ASSESSMENT OF THE MAGNITUDE OF SUSPENDED SEDIMENT PRODUCED BY THE GORUBA TRIBUTARY OF THE KUBANNI RIVER, ZARIA

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Abstract

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. An earlier study 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 and Specific Sediment Yield (SSY) value of 92 tons/km^2/yr were derived for the catchment area. Part of the recommendation was that future studies should look into the spatial spread of sediment contribution into the reservoir by all the in-flowing streams so as to determine which inflow is the most problematic in terms of reservoir sedimentation. An attempt is being made here, using similar method, to look at the southernmost tributary which is the Goruba tributary in order to make a comparison between the two. The study area was monitored for one year with data on sediment concentration and stream discharge collected from the gauging station. The discharge was derived using the Velocity-Cross sectional area method while suspended sediment samples, collected at the gauging station using the USDH 48 sampler with onward analysis in the laboratory were used to determine the suspended sediment concentration and the rating curve was used to allow a reasonable estimate of suspended sediment yield for the study area. Although the number of days of continuous flow differ significantly for the two sub-basins, with that of Goruba being much lesser, the statistics including the channel and specific suspended sediment yield of the Goruba stream (12880.547 tons/yr and 702.7 tons/km^2/yr) is more than that of the Malmo stream in folds. The higher sediment yield value and the information thus provided portend the need for increasing catchment management and conservation measures to control sediment yield into the Ahmadu Bello University reservoir as it was observed that sand mining and intensive cultivation is still going on within the basin.

Key Words: Discharge, Suspended Sediment Concentration, Suspended Sediment Discharge, Channel Sediment Yield, Malmo Stream and Goruba Stream.

1. Introduction

Water is essential to life and its distribution and availability are closely associated with the development of human society. Apart from air, water is the most important resource to man. He can survive longer without food than without water. Without it, life is impossible. It is a foundation for human prosperity because adequate and high quality water supplies provide a basis for the growth and development of human, social, economic, cultural and political systems (Young, 2006). The demand for water doubles every 20 years which is more than twice the rate of the world's population growth. New water resources are becoming scarcer and to treat and remediate existing sources more expensive (Clothier *et al.*, 2008).

Inevitably, modern man needs water for three basic purposes: agriculture, industry and domestic and municipal use (water for drinking, cooking, washing, general sanitation and so forth), and he depends largely on the rivers, lakes and aquifers to meet his water needs (McCully, 2006).

Rainfall is determined by uneven weather patterns and as a result, some area of the world gets more precipitation than others. As a result of extreme fluctuations in river discharges in some climatic regions, dams are constructed across rivers to create water reservoirs for power generation, irrigation, flood control, recreation and domestic water supply (Spencer, 2003).

When a dam is constructed across a river, the resultant reservoir receives water and sediments from the catchment area of the river network. Eroded sediments are transported and deposited into the reservoir 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 overtime 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.

The materials carried by rivers are termed sediment load. Sediment load is composed of eroded materials of different shapes and sizes, determining their mode of transportation downstream. It is possible to divide sediment load into bedload, suspended load, and solution or solute load. Sediment yield is the total amount of sediments that are generated within the catchment area of the river and subsequently moved from a drainage basin through a cross-section during a specified period of time to be deposited on flood plains, in storage reservoirs, or carried off to the seas and 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 deposited in them. Dasma *et al*. (1973), identified a similar phenomenon for reservoirs downstream of mining areas while Platt (1971), reported similar occurrence in reservoirs downstream of logged areas. In Nigeria, Imevore *et al.* (1988) for example, 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 example is that of Effon Alaye reservoir 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. The situation in northern Nigeria where there is marked seasonality in rainfall is even worse (Ologe, 1973a).

The problem of reduction in the installation capacity of dams, especially in the northern part of the country, as a result of rainfall seasonality cannot be overemphasized. The Kubanni dam, on which the entire community of the Ahmadu Bello University and immediate environs depend, is not an exception.

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 25 km south-east of the institution. The desire to achieve equilibrium between water supply and demand led the 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 10^6 m^3 with maximum depth of about 8.5m, a catchment area of $57km^2$, a lake surface area of 83.4 ha and supply capacity of 13.64 million litres per day to cater for about 50,000 people (Committee on Water Resources and Supply, 2004).

The dam was designed to have a hollow spill way, such that excess water over the storage capacity of the lake spills into this hollow and is evacuated through pipes under the embankment. However, the facility for flushing out sediments was not provided. It has therefore had its fair share of the sediment yield problem over the years. Although efforts have been made by the authorities concerned to nip the problem in the bud, it seems to persist.

Iguisi (1997), in his study of the extent of sedimentation in the dam recorded a maximum depth of 5.2m as against the initial 8.5m which indicate a loss of about 3.3m (i.e. about 30% loss in storage capacity in 23 years) and an average annual loss of depth of about 14.3cm. This is the result of eroded materials transported and deposited on the reservoir floor.

In 2008, the report of the ABU committee on protection of the Kubanni dam surmised that from year 2023, 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, completely silted up, will disappear from maps (Committee on the Protection of Kubanni Dam, 2008).

Thus, sediment production within the basin is very high confirming Ologe's statement in 1973 before the construction of the dam that unless precautions are taken, the Kubanni reservoir is likely to silt up like the Daudawa dam in Katsina state, where dredging has been carried out in an attempt to restore storage capacity (Ologe, 1973b). It also confirms the statement of Ogunrombi (1979) that high rates of sediment supply to the reservoir by sheet erosion and from gullies, which are widespread in the catchment, should normally be expected.

The study of Iguisi (1997) did not address the issue of sources and nature of sediment delivery into the dam. His primary concern was the net accumulation of sediments in the dam. It is however, important to find out the relative contribution of sediments and their nature for the purpose of designing strategies for controlling sedimentation of the dam.

Yusuf (2006), assessed the magnitude of suspended sediment produced by the northernmost (Malmo) tributary of the Kubanni River. A high 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 part of his recommendation was that future studies should look into the spatial spread of sediment contribution into the reservoir by all the in-flowing streams so as to determine which inflow is the most problematic in terms of reservoir sedimentation. An attempt is being made here to look at the southernmost tributary which is the Goruba tributary in order to make a comparison between the two.

The aim of this study is to assess the magnitude of sediment produced by the Goruba tributary of River Kubanni. This aim will be achieved by;

i) determining the stream discharge and suspended sediment concentration,

ii) establishing a rating curve for discharge and suspended sediment discharge and

iii) determining the river's suspended sediment yield

2. Study area

The study area is in Zaria, Kaduna State. Zaria is located between latitudes 11°03′ and 11^0.10' North and between longitudes 7°30′ and 7°45′ East of the Greenwich meridian. The town is almost centrally located in Northern Nigeria and is a major city in Kaduna state. The plain of Zaria is on an undulating one, which is gently rolling and about 670m above mean sea level and has numerous valleys and streams (Wright and McCurry, 1970).

Zaria experiences the typical seasonal climate of northern Nigeria. It belongs to the Aw climate of the Koppen's classification that has two distinct seasons; the dry or the harmattan season lasting between October to May, while the other season is the rainy season and lasts from May to October. The temperature of Zaria varies throughout the year. Mean monthly minimum temperature rises gradually from its lowest 9.4°C in December to its highest 26.0°C in April while mean monthly maximum temperature rises gradually from its lowest 29.7°C in January to highest 40.6°C in April (Oladipo, 1985).

The soil of Zaria is termed "the Zaria soil group" and usually has material covering up to 14 feet (4.27m) in depth and consists of deposited silt and overlying sedimentary decomposed rocks. Alluvial soils are expansive in Zaria and in low land areas they are easily drained to produce what is known as the Hydromorphic fadama soils. These are found around the Kubanni and Galma river basins and are mainly for sugarcane cultivation. It also supports vegetables like onions, spinach, pepper, tomatoes; hence contributing to market gardening (Ologe, 1973a).
Although the Zaria environment belongs to the northern guinea savannah which is moist woodland undergrown with thick bushes and shrubs, the vegetation is gradually becoming artificial. Some of these vegetation include elephant grass, *Isoberlinia doka*, *Isoberlinia tomentosa*, *Tamarindus* spp, locust beans, silk cotton trees, and baobab tree are commonly seen. Human activities such as cultivation, construction, bush burning and grazing have greatly modified the natural vegetal cover and composition (Jaiyeoba, 1995).

The accumulated sediment in the Kubanni reservoir of Ahmadu Bello University, Zaria come from the catchment area of the river network composed of four tributaries including the northernmost (Malmo), Tukurwa, Maigamo and Goruba streams. The Goruba stream is the focus of this study (fig.1).

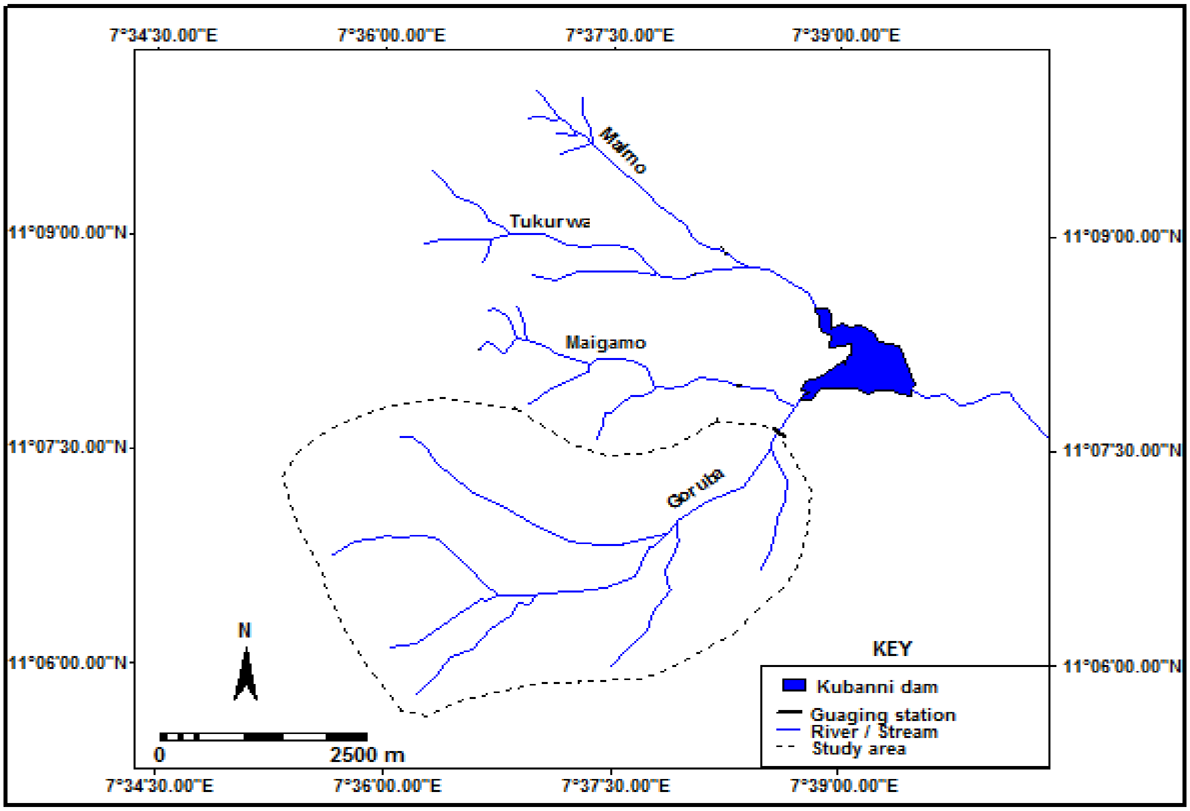

Fig.1 The Kubanni Dam, Goruba Stream and Gauging Station Upstream
Source: Adapted and Modified from Zaria SW Topographic Map

3. Materials and methods

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

3.1 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. The velocity-area (AV) technique, the most widely used for spot measurements of discharge (Gregory and Walling, 1973) 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.

3.2 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 Matthes *et al* (1991).

3.3 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).

3.4 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 that will be used in accepting or rejecting the hypotheses is 95% corresponding to an alpha value of 0.05.

4. Results and discussion

4.1 Discharge: Table 1 and figure 2 show the summary statistics for the daily mean instantaneous discharge and the discharge regime for the Goruba tributary respectively.

Table 1 Summary Discharge Statistics for the Goruba Tributary

Statistics	Value
N (Days)	175
Minimum (m^3/s)	0.0004
Maximum (m^3/s)	22.2786
Range	22.2782
Mean (m^3/s)	1.4744
Std. Error of Mean	0.2842
Std. Deviation	3.7592
Variance	14.131
Sum (m^3/s)	258.01

The table above shows that the Goruba stream had flow period of 175 days with the measured daily mean instantaneous discharge values in m^3/s throughout the study period recording the highest and lowest values of 22.2786 and 0.0004 on 18th of August and 27th November, 2011 respectively. The total instantaneous discharge is 258.01 m^3/s while the mean discharge for the year is 1.4744 m^3/s. These values are much higher than those of the Malmo stream and the reason can be attributed to the much larger size of the Goruba stream; 18.33 km^2, except for the flow period of Malmo that was almost throughout the year (359 days). The two situations however confirm contribution to surface flow by subsurface flow during the dry season (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 with a single maximum which correlates with the rainfall period in the study area and relegates the significance of the contribution to discharge by subsurface flow during the dry season as was evident in the Malmo stream except for the difference in the month of maximum discharge that is August. This can be attributed to the difference in their sizes and therefore lag time as was the result in River Kaduna which is bigger in size (Muhammad, 2012).

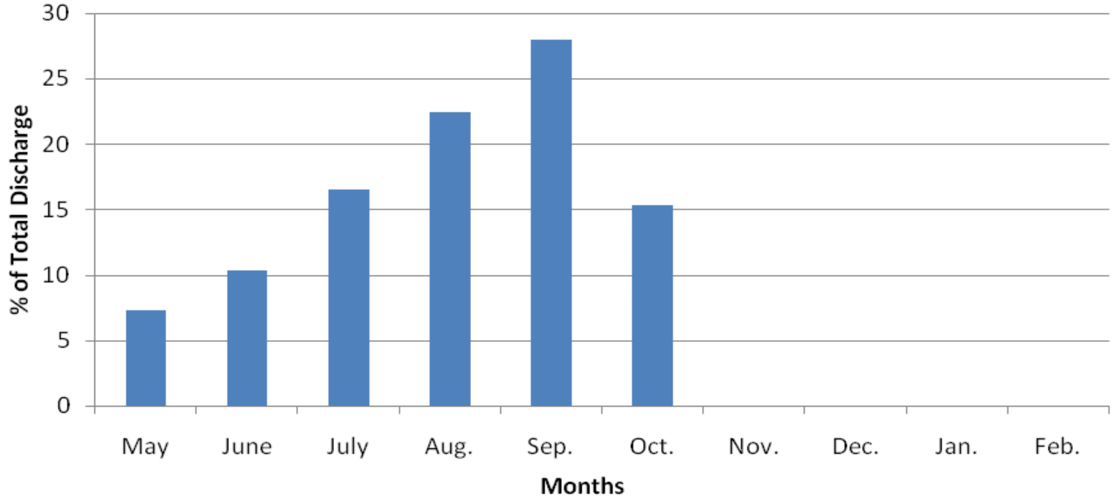

Fig. 2 Discharge Regime Diagram for Goruba Stream

4.2 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 Table 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	26	26
Minimum	68	13.32
Maximum	4984	97800
Mean	1060.15	8270.9
Std. Error of Mean	256.6384	3727
Std. Deviation	1308.6041	19004
Variance	1712000	361200000
Sum	27564	215000

Table 3a Coefficients of Qs-Q Relation

Basin	Factor	Coefficients	Std. Error	t	Sig.
Goruba	Constant	2.847	0.114	24.931	0.000
	LOGQ	0.895	0.119	7.552	0.000

3b Model Summary for Qs-Q Relation

R	r^2	Std. Error of the Estimate	F	Sig.
0.839	0.704	0.46018	57.034	0.000

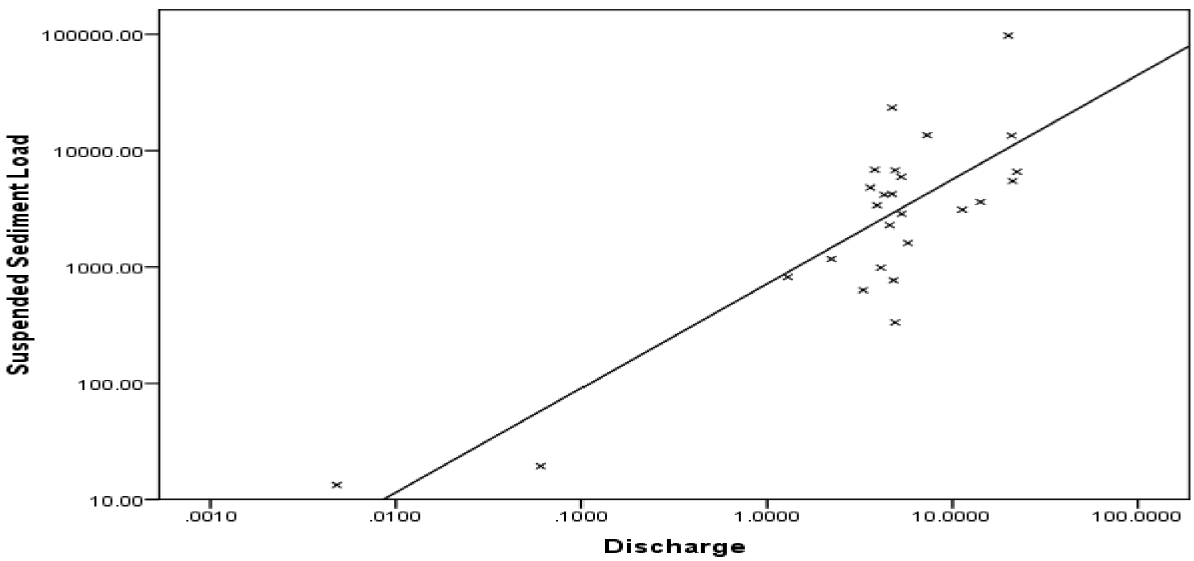

Fig. 3 Qs-Q Relation for Goruba Stream

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 the Malmo stream is almost the same except for the higher correlation coefficients.

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. Also included is the specific sediment yield in tons/km^2/yr after dividing by the basin area 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 differ significantly for the two sub-basins, the statistics including the channel and specific suspended sediment yield of the Goruba stream (12880.547 tons/yr and 702.7 tons/km^2/yr) is more than that of the Malmo stream (Yusuf, 2006).

Table 4 Summary Statistics for Derived Suspended Sediment Load for the Goruba Tributary

Statistics	Values
N (Days)	175
Minimum (mg/s)	0.64
Maximum (mg/s)	11307.32
Mean (mg/s)	851.8846
Std. Error of Mean	149.2601
Std. Deviation	1974.5261
Variance	3898753.316
Sum (mg/s)	149080.4
Sediment Yield (kg/yr)	12880547
Channel Sediment Yield (tons/yr)	12880.547
Specific Sediment Yield (tons/km^2/yr)	702.7

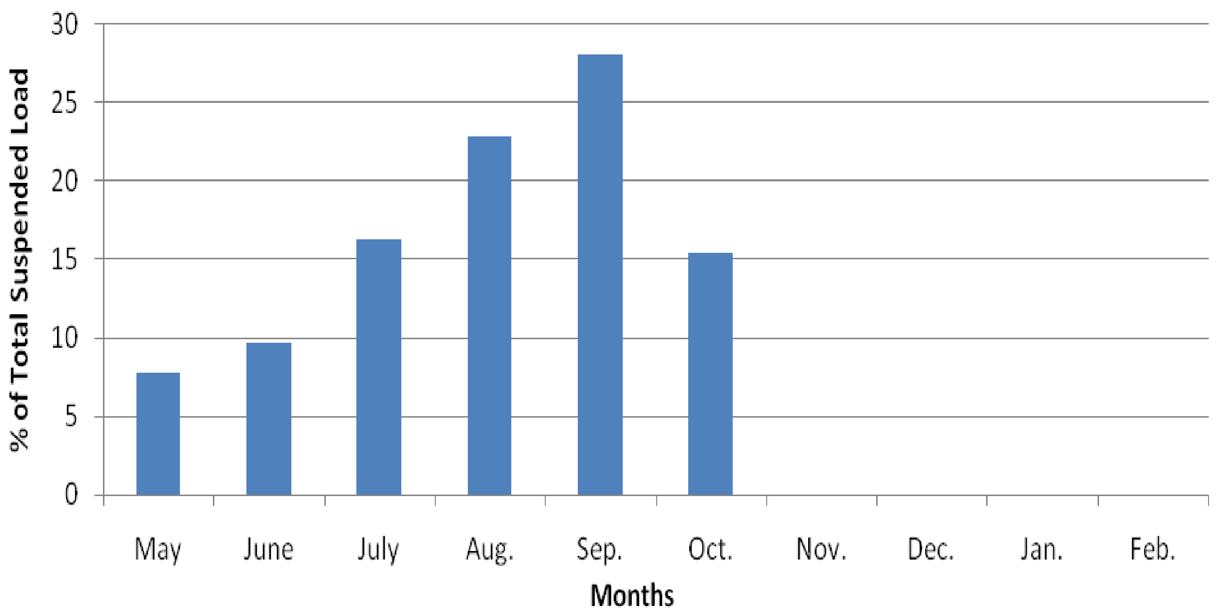

Fig. 4 Suspended Sediment Load Regime Diagram for Goruba Stream

A very interesting observation however is that the difference in channel sediment yields is much higher than that in the specific sediment yields which is undoubtedly as a result of the difference in size and goes a long way to confirm that the decrease in sediment yield can be explained by increases in deposition and sediment storage within the channel network with increasing watershed size (Gottschalk, 1964; Nichols and Renard, 1999).

The suspended sediment load regime diagram below reveal that the month of September, which is the month with highest discharge, has the highest suspended sediment load while the month of May has the least value. Unlike the Malmo stream regime diagram with double maxima in Yusuf (2006), that of Goruba has a single maximum in September 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.

5. Conclusion

The sedimentation of the Ahmadu Bello University (ABU) reservoir which provides water for the University community is the result of eroded materials transported and deposited on the reservoir floor which consequently affects the water holding capacity of the dam. The reservoir 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 and Specific Sediment Yield (SSY) value of 92 tons/km^2/yr were derived for the catchment area. Part of his recommendation was that future studies should look into the spatial spread of sediment contribution into the reservoir by all the in-flowing streams so as to determine which inflow is the most problematic in terms of reservoir sedimentation. An attempt was made here, to look at the southernmost tributary which is the Goruba tributary in order to make a comparison between the two.

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