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*Full Length Research Paper*

# Estimate of bed load transport in Kubanni Watershed in Northern Nigeria using grain size distribution data

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**Representative bed material samples were taken from the gauging sites located on two rivers, Samaru River and Goruba River, in the Kubanni Watershed for sieve analysis to obtain the grain size distribution of the bed materials. The analyses of the grain size distribution showed that the bed load accounted for 7% of the total suspended sediment load of 19,039,450 kg/annum in the Kubanni Watershed. Samaru River bed material had a geometric mean particle size, $D_{50}$, of 0.38 mm and consequently, the river transported bed material of larger diameter than Goruba River with bed material of lesser $D_{50}$ of 0.30 mm. It is recommended that 7% of the total suspended load should be used as bed load estimate for sedimentation studies in the basin and also, this simple method should be encouraged for estimating bed load transport in other basins.**

**Key words:** Kubanni Watershed, bed load, sediment load, sieve analyses, transport.

## INTRODUCTION

Bed load dominates the lower portion of sediment load in natural rivers. Sediment load denotes material that is being transported by rivers. Based on the mode of transport, sediment load can be divided into bed load and suspended load. Bed load is the sediment load transported close to the bed where particles move intermittently by rolling, sliding, or jumping. Turbulence supports suspended load throughout the water column, and sediment is swept along at about the local flow velocity.

Knowledge of sediment transport is important in engineering hydrologic practices such as river restoration, ecosystem protection, navigation, watershed studies and reservoir management. Bed load transport in natural rivers is a complicated phenomenon. This is because the movement of bed load is quite uneven in both the transverse and longitudinal directions and flunctuates considerably (Xlaoqing, 2003). In practice, it is more difficult to measure the bed load discharge accurately than it is to measure suspended load (Xlaoqing, 2003; Robert, 2010).

Bed load can be measured directly by using bed load samplers. Direct measurements of bed load have traditionally been made by placing samplers in contact with the bed, allowing the sediment transported as bed load to accumulate inside the sampler for a certain period of time, after which the sampler, with the content, is removed and the material is emptied and weighed to determine the weight of transported bed load per unit of time (that is, bed load discharged). Samplers used may be classified into basket-type, pressure-difference-type, pan-type and pit-type categories. Nevertheless, the direct measurement is marred with some shortcomings such as varying efficiencies of the available samplers which is from 10 to about 150% for different types of samplers (Xiang, 1980; ISO, 1981; Xlaoqing, 2003) and the weight of the sampler which may sink into soft sands and thereby collect a biased sample (Nani, 1981). However, Xlaoqing (2003) and Robert (2010) noted the ease of operating samplers, if proper hoisting facilities are available, as the advantage of the direct method.

The indirect measurement involves the various methods such as sedimentation process, tracer method, dune tracking and bedform velocimetry. Also, Bed load can be estimated using various bed load transport functions available in the literature especially when the rivers have a moveable bed of coarse sediment, but this method is subject to considerable uncertainty (Morris and Fan, 1998). Nevertheless, Chien (1980) analyzed several bed load formulae and pointed out that they have common properties and give similar results under certain

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**Table 1.** Recommended quantities for particle-size analysis.

| Method | Size range (mm) | Analysis concentration (mg/l) | Quantity of sediment (g) |
|---|---|---|---|
| Sieve | 0.062 - 32 | | 0.07 – 64. 000 |
| VA tube | 0.062 - 2.0 | | 0.05 – 15.0 |
| Pipet | 0.002 - 0.062 | 2,000 – 5, 000 | 1.0 – 5.0 |
| BW tube | 0.002 - 0.062 | 1, 000 – 3, 000 | 0.5 – 1.8 |
| Hydrometer | 0.002 - 0.062 | 40, 000 | 30.0 – 50.0 |

Source: American Society of Civil Engineers (ASCE) (1975).

conditions notwithstanding their different forms.

Based on measurement technique, US Army Corps of Engineers (1995) categorized total sediment loads into measured and unmeasured loads. The measured load is mainly the suspended sediments that can be sampled with depth integrated hand held samplers while the unmeasured loads include some of the unaccounted suspended load, within the lower 0.15 m depth portion of a sampled water column and the entire bed load (US Army Corps of Engineers, 1995; Adeogun, 2008; Otun and Adeogun, 2010). Since the bed materials wholly represent the unmeasured loads, it is pertinent that the bed materials be separated into its components.

In order to distribute the bed materials into suspended and bed loads, the limit particle size is required. Theoretically, the limit particle size would be defined by the diameter of the largest sediment particle maintain in suspension or, conversely, by the diameter of the smallest particle contained in the bed load. Borgadi (1974) was of the opinion that the former and latter particle sizes were 0.5 and 0.2 mm respectively and concluded that the limit particle size lied in between the two extremes. Practically, based on investigations in the United States and in Italy the limit particle size has been estimated at 0.35 mm by Gallo and Rotundi. Nevertheless, the use of limit particle size in such a sedimentation study necessitates the distribution the bed material particles into sub groups of different grain size distribution. The grain size distribution data are obtained from a cumulative size-frequency distribution curve which is drawn from particle size analysis. Methods for obtaining particle size analysis are size dependent and are summarized in Table 1 (ASCE, 1975).

Moreover, because of the difficulty and uncertainty involved in bed load measurement, one common method to estimate bed load is to compute it as a percentage of the total suspended sediment load. Mudi (1995) is of the same opinion and suggested that bed load accounts for about 3 to 15% of the suspended load depending upon the nature of the bed materials and it is usually taken as 10%. However, in a highly erodible watershed like Kubanni with so many gully incisions (Ologe, 1973), it would be of great practical advantage if the bed load transport from such a particular watershed is known. This study therefore, applies the grain size distribution data to estimate the percentage of total sediment load which is bed load to quantify the amount of bed load transport in Kubanni Watershed in Northern Nigeria.

## METHODOLOGY

### Study area

The Kubanni Watershed has an area of 57.6 km$^2$ and drains two rivers - Samaru River and Goruba River - into the Kubanni River downstream of Kubanni Reservoir (that is, Ahmadu Bello University Reservoir) as shown in Figure 1. It was reported that Samaru River carries higher sediment concentrations than Goruba River from the Kubanni watershed as shown in Table 2 (Otun and Adeogun, 2010). Also, their work reflected that the annual discharge observed at the Samaru River gauge site was19, 631, 635 m$^3$/annum while the annual discharge at the Goruba River gauge site was 10, 485, 158 m$^3$/annum as shown in Table 3.

### Study approach

As stated earlier, the total sediment loads consist of both measured and unmeasured sediment loads. The study approach therefore, aims at quantifying these two components and then accounting for the bed load portion of the unmeasured sediment.

### Quantifying measured sediment loads

The US Army Corps of Engineers (1995) and Ongley (1996) established Equation (1) for estimating the measured suspended sediment load Qs in kg/day.

$$Q_s = K.c.q \quad (1)$$

Where Qs = sediment discharged (kg/day), c = sediment concentration (mg/l), q = water discharge (m$^3$/s), and K = 86.4. The value of c is obtained as the concentration of the sampled sediments using a standard lightweight hand-held US DH-48 sediment sampler, q is obtained from an established stage-stream flow relationships (rating curve) for the gauge stations at Samaru River and Goruba River.

By applying this method, Otun and Adeogun (2010) obtained the records of measured sediment as shown in Table 2 for the two rivers.

Also, measurement of sediments is usually computed in relation to river discharges. Otun and Adeogun (2010) extensively studied the hydrology of the Kubanni Rivers and established a rating curve for the two rivers from which their flow records are as presented in Table 3.

### Quantifying unmeasured sediment load

The unmeasured sediment loads discharged at the gauging sites

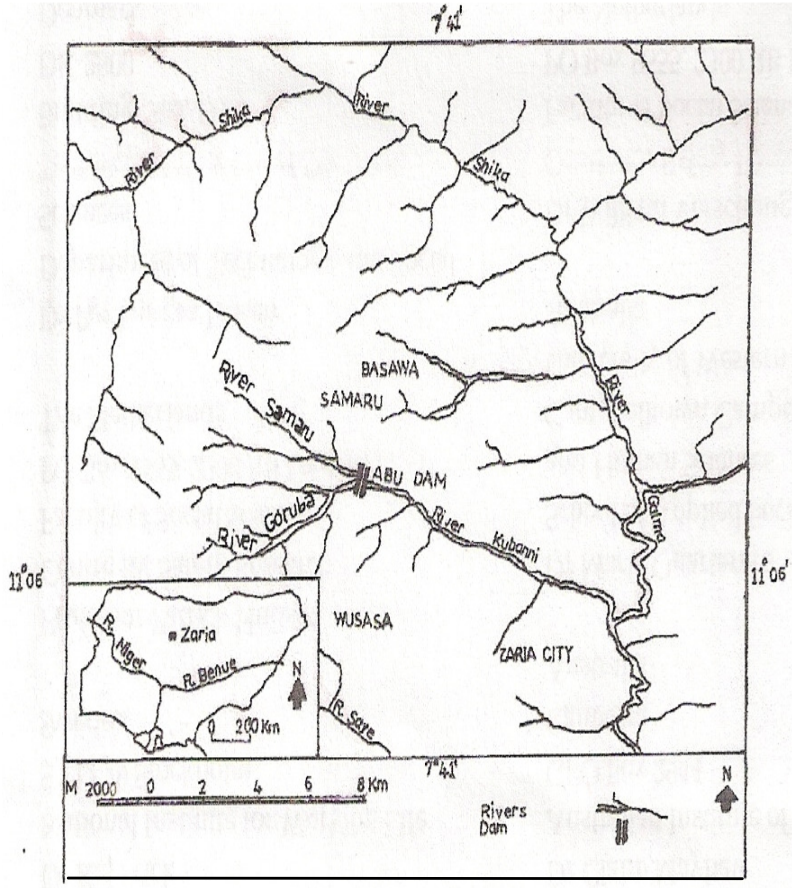


**Figure 1.** Location of Kubanni Watershed (Source: Adeogun, 2008).

**Table 2.** Seasonal sediment load (in kg/annum) transport in Kubanni Watershed.

| Month | Samaru River | | Goruba River | | Total ($\times10^3$) (kg/annum) |
|---|---|---|---|---|---|
| | Measured sed. load $\times10^3$ (kg/month) | Unmeasured sed. Load $\times10^3$ (kg/month) | Measured sed. load x$10^3$ (kg/month) | Unmeasured sed. load $\times10^3$ (kg/month) | |
| June | 44 | 10 | 8 | 2 | 64 |
| July | 929 | 97 | 210 | 22 | 1258 |
| August | 3137 | 243 | 816 | 101 | 4297 |
| September | 5339 | 349 | 1346 | 152 | 7186 |
| October | 4369 | 307 | 1183 | 134 | 5993 |
| November | 1062 | 107 | 285 | 41 | 1495 |
| December | 64 | 12 | 15 | 3 | 94 |
| Total | 14944 | 1125 | 3863 | 455 | 20387 |

Source: Otun and Adeogun (2010).

located at Samaru and Goruba Rivers are estimated by using Colby approach as described by Otun and Adeogun (2010). Their results are as presented in Table 2.

### Sampling of bed materials

The bed load component of the unmeasured sediment is accounted for by analyzing the bed materials sampled at the gauging sites of the Kubanni Rivers. The bed material samplers designed by the US Federal Interagency Sedimentation Project are expensive and not readily available in the country. However, a scoop, the Jarocki type, described by Daryl and Fuat (1976), shown in Figure 2, was improvised to take bed material samples. The scoop was designed such that it has top and bottom length of 0.3 and 0.2 m respectively, and a width of 0.1 m. It has a shutter with lead weight attached so that it snaps under the weight once the wire tension is released. The scoop was used to take bed material samples at the gauging

**Table 3.** Seasonal inflow into Kubanni reservoir.

| Month | Total monthly Inflow ($m^3$/month) | | Total |
|---|---|---|---|
| | Samaru River | Goruba River | |
| June | 456451 | 184118 | 640569 |
| July | 2243376 | 1075507 | 3318883 |
| August | 4118688 | 2245104 | 6363792 |
| September | 5149872 | 2810765 | 7960637 |
| October | 4784400 | 2695939 | 7480339 |
| November | 2384640 | 1258848 | 3643488 |
| December | 494208 | 214877 | 709085 |
| Total | 19631635 | 10485158 | 30116793 |

Source: Otun and Adeogun (2010).

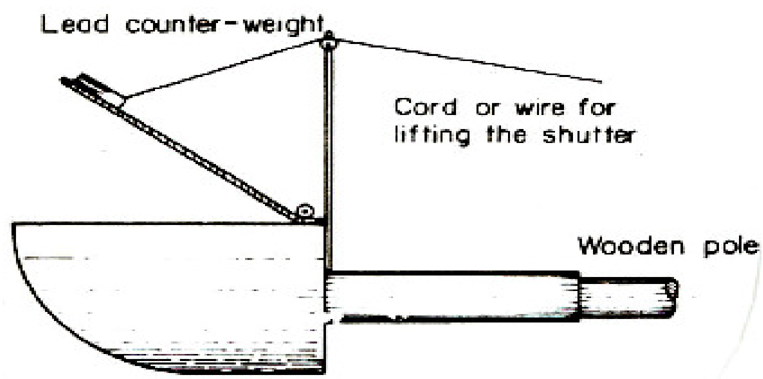


**Figure 2.** Scoop sampler with shutter.

site by positioning it at an angle on the stream bed and the wire pulled in order to raise the shutter. The sampler was used to scoop the bed material from top two inches of the streambed to obtain a quantity of sample and then, the wire tension was released so that the shutter snapped out and shut. The scoop was gradually raised from the river bed. Bed material samples were taken for sampling verticals ¼, ½, ¾ width of the river cross-section and the average of the mixture was taken to the laboratory for analysis.

### Laboratory analyses of samples

Sieve analysis is employed for this study because most fluvial sediment particles diameter fall within the range specified for sieve analysis as shown in Table 1. The method was carried out by oven-drying the representative sample from which 200 g was weighed and put in a set of U.S. Standard Sieve with mechanical shaker and then shaken vigorously. The sediments retained on each sieve were weighed and recorded. From the records particle graduation curves were plotted to find out their particles sizes and their percentages.

### Distribution of grain sizes

The two river bed materials were then distributed into sub groups using U.S. Standard Sieve grain sizes (in millimeter), so that the unaccounted suspended sediment load and the bed load could be quantified using the limit particle size of 0.35 mm in accordance with Borgadi's (1974) observation. In accordance with the U.S. Standard Sieve grain size distribution, the following sediment particle sizes are identified: gravel (5.0 to 50), coarse sand (2.0 to 5.0), medium sand (0.4 to 2.0), and fine sand (0.07 to 0.4). The study therefore employed the following grain size distributions: grain size diameters (D) of particles greater than medium sand that is, grain sizes that are wholly coarse sand and gravel (fine and coarse) (that is, D > 2.000); D of particles that are wholly medium sand (that is, 2.000 > D > 0.600); D of particles that are mixture of medium sand and fine sand (that is, 0.600 > D > 0.200) and lastly, D of particles that are wholly fine sand and silt/clay (that is, 0.200 > D).

The percentage of the latter grain size distribution comprising of fine sand and very fine particles such as silt and clay represent the unaccounted suspended sediments in the bed materials analyzed. The sum of the fractional percentages of the other grain size distributions implies the percentage of the unmeasured sediment loads representing the bed loads. Also, the average grain size for each of the size distribution is determined and compare with the limit particle size of 0.35 mm to confirm the grain size distributions of the bed materials into unaccounted suspended sediment and bed loads.

## RESULTS AND DISCUSSION

The particle size distribution for Samaru River and Goruba River bed materials are shown in Figures 3 and 4

**Table 4.** Grain size distribution for Samaru River bed materials.

| Grain size (mm) | Average grain size (mm) | Percentage distribution | |
|---|---|---|---|
| | | is% | ib% |
| D > 2.000 | - | | 1 |
| 2.000 > D > 0.600 | 0.919 | | 11 |
| 0.600 > D > 0.200 | 0.356 | | 73 |
| 0.200 > D | - | 4 | |

$D_{35}$ = 0.34 mm, $D_{50}$ = 0.38 mm, $D_{65}$ = 0.43 mm.

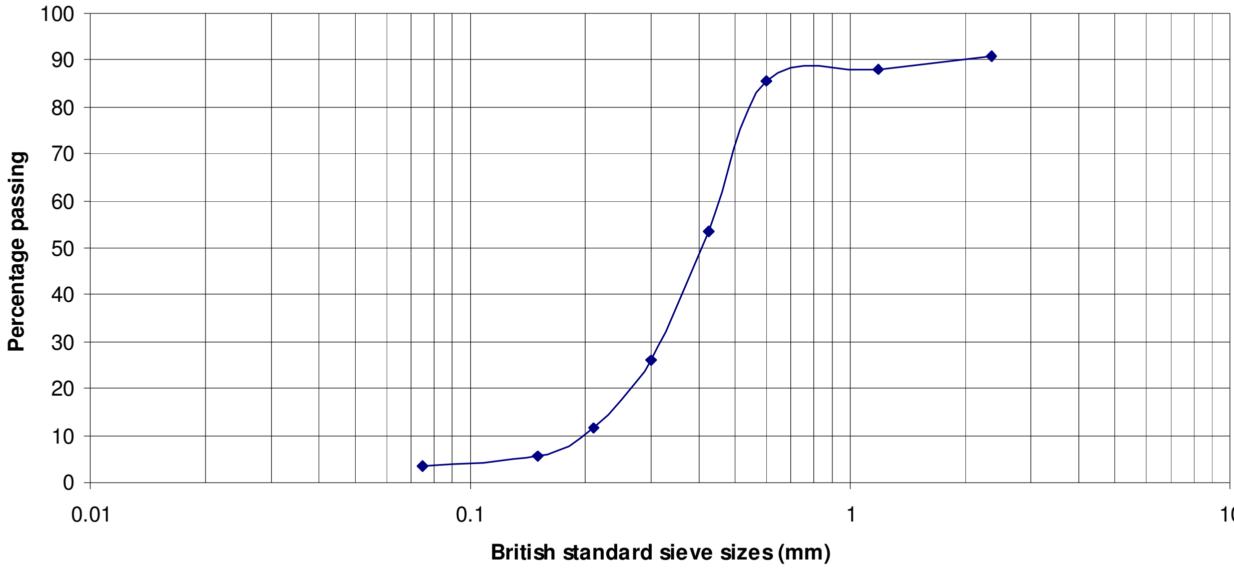


**Figure 3.** Particle size curve for Samaru River bed material.

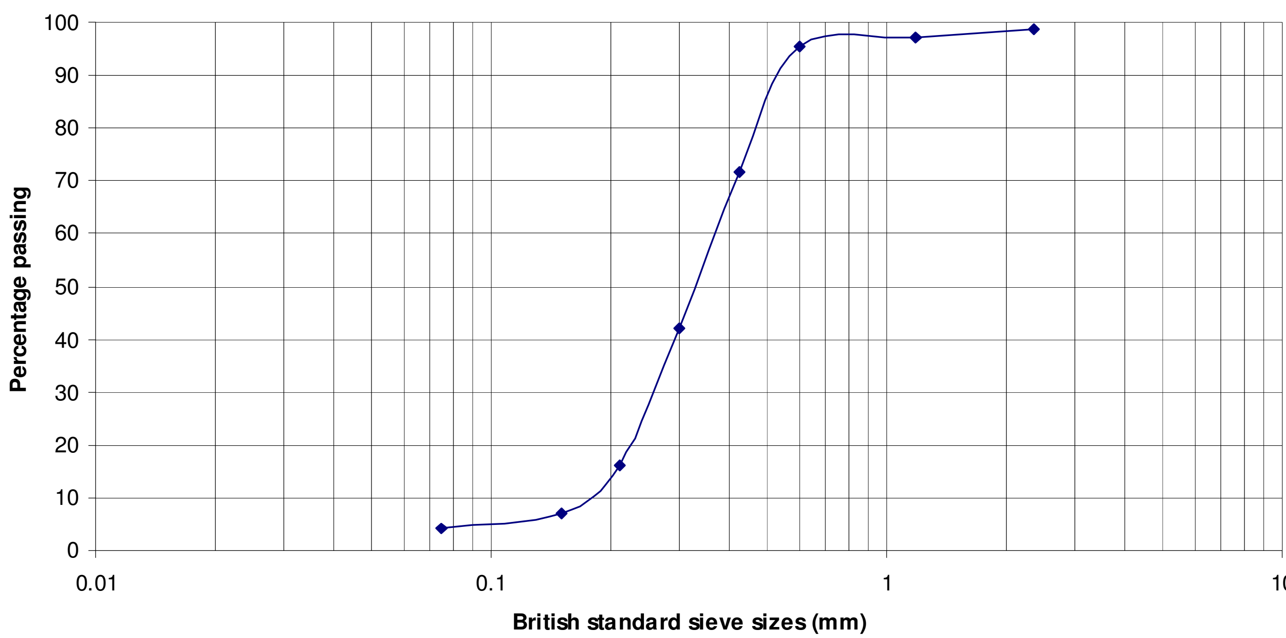


**Figure 4.** Particle size curve for Goruba River bed material.

**Table 5.** Grain size distribution for Goruba River bed materials.

| Grain size (mm) | Average grain size (mm) | Percentage distribution | |
|---|---|---|---|
| | | is% | ib% |
| D > 2.000 | - | | 1 |
| 2.000 > D > 0.600 | 0.800 | | 10 |
| 0.600 > D > 0.200 | 0.348 | | 75 |
| 0.200 > D | - | 9 | |

$D_{35}$ = 0.28 mm, $D_{50}$ = 0.30 mm, $D_{65}$ = 0.37 mm

**Table 6.** Estimation of total annual suspended load and total bed load transported from Kubanni Watershed.

| Rivers | Total suspended load (ton/yr) | | Total bed load (ton/yr): $i_b$% of unmeasured |
|---|---|---|---|
| | Measured | (100- $i_b$) % of unmeasured | |
| Samaru | 14944 | 168.75 | 956.25 |
| Goruba | 3863 | 63.70 | 391.30 |
| Total | 18807 | 232.45 | 1347.55 |

respectively.

The limit particle size of 0.35 mm as stated by Borgadi (1974) is used to distribute the sediment particles into the unaccounted suspended sediment load and bed load. From Figures 3 and 4, the grain size distributions of the bed materials for the two rivers are shown in Tables 4 and 5 respectively. Table 4 shows that the grain size distribution of 0.600 to 0.200 mm has an average grain size of 0.356 mm, close to the limit particle size of 0.35 mm, and this implies that the Samaru River bed material has a total percentage size distribution of bed load of 85% ($i_b$%) and size distribution of unaccounted suspended sediment of (100-$i_b$%), that is, $i_s$% consisting of 4% and other sediment wash load deduced by extrapolating the curve in Figure 3.

The total annual unmeasured sediment load of 1125 × $10^3$ kg/annum in Table 2 can be divided into 168.75 × $10^3$ kg/annum suspended sediment load and 956.25 × $10^3$ kg/annum bed load. This means that total sediment loads at Samaru River gauging site consists of 15,112.75 ×$10^3$ kg/annum suspended sediment load and 956.25 × $10^3$ kg/annum bed load.

Similarly, Table 5 reflects that the grain size distribution of 0.600 to 0.200 mm has an average grain size of 0.348 mm, which is also close to the limit particle size of 0.35 mm, and this implies that the Goruba River bed material has a total percentage size distribution of bed load of 86% ($i_b$%) and size distribution of unaccounted suspended sediment of (100-$i_b$%), that is, $i_s$% consisting of 9% in addition to wash load by extrapolation from Figure 4. Hence the unmeasured sediment load of 455 × $10^3$ kg/annum at Goruba River gauging site is distributed as 63.70 × $10^3$ kg/annum unaccounted suspended sediment load and 391.30 × $10^3$ kg/annum bed load. Hence, the sediment loads at Goruba station totals 3926.7 × $10^3$ kg/annum suspended load and 391.3 × $10^3$ kg/annum bed load as shown in Table 6.

Consequently, the total annual sediment load transported by the two rivers from Kubanni Watershed consists of 19,039.45 × $10^3$ kg/annum suspended sediment load and 1,347.55 ×$10^3$ kg/annum bed load.

Moreover, the geometric mean particle size, $D_{50}$, of 0.38 mm was deduced from Figure 3 for Samaru River bed material while Goruba River bed material reflects a lower value of 0.30 mm as shown in Figure 4. This implies that the higher annual discharge of 19, 631, 635 $m^3$/annum observed by Otun and Adeogun (2010) for Samaru River has the capacity to transport bed materials of larger diameter than Goruba River with an annual discharge of 10, 485, 158 $m^3$/annum.

## CONCLUSIONS AND RECOMMENDATIONS

The bed load component of the total sediment load transported from the Kubanni Watershed has been evaluated using grain size distribution of the bed materials of the rivers in the watershed and the following conclusions were drawn from the study:

(a) The total annual sediment load of 20,387 x $10^3$ kg/annum transported from the Kubanni Watershed has been sub divided into important practical terms; annual suspended sediment load of 19,039.45 x $10^3$ kg/annum and annual bed load of 1,347.55 x $10^3$ kg/annum.

(b) From aforegoing, it can be deduced that the bed load accounted for 7% of the total suspended sediment load in Kubanni basin.

(c) Hence this bed load percentage of 7% could be of practical use in further sedimentation studies on the watershed. This is in agreement with the observation of Mudi (1995) that bed load accounts for about 3 to 15% of the suspended sediment load depending on the nature of a basin

(d) Total bed load size distributions of 85 and 86% of bed materials for Samaru and Goruba Rivers reflect that the bed load transport hydraulics of the two rivers are similar in the Kubanni Watershed.

(e) Samaru River bed material has a geometric mean particle size, $D_{50}$, of 0.38 mm and transports bed materials of larger diameter than Goruba River which has $D_{50}$ of 0.30 mm.

(f) The study approach could be applied to other catchment areas for estimating bed load in sedimentation studies.

However, it is recommended that the bed load percent-tage of total load transport in the watershed should be investigated periodically as any change in the river flow hydraulics and/or hydrology of the basin might influence the amount of bed load transport. Moreover, the limit particle size of the catchment sediments should be determined and applied to similar future studies.

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