, t-ratios to check the significance of the regression coefficients, F-ratio to check the statistical significance of the correlation coefficient of determination (r^2). All analyses were carried out by the use of Microsoft Excel and SPSS statistical package. The confidence level used in accepting or rejecting the hypotheses was 95% corresponding to an alpha value of 0.05.

RESULTS AND DISCUSSION

Discharge (Q)

Table 1 and figure 2 show the summary statistics for the daily mean instantaneous discharge and the discharge regime for the Malmo tributary respectively.

Table 1 in comparison with Yusuf (2006) shows that the Malmo stream had lower statistics and a shorter flow period of 246 days with the measured daily mean instantaneous discharge value of 5.3087 m^3/s throughout the study period recording the highest and lowest values of 0.364 m^3/s and 0.0001 m^3/s on 18^{th} of August, 2011 and 3^{rd} February, 2012 respectively.

Table 1 Summary Discharge Statistics for the Malmo Stream

Statistics	**Value**
N	246
Minimum	0.0001
Maximum	0.364
Range	0.3639
Mean	0.0216
Std. Error of Mean	0.0034
Std. Deviation	0.0537
Variance	0.003
Sum	5.3087

The lower values of the discharge statistics is an indication that there is reduction in overland flow which can be attributed to the intensive afforestation program of the University which increases the infiltration capacity of the soil within the sub-basin (Gregory and Walling, 1973; Knighton, 1998; Rawat, 2011).

A careful observation of the regime diagram in figure 2 reveal that September is the month with highest discharge with the fact that the discharge regime is noticed clearly as from May to October which correlates with the rainfall period in the study area. This is closely related to the regime diagram in Yusuf (2006) except for the month of maximum discharge that is August.

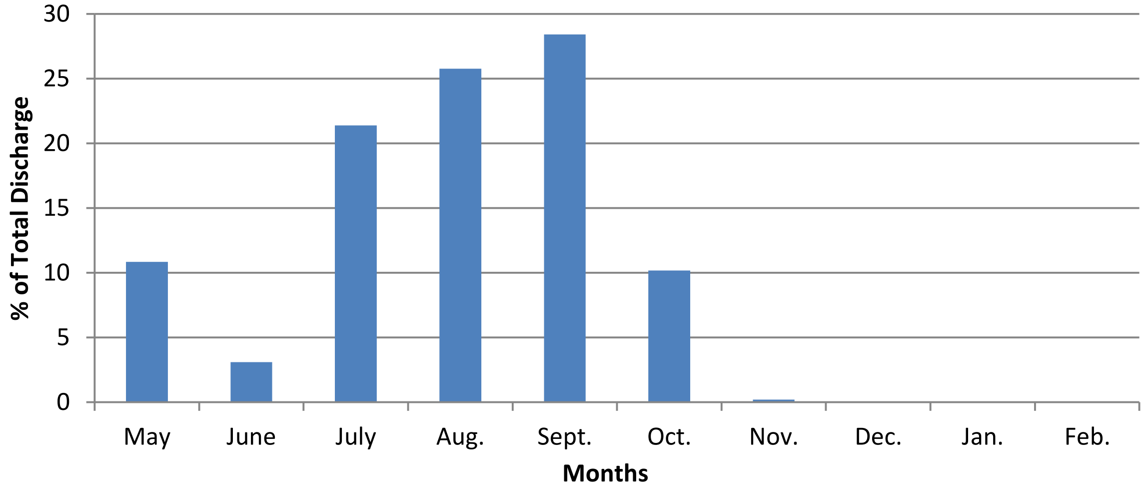

Fig. 2 Discharge Regime Diagram for Malmo Stream

Suspended Sediment Concentration/Load – Discharge Relationship

Table 2 presents the summary statistics for the suspended sediment concentration (Cs) derived in the laboratory from the water samples collected at the gauging station during instantaneous discharge monitoring and the summary statistics for the instantaneous suspended sediment loads (Qs) while tables 3a and b present the coefficients of Qs-Q relation and their model summary.

Table 2 Summary Statistics for Instantaneous Suspended Sediment Concentration and Load

Statistics	**Cs**	**Qs**
N	25	25
Minimum	180	3.79
Maximum	2216	607.18
Mean	661.12	106.79
Std. Error of Mean	92.1649	25.36
Std. Deviation	460.8247	126.801
Variance	212359.36	16080
Sum	16528	2669.76

Table 3a Coefficients of Qs-Q Relation

Basin	Factor	Coefficients	Std. Error	t	Sig.
Malmo	Constant	2.865	0.158	18.137	0
	LOGQ	1.137	0.162	7.014	0

3b Model Summary for Qs-Q Relation

R	r^2	Std. Error of the Estimate	F	Sig.
0.825	0.681	0.26502	49.199	0

Table 3a indicates that there is a direct relationship between suspended sediment discharge and discharge of the basin as exhibited in fig. 3. There is a good relationship between the regression coefficients in both cases as they were statistically significant using the t-test. Therefore, we can say that there is a strong relationship between the regression coefficients in both cases.

The coefficient of correlation (r) and coefficient of determination (r^2) were also high. Although the values are high, inference on these values cannot be made without checking the statistical significance of the r^2 computed, as their high values do not conclude that the independent variable (Q) is a good determinant of the dependent variable (Qs). Using the F-ratio (ANOVA) test, the regression coefficient of determination (r^2) was found to be statistically significant at the 0.05 level of significance, indicating that discharge (Q) is a good determinant of the suspended sediment discharge (Qs) as illustrated in table 3b. The situation in Yusuf (2006) is almost the same except for the higher correlation coefficients which can be attributed to poorer land use. Consequently, using the regression coefficients, table 4 presents the summary statistics for the continuous suspended sediment loads including the sediment yield and channel sediment yield in kg/yr and tons/yr after dividing by 1000 while figure 4 shows the suspended sediment load regime diagram in an attempt to examine the temporal variation.

The summary statistics indicate that, although the number of days of continuous flow differs considerably, the statistics including the channel suspended sediment yield is lower than that of Yusuf (2006) that was as high as 482 tons/yr. This is an indicator that the efforts of the university administration in afforestation through their annual tree planting campaign and reduction of cultivation is yielding results and is quite commendable.

The suspended sediment load regime diagram reveal that the month of September, which is the month with highest discharge, has the highest suspended sediment load relating perfectly with the discharge regime diagram as illustrated in figure 2 confirming the strong correlation between discharge and suspended sediment yield as indicated in table 3b. It can also be observed that high suspended sediment loads of about 25% were experienced from July to September. These 3 months alone contributed almost 80% of the total suspended sediment load of the river. This was the case in Yusuf (2006) except for the anomaly of the suspended sediment load of July exceeding that of August slightly.

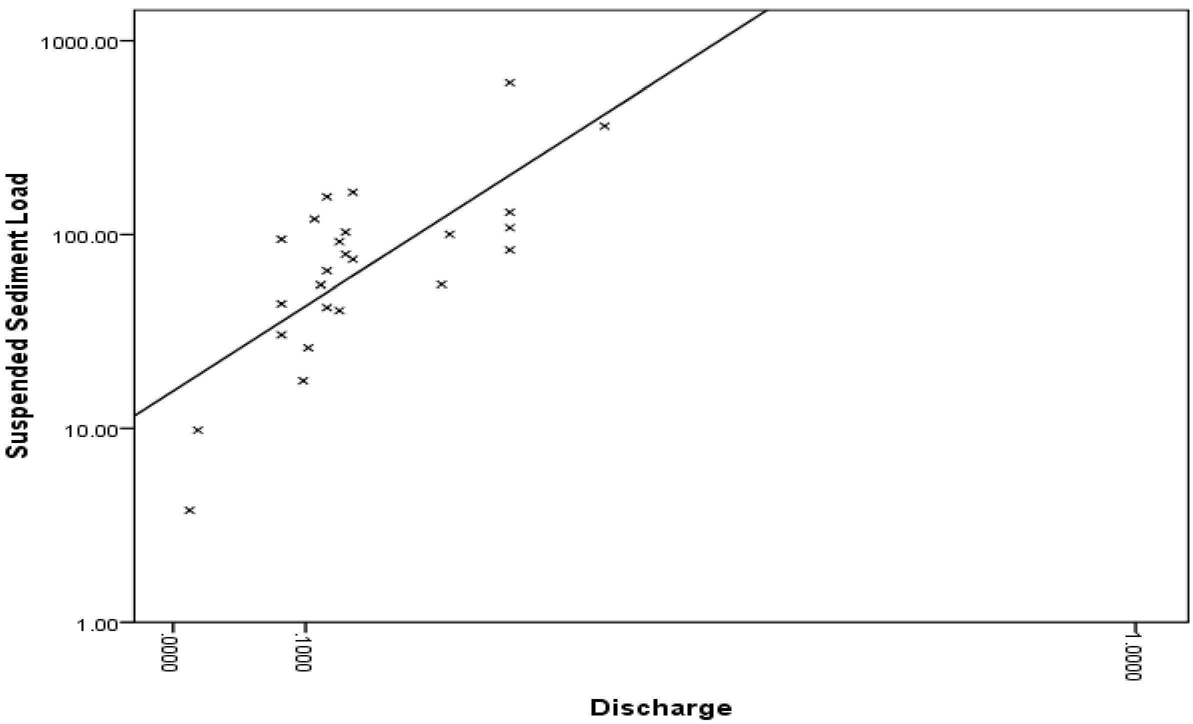

Fig. 3 Qss-Q Relation for Malmo Stream

Table 4 Summary Statistics for Derived Suspended Sediment Load for the Malmo Stream

Statistics	Values
N	246
Minimum	0.02
Maximum	232.26
Mean	11.6819
Std. Error of Mean	2.0551
Std. Deviation	32.2324
Variance	1038.927
Sum	2873.75
Sediment Yield	248292
Channel Sediment Yield	248.292

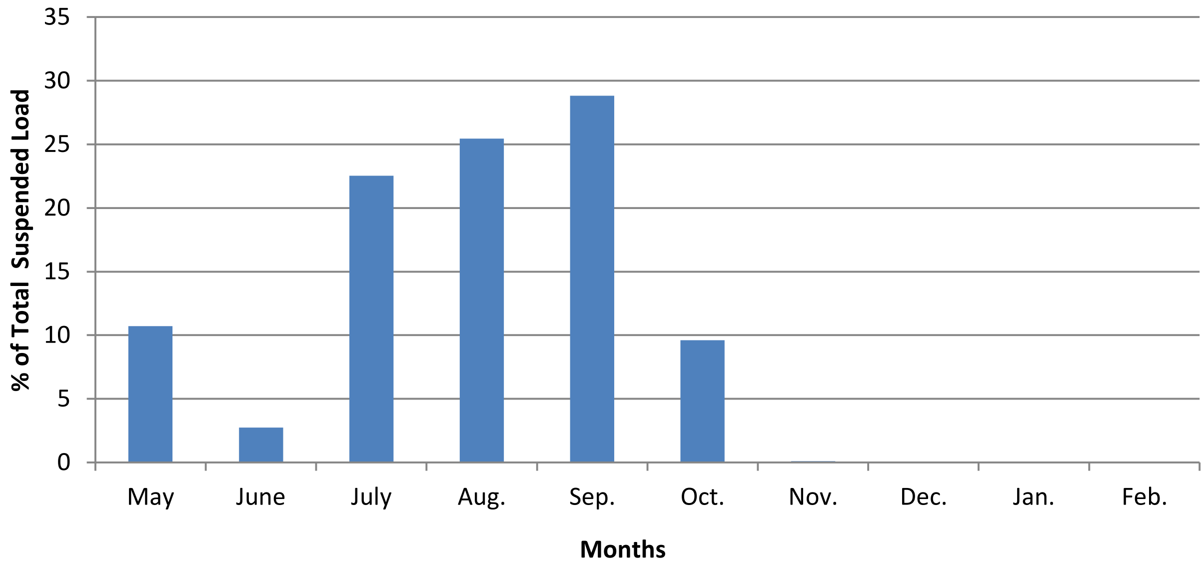

Fig. 4 Suspended Sediment Load Regime Diagram for Malmo Stream

RECOMMENDATIONS AND CONCLUSION

The Ahmadu Bello University (ABU) dam, constructed to provide water for the university community, receives water and sediments from the upstream catchment area of River Kubanni, which is made up of four tributaries. Yusuf (2006) attempted an assessment of the magnitude of sediment produced by the northernmost (Malmo) tributary of the river where a Channel Sediment Yield (CSY) of 482 tons/yr was derived for the catchment area. Using similar methods in this study, reduced summary statistics with a CSY of 248.292 tons/yr was derived indicating that the sediment yield has been reduced almost by half.

The above is an indication that the efforts of the university administration in afforestation through an annual tree planting campaign and reduction of cultivation and mining, which increases the infiltration capacity of the soil within the sub-basin thereby reducing overland flow (Gregory and Walling, 1973; Knighton, 1998; Restrepo and Syvitski, 2006; Rawat, 2011) is yielding results, and is quite commendable.Although the ABU authority has banned farming around the basin, full compiance was observed at the immediate environment around the campus while people are still farming on crossing the Malmo stream and this contributes to the sediment yield of the basin. There is therefore the need to enforce the ban, which should also be extended to the prevention of grazing by animals and soil mining for construction.

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