Nigerian Journal of Water Resources
2021, 7(1): 22-32
Print ISSN: 115-9944
Online ISSN: 2795-3793

ESTIMATION OF BEDLOAD TRANSPORT INTO GURARA WATERSHED USING GRAIN SIZE DISTRIBUTION DATA

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ABSTRACT

An improvised scoop was used to take bed material samples from the six (6) gauging sites located on each of the inflowing rivers into Gurara dam reservoir in the Gurara Watershed. Sampling verticals of ¼, ½, ¾ width of the river cross-section were used and the average of the mixture was taken to the laboratory 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 13% of the total suspended sediment load of 22,254,820 kg/year in the Gurara Watershed. The geometric mean particle size (D_{50}) D_{60}, D_{30} and *D_{10} were calculated. The uniformity coefficient and coefficient gradations of the six inflowing rivers were calculated which ranged from 0.542mm to 1.146mm and showed that the soils are poorly/uniformly graded. The 13% of the total suspended load should be used as bed load estimate for sedimentation studies in the Watershed and neighbouring watershed with similar hydrology. This simple method should be encouraged for estimating bed load transport in other basins.*

KEY WORDS: *Bed load, Sediment load, Sieve Analyses, Gurara Watershed, Transport.*

1.0 INTRODUCTION

Bed load is the bottom component of sediment load that moves in nearly continual contact with the river bed by siltation and traction, in other word, by bouncing, sliding and rolling along the bottom of the river bed by the force of the water. This means that the particles do not go into suspension along the bed. Sediment load can be split into bed load and suspended load on the basis of mode of transport. Xlaoqing, (2003); Adeogun et al, 2011; Adegbola and Olaniyan, (2012a) explained that bed load movement is quite uneven in both the transverse and longitudinal directions and fluctuates considerably. Bed load movement is a complex phenomenon and essential type of sediment transport in rivers, which comprises largely of coarser particles. Bed load has crucial effects on the fluvial process, although its quantity is not as large as that of the suspended load. Therefore, sediment transport knowledge is essential in hydrologic engineering practices like watershed studies, river restoration, reservoir management, ecosystem protection and navigation etc. In practice, it is more difficult to measure the bed load discharge accurately than it is to measure suspended load (Xlaoqing, 2003; Otun and Adeogun, 2011). On the basis of data collection conditions, bed load measurement methods can be divided into two classes: the direct and the indirect methods. The direct method measures the bed-load discharge by directly taking samples from the river with a suitably designed sampler. Weight of the sample taken by the bed load sampler in a specific time interval represent the bed load discharge per width of the sampler. This was also explained by Suresh (1997) that the estimation of rate of bed load movement through the stream flow is carried out by placing the sampler over the bed and measuring the amount of materials collected for a given time. The bed load samplers are used for collecting the bed load samples. Bed load samplers used in the direct method are categorised into the basket type, pressure-difference type, pan type and pit type based on the construction and principle of operation. The sampler is lowered into the stream or reservoir over the bed, keeping its open end towards the upstream side of the flow, to collect the sample of moving material. For estimating the bed load, the sample collected through the sampler are dried and weighted. The dry weight is then divided by the time taken for measurement per unit stream width. However, Xlaoqing (2003) explained that the bed load samplers used in direct method are produced in portable form and are relatively simple to operate, although the required sampling can be difficult and time-consuming. Though, the direct measurement is featured with some deficiencies like varying efficiencies of the available samplers which is from 10 to about 150% for different types of samplers (Xiang, 1980; Xlaoqing, 2003; Adeogun et al, 2011; Adegbola, 2012a) and the weight of the sampler which may sink into soft sands and thereby collect a biased sample (Nani, 1981). According to Adegbola, 2012b; Adeogun et al, 2011; and Xlaoqing, 2003 noted that the indirect measurement includes the various methods like sedimentation process, tracer method, dune tracking and bedform velocimetry.

Table 1: Recommended quantities for particle – size analysis

Method	Size Range, mm	Analysis Concentration mg/1	Quantity of sediment (g)
Sieve	0.062- 32		0.07-64,000
VA tube	0.062-2.0		0.05-15.0
Pipit	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: US Army corps of Engineers (1995)

US Army Corps of Engineers (1995) classified total sediment loads into measured and unmeasured loads based on measurement technique. Therefore, the total sediment load is the measured, unmeasured suspended sediment discharge and bed load. 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, Adeogun et al., 2011; Adegbola, 2012a; Ugbala, 2021). Given that the bed materials entirely represent the unmeasured loads, it is in point that the bed materials be split up into its components. This can be obtained by using particle size analysis to distribute the bed materials into suspended and bed loads. The limit particle size is the diameter of the largest sediment particle maintained in suspension or, at the same time, is the diameter of the smallest particle contained in the bed load. The values are 0.5 and 0.2 mm respectively according to some researches. 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 shown in Table 1 and are size dependent (ASCE, 1975; Adeogun et al., 2011). Due to the complexity and uncertainty in bed load estimation, one common method to estimate bed load is to compute it as a percentage of the total suspended sediment load. Mudi (1995) suggested that bed load accounts for about 3 to 15% portion of the suspended load depending upon the nature of the bed materials from the basin. Therefore, in watershed like Gurara, it would be of great practical advantage if the bed load transport from such a particular watershed is known. This research, applied the grain size distribution data to estimate the percentage of bed load transport in Gurara Watershed, Nigeria.

1.1 Study area

The Gurara River basin is situated in Northern Nigeria, between latitudes 8°15' and 10°05' N and longitudes 6°30' and 8°30' E. It drains six rivers that recharge the Gurara Dam Reservoir as shown in Figure 1 and 2. It was reported that Gurara River carries highest sediment concentrations than other Rivers from the Gurara watershed as shown in Table 2 (Ugbala, 2021). Also, his work reflected that the total annual discharge observed at the six River gauge sites was 25,725,000 m^3 /year as shown in Table 3. The six Rivers are of beneficial use to the inhabitants for domestic, industrial, agricultural and other purposes.

2.0 MATERIALS AND METHODS

2.1 Methods

The total sediment loads comprise of both measured and unmeasured sediment loads. This research estimated these two parts of the total sediment loads and then applied grain size distribution data to account for the bed load part of the unmeasured sediment.

2.2 Quantification of measured sediment loads

Adeogun (2008), Otun and Adeogun (2010), Adeogun et al., (2011), Adegbola and Olaniyan (2012a), and Ugbala (2021) reported that US Army Corps of Engineers (1995), and Ongley (1996), established equation (1) below for estimating the measured suspended sediment load Q_s *kg/day*

$Q_s = 86.4CQw$..........(1)

Where Qs = Sediment discharged (kg/day), C=Sediment concentration (mg/l), Qw = water discharge (m3/s), and 86.4 = K. The value of C is obtained as the concentration of the sampled sediments using a standard lightweight hand-held US DH-48 sediment sampler, Qw is obtained from an established rating curves (stage-stream flow relationships) for the gauge stations at Gurara River, Akwana River, Awam River, Igoh River, Apela and Atara River. Applying this approach, Ugbala (2021) obtained the records of measured sediment as shown in Table 2 for the six rivers. Ugbala (2021) carried out a fluvial sediment study of Gurara and established a rating curves for the six rivers from which their flow records are shown in Table 3.

2.3 Quantification unmeasured sediment load

The unmeasured sediment loads discharged at the gauging sites located at Gurara River, Akwana River, Awam River, Igoh River, Apela and Atara Rivers were determined by applying Colby approach as described by Otun and Adeogun (2010). Their results are as shown below in Table 2a and 2b.

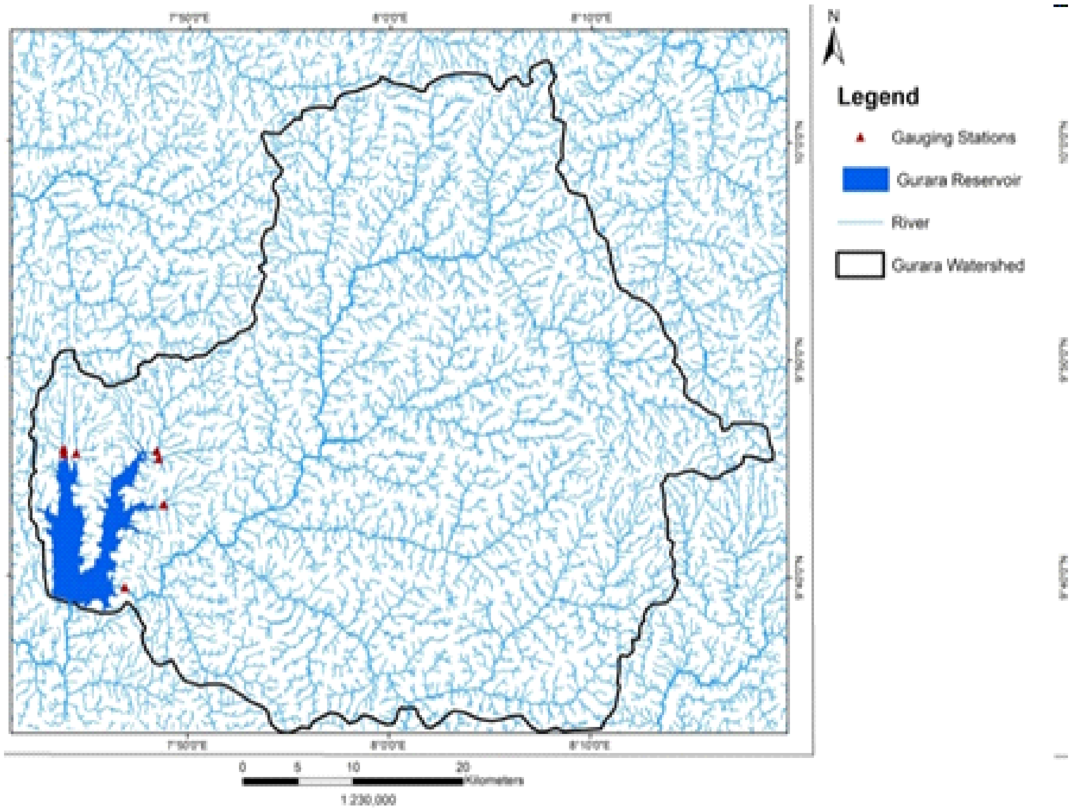

Figure 1:Location Gurara Watershed
(Source: Ugbala E.N, 2021).

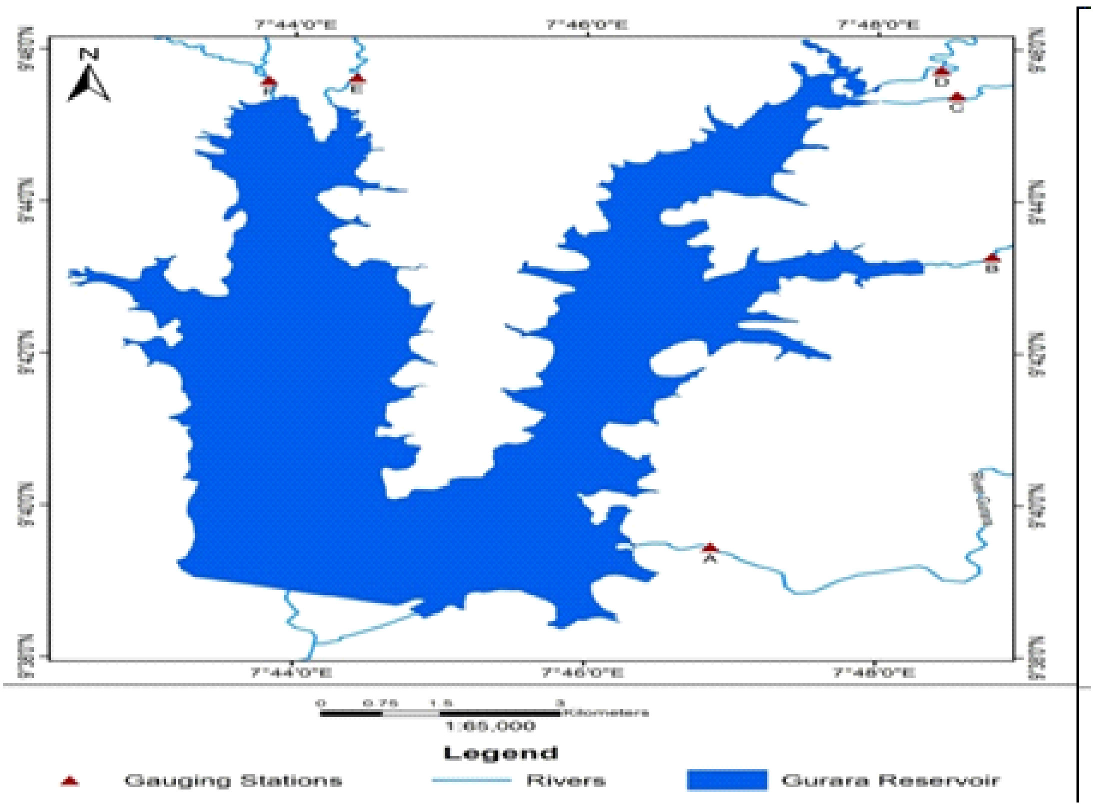

Figure 2: The location of the gauging stations
(Source: Ugbala E.N, 2021)

Table 2a: Annual sediment load Discharged (kg/year) into Gurara Reservoir from Gurara, Akwana and Awam river stations

Mon	Gurara River		Akwana River		Awam River		Sub Total 1 10^3 (kg/year)
	Measured sediment Load 10^3 (kg/month)	Unmeasured sediment Load 10^3 (kg/mon.)	Measured sediment Load 10^3 (kg/mon.)	Unmeasured sediment Load 10^3 (kg/mon.)	Measured sediment Load 10^3 (kg/mon.)	Unmeasured sediment Load 10^3 (kg/mon.)	
Jan.	32	3			8	3	46
Feb.	30	4			7	3	44
Mar.	50	6			8	5	69
Apr.	80	8	10	4	11	7	120
May	170	10	12	4	15	8	219
Jun.	585	12	90	6	124	9	826
Jul.	920	90	145	20	195	58	1,428
Aug.	1550	246	510	118	613	135	3,172
Sep.	1950	369	823	162	956	170	4,430
Oct.	1250	312	524	124	630	145	2,985
Nov.	412	98	260	43	280	57	1,150
Dec.	80	14	37	6	49	8	194
	7,109	1,172	2,411	487	2,896	608	14,683

Table 2b: Annual sediment load Discharge (kg/year) into Gurara Reservoir from Igoh river station, Apela river station and Atara river stations.

Mon	Igoh River		Apela River		Atara River		Sub Total 2 10^3 (kg/year)
	Measured sediment Load 10^3 (kg/month)	Unmeasured sediment Load 10^3 (kg/month)	Measured sediment Load 10^3 (kg/mon)	Unmeasured sediment Load 10^3 (kg/mon.)	Measured sediment Load 10^3 (kg/mon)	Unmeasured sediment Load 10^3 (kg/month)	
Jan.	10	6					16
Feb.	12	6					18
Mar	15	7					22
Apr	40	10	12	5	8	6	81
May	65	13	25	6	24	10	143
Jun.	190	15	50	7	54	11	327
Jul.	480	65	180	35	160	28	948
Aug	880	205	420	125	486	101	2,217
Sep.	1450	275	870	168	846	152	3,761
Oct.	920	228	450	148	483	134	2,362
Nov	360	62	180	48	235	41	926
Dec.	110	8	40	6	51	5	220
	4,532	900	2,227	548	2,347	488	11,042

Hence, the total annual sediment, T = subtotal 1 + subtotal 2 = 14,683 + 11,042 = 25,725,000 kg/year.

Table 3: Annual Inflow into Gurara Reservoir

Mon	Total monthly inflow (m^3/month)						Total (m^3/month)
	Gurara River	Akwana River	Awam River	Igoh River	Apela River	Atara River	
Jan	60,095		20,000	35,000			110,095
Feb	100,000		25,000	45,000			170,000
Mar	160,222		35,100	50,000			245,322
Apr	300,342		40,200	85,000			425,542
May	434,786	128,988	135,000	201,000	96,432	98,534	1,094,740
Jun	556,451	199,118	201,001	254,009	88,249	92,674	1,391,502
Jul	2,295,376	109,550	110,121	1,212,987	98,342	105,345	3,931,721
Aug	4,118,688	224,510	230,700	2,342,564	186,876	210,780	7,314,118
Sep	5,169,872	2,910,765	3,001,118	2,456,784	1,234,121	978,575	15,751,235
Oct	4,784,400	2,700,939	2,831,000	2,342,654	1,212,112	923,563	12,244,668
Nov	2,484,640	1,258,848	1,234,675	1,221,000	678,000	897,987	7,775,150
Dec	498,208	214,877	218,453	26,491	107,233	465,000	1,530,262
Total	20,963,080	7,747,595	8,082,368	10,563,489	3,701,365	3,772,458	54,635,752

2.4 Bedload sediments sampling

The bedload sediment part of the unmeasured sediment was taken into account by examining the bedload sediments sampled in such a manner as to ascertain its elements. A fabricated submersible bedload sampler (improvised scoop) that is identical was improvised to take bedload sediment samples. This is because the bedload sediment samplers designed by the US Federal Interagency Sedimentation Project are high priced and not easily obtainable in Nigeria. The fabricated submersible bedload sampler was designed such that it has top and bottom length of approximately 0.5m and 0.3m respectively, and a width of 0.2 m. The fabricated submersible bedload sampler was used to scoop bedload sediment samples at the gauging sites by lowering to the streambed (bottom) of the inflowing rivers, dragged along the bed to obtain a quantity of sample and then, the wire tension was released so that the shutter snapped out and shut. The sampler was carefully raised back from the river bed to the surface and samples collected to obtain the quantity of the sample. Bed material samples were taken for sampling verticals ¼, ½, ¾ width each of the river cross-section and the mixed samples were taken to the laboratory for analysis.

2.5 Laboratory analyses of Bedload sediment samples

Method of sieve analysis was applied for the grain sizes distribution in laboratory since most sediment particles diameters are within the range recommended for sieve analysis as shown in Table 1. The method was carried out by oven drying the representative sample from 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 particle sizes and their percentages as shown in figure 3 – 8.

2.6 Uniformity Coefficient (C_u) and Coefficient of gradation (C_c)

Uniformity coefficient and coefficient of gradation were some of the basic soil parameters computed from grain size distribution curves by using equation 2 and 3 to categorize granular soils as shown in table 5. The uniformity coefficient, C_u clears the heterogeneity in particle sizes and is given

$$C_u = \frac{D_{60}}{D_{10}} \quad ....(2)$$

If $C_u > 4$, the soil is well graded, whereas if $C_u < 4$, the soil is poorly/uniformly graded while the coefficient of gradation, C_c is computed by using equation 3 below

$$C_c = \frac{D^2_{30}}{D_{60} D_{10}} \quad ....(3)$$

2.7 Distribution of grain sizes

The six river bedload sediment materials were then distributed into sub groups using U.S. Standard Sieve grain sizes (mm), in order that the unaccounted suspended sediment load and the bed load could be quantified using the limit particle size in line with Otun and Adeogun (2010), and Borgadi's (1974) adherence in practice. The sediment particle sizes undermentioned were applied: 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) in line with the U.S. Standard Sieve grain size distribution. The undermentioned grain size distributions were used accordingly: 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 compared 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.

3.0 RESULTS AND DISCUSSION

The particles sizes analysis results are presented in Figures 3-8 which show that the samples have some high percentage of fine sands. The particle size distribution curves for Gurara River, Akwana River, Igoh River, Awam River, Apela River and Atara River bedload materials are shown in Figures 3-8

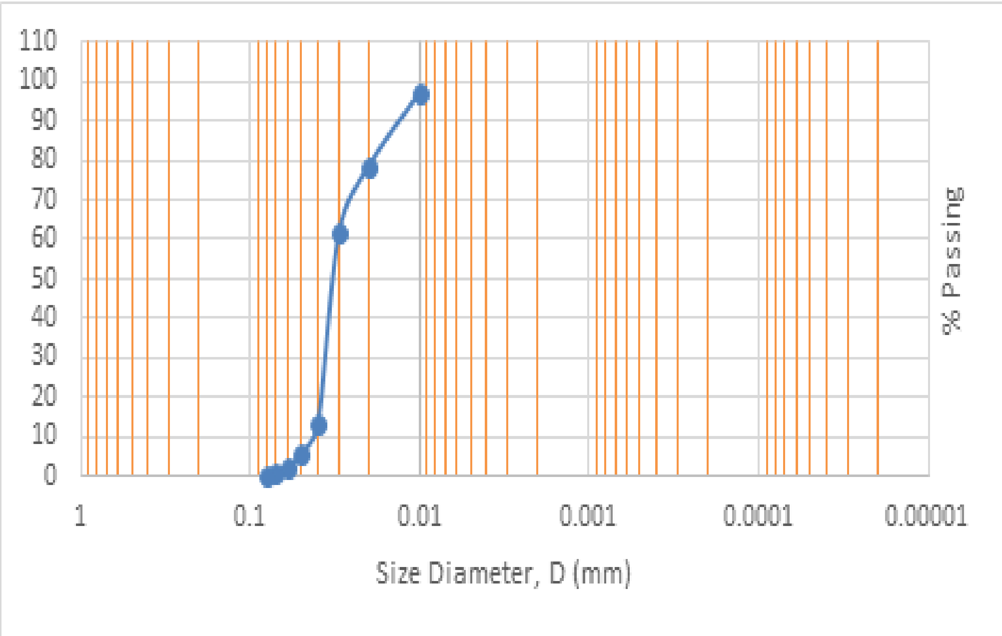

Figure 3: Particle size curve for Gurara River bed material

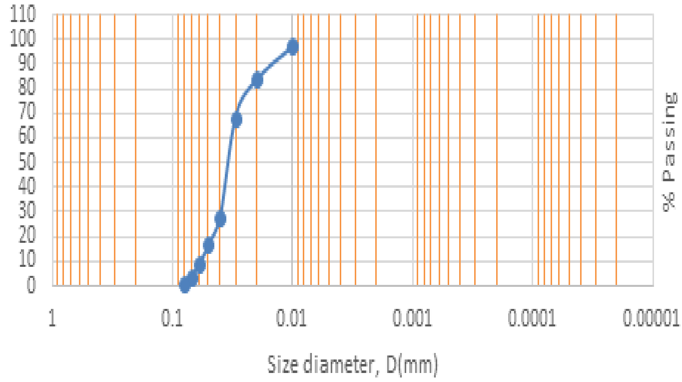

Figure 4: Particle size curve for Akwana River bed material

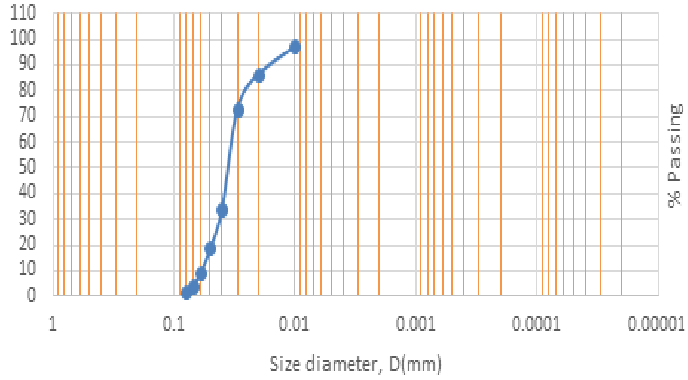

Figure 6: Particle size curve for Awam River bed material

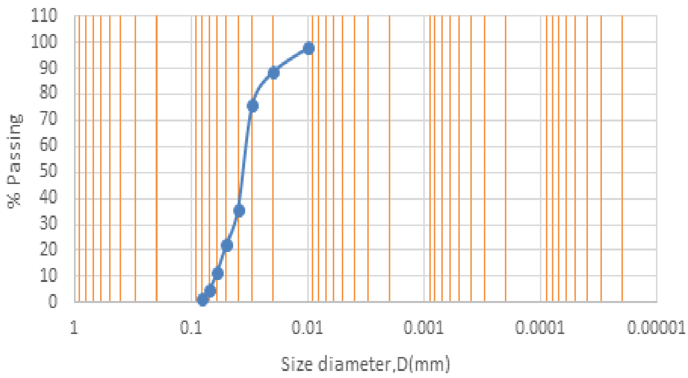

Figure 5: Particle size curve for Igoh River bed material

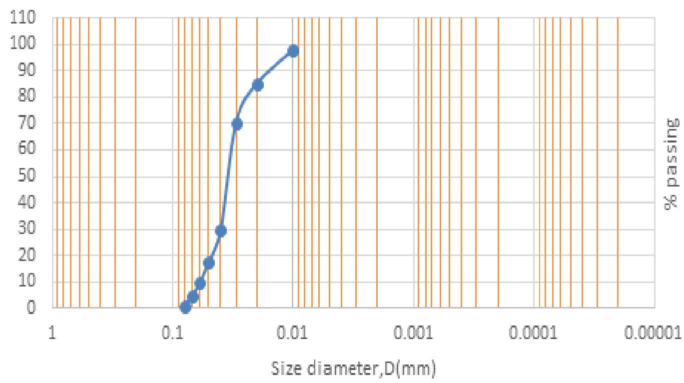

Figure 7: Particle size curve for Apela River bed material

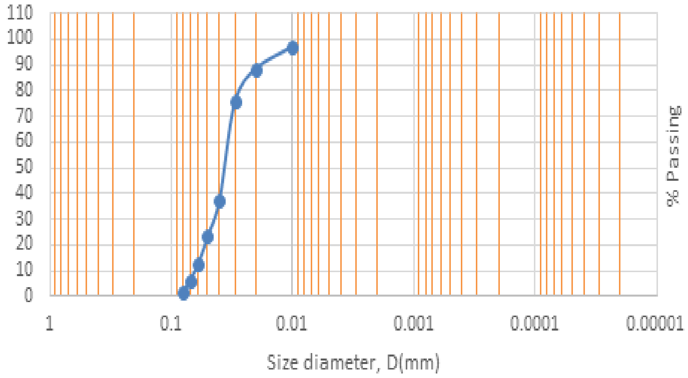

Figure 8: Particle size curve for Atara River bed material

Table 4a: Grain size distribution for Gurara Watershed Bedload

Grain size (mm)	**Percentage distribution I_b %**					
	Gurara River	Akwana River	Awam River	Igoh River	Apela River	Atara River
D > 2.000	-	-	-	-	-	-
2.000 > D > 0.600	-	-	-	-	-	-
0.600 > D	-	-	-	-	-	-
0.200 > D	85	82	81	82	81	81
Total I_b %	85	82	81	82	81	81

Table 5: Computation of uniformity coefficients and coefficient of gradation

Diameter(mm)	Gurara River	Akwana River	Awam River	Igoh River	Apela River	Atara River
D_0	0.030	0.032	0.034	0.035	0.034	0.035
D_0	0.032	0.035	0.038	0.038	0.035	0.038
D_0	0.038	0.040	0.040	0.042	0.040	0.042
D_0	0.042	0.059	0.060	0.060	0.060	0.062
$C_u = \frac{D_{60}}{D_{10}}$	0.714	0.542	0.567	0.583	0.567	0.565
$C_c = \frac{D^2_{30}}{D_{60} D_{10}}$	1.146	0.847	0.784	0.840	0.784	0.813

*C_u= Uniformity coefficients *C_c= Coefficient of gradation

Table 6: Estimation of Total Annual Suspended Load and Total Bedload Discharged into Gurara Watershed

Rivers	Total Suspended Load (kg/year)			Total Bed Load (kg/yr) = I_b % of Unmeasured
	Measured	Unmeasured	(100-I_b) % of Unmeasured	
Gurara, I_b = 85	5,489,000	1,172,000	175,800	996,200
Akwana, I_b = 82	2,911,000	487,000	87,660	399,340
Awam, I_b =81	3,396,000	608,000	115,520	492,480
Igoh, I_b = 82	4,152,000	900,000	162,000	738,000
Apela, I_b = 81	2,722,000	548,000	104,120	443,880
Atara, I_b = 81	2,847,000	488,000	92,720	395,280
Total	21,517,000	4,208,000	737,820	3,465,180

The limit particle size as established by Borgadi (1974) was applied to distribute the sediment particles into the unaccounted suspended sediment load and bed load. The grain size distributions of the bed materials for the six rivers are shown in Tables 4a. Gurara 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%) in Figure 3. The Gurara River has a total annual unmeasured sediment load of **1,172**,000kg/year (Table 6) which can be divided into **175,800**kg/year suspended sediment load and **996,200kg**/year bed load. Similarly, the compositions of other river gauging sites are shown in Table 6. As a result, the total annual sediment load transported by the six rivers from Gurara Watershed comprises of 22,254,820kg/year suspended sediment load and **3,465,180**kg/year bed load. Additionally, all the gauging sites have similar values of the geometric mean particle size, $D_{50,}$ $D_{60,}$ D_{30} *and* D_{10} as shown in Table 5. This means that all the six rivers have the capacity to transport bed materials.

Again, the values of uniformity coefficient for the gauging sites are all less than 4.0. This means that the soils are all poorly/ uniformly graded.

CONCLUSIONS AND RECOMMENDATIONS

(a) The total annual sediment load of 25,725,000 kg/year transported from the Gurara Watershed has been sub divided into important practical terms; annual suspended sediment load of 22,254,820 kg/year and annual bed load of 3,465,180kg/year.

(b) The total bed load size distributions of 85%, 82%, 81%, 82%, 81% and 81% of bed materials for six inflowing Rivers into Gurara Dam reservoir reflect that the bed load transport hydraulics of the six rivers are similar in the Gurara Watershed.

(c) The bed load accounted for 13% of the total suspended sediment load in Gurara Watershed. This is in accordance with the observation of Mudi (1995), Adeogun et al (2011, **Adegbola and Olaniyan** (2012a) that bed load accounts for about 3 to 15% of the suspended sediment load depending on the nature of the watershed.

(d) This bed load percentage of 13% could be of practical use in further sedimentation studies on the watershed and on neighbouring watersheds with similar hydrology for estimating bed load.

Consequently, the bed load percentage of total load transport in the Gurara watershed should be studied periodically since a change in the river flow hydraulics and hydrology of the watershed might influence the amount of bed load transport.

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