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The Effects of Reservoir Operation on Bed-Sediment Characteristics Downstream of River Karadua in Dutsin-Ma, Katsina State, Nigeria

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Abstract

This paper examined the impact of Zobe dam Reservoir on the physical properties of Bed-sediment and Bed-form at the immediate downstream of Karadua River in Karadua Catchment, Katsina state, Nigeria. Sediment samples were collected along the upstream and downstream of the river bed and was analysed in the Laboratory. The vertical section of the River bed was cut at the two river reaches and observed and examined in the field. The result revealed that the river bed upstream constitutes two layer-bands while, the downstream has three well distinct layers. The disparity between the layers also shows that amount of sand in the Bed load downstream of the reservoir is less than that of the Upstream with -28 percent. On the other hand, the amount of fine materials (silt and clay), downstream is greater than that of the Upstream with up to +33 percent. It is also found that generally, the thickness of the riverbed is grater upstream than downstream with an average of 26.8cm and 14cm respectively.

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The study concludes that the deficiency of sediment downstream is resulted by the trap action of the reservoir behind the dam. Secondly, the silt and clay layer downstream is a newly developed band resulted by the release of less turbid water from the reservoir. Further detailed study on bed-sediment is therefore, suggested and in all individual dammed river catchments.

INTRODUCTION

One of the most important geomorphological processes in a drainage basin is the generation and deposition of sediment. The process which is initiated by erosion and transportation within a stream channel are complemented by processes of deposition.

The geomorphologist is often criticised for paying too little attention to sediment (Allen, 1970), and any study of channel dynamics should attempt to document the occurrence of deposition. In this context, Gregory et al, (1976), pointed out that in spite of the fact that detailed investigations on sediments are the realm of the sedimentologist, there is a need for general study of channel and floodplain cross-section and long profile, and for consideration of individual bed-form.

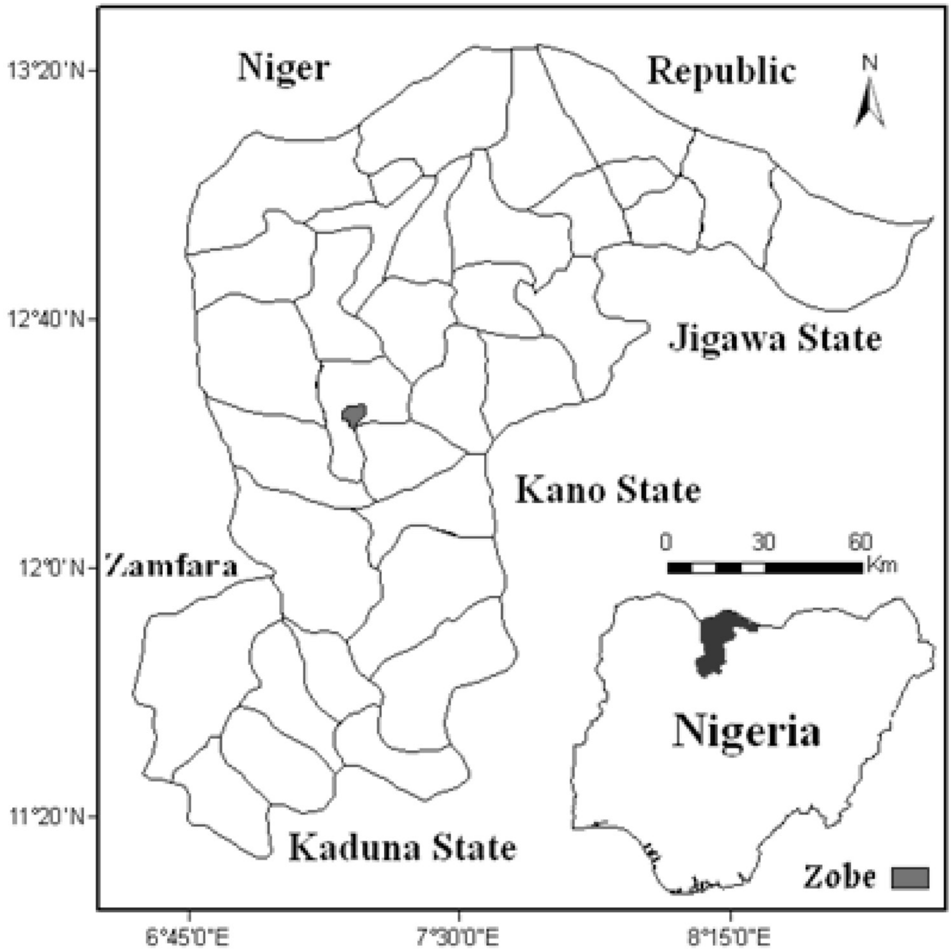
River channels are assumed to be in equilibrium with present flow levels; i.e. a balance between water discharge, sediment transport, erosion and deposition such that even where channels move across their flood plain they tend to maintain a fairly constant size. This equilibrium state may change as a result of human activities; such as replacement of natural vegetation; urban development; reservoir construction etc. The construction of Dam and reservoir behind it, for example, tends to alter the magnitude of flood event for a given rainfall event. The construction and operation of a dam and the associated reservoir for irrigation facilities represent a major and common developmental project in Nigeria, particularly the Northern part (Jeje, 2007).

This activities initiated by decrease in flow as a result of the trap impact of the reservoir, also reduces the amount and character of sediment below the upstream. Subsequently, this variation in the temporal pattern of sediment characteristics is reflected in the increase erosive potential of the less turbid water; actual channel deepening, lithology and morphology of floodplains upstream.

To study the nature of present day processes that produce changes in river morphology and examine the direction and magnitude of change, it is vital to analyse the physical characteristics of sediment and the structure of the River bed. Also detailed information on the characteristics of the bed material is needed for many bed load formulae, in order to calculate the critical shear stress or attractive force required to move the material.

The Study Area

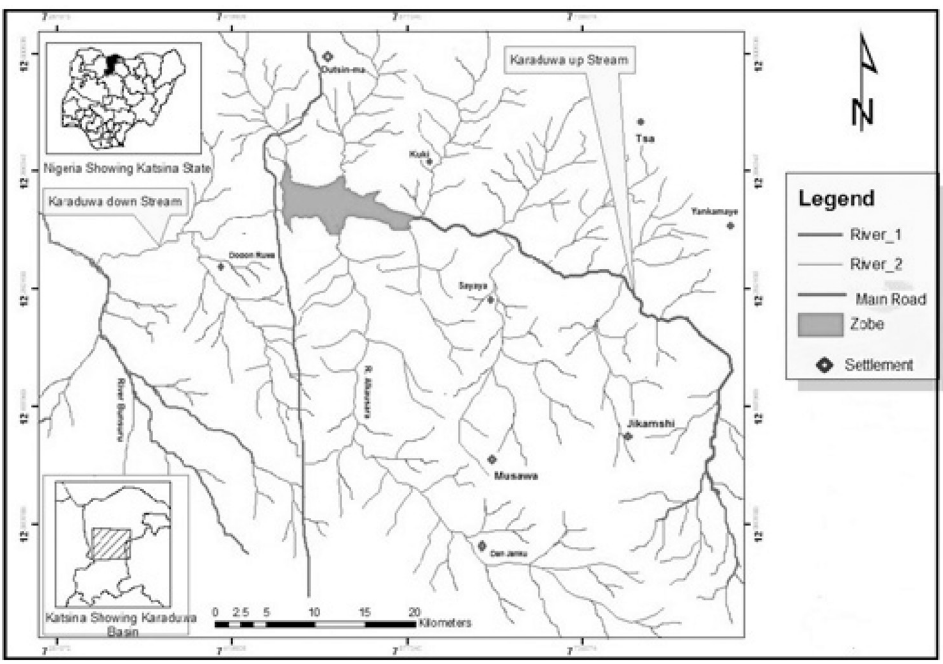
The study Catchment is the Karadua basin located in Katsina State in northern part of Nigeria. It lies between 12o 00' and 12o 50' north of the Equator, and between 07o00' and 08o00' east of Greenwich (figure 1). The area is found within the southern margin of the Mesozoic and tertiary lullameden basin of the South Sahara. The crystalline base portion of this area, predominantly consist of granite- magmatite and gneiss rock, (Kogbe, (1976).



The unconsolidated quaternary deposits of the region cover the basement rocks and the cretaceous sandstones to a large extent. The area is generally known as the savannah plain of Nigeria with quite insignificant difference in elevation, forming as high as 600 metres Above Mean Sea Level around the central area sloping North-West direction toward Sokoto, with an average height of 300 metres above sea level, (Buckle,1978). The area is in the Sudan savannah zone experiencing a continental wet and dry type of climate with a maximum monthly temperature of 24 - 38 and a mean annual rainfall of 562mm (NIMET, 2011). The vegetation is the savannah type dominated by grasses and scattered threes (Maxlock Group, 1977). The soil type of the region is ferruginous tropical brown and reddish – brown soils of the basement complex rock.

The Karadua catchment is a dendritic type, draining an area approximately 1838 km2. As a 6-oreder stream, the Karadua River is a major tributary of River Bunsuru within the main Sokoto River Basin. The stretch of the Karadua is 38km Downstream and 26km upstream of Zobe Dam. The Watershed has a drainage density of 1.06 and a slope angle of 1.5o. The average monthly discharge in the rainy months is 356m3/sec above the dam and 253m3/sec below the dam. Suspended sediment for the river is given as 4.16 grams/litre and 0.83 grams/litre for the above and below the dam reservoir respectively.

Figure 2: Map the Karadua drainage Basin



Source: Sheet 9, Sport 4 Imagery, 2008.

OBJECTIVES OF THE STUDY

The main objectives of this study is to examine the bed-sediment particle sizes; identify the vertical composition and arrangement of layers in the bed-load; and discover the possible changes that might have taken places between the river reach above the dam/reservoir and that of upstream of the reservoir.

METHODS OF THE STUDY

Of great importance in the analysis of sediment is the proper selection of scientific investigation method. This means that accurate measurement of relevant sediment properties is essential. Studies of the evolution and modification of such bed-forms as sand ribbons, for example, can be based on field observations. Bed-load studies in the field have generally been held back by a lack of adequate sampling devices. The International Organization for Standardization (ISO) has not yet established standards for bed-load samplers or for sampling methods. ISO has issued guidelines for bed material sampling, but the spacing or frequency of bed-load sampling has not been specified. Very little is known about the factors that control the transverse variations of bed particle sizes at a given cross section or how these distributions vary with time and flow conditions (Nordin, 1981). However, following the guidelines worked out in successful researches, the data collection in this work was made a success.

BED SEDIMENT SAMPLES

The bulk sampling of bed-material for grain-size analysis along the channel was carried out following Bunte and Abt (2001). The sampling strategy intended a homogenous distribution of sampling locations from Downstream to upstream to account for the variability in size distributions of the armour layer of the river bed.

The exercise was achieved by sampling four sites within the 38 km stretch of the reach above the dam, and two sites selected within the 22 km stretch of the reach below the dam. This is because only immediate upstream reach is relevant to this type of study. Within these major sites sampled at regular intervals (4 to 8km interval based on accessibility and suitability), another selection of two points was conducted at each site and all were dug for the sectional observation.

For bed sediment grain size analysis, two points were selected at 100 meters interval within each of the major sampled sites. And at each point, bed sediment sample was collected at three parallel points, which are left bank, centre and right bank of the channel width.

For the analysis of bed material vertical section of the channel bed was cut at the sampled sites and were observed and studied in the field. In another exercise, bed sediment samples were collected at three parallel points that is left bank, centre and right bank of the channel width. The sediment collected was mixed up to ensure a reliable sample with good representation and was then used for particle size distribution analysis. The results were obtained and analyzed in the Laboratory by weight of samples and were presented in the form of percentage weight.

RESULT AND DISCUSSION

Upstream Bed Sediment Vertical Characteristics

Along the stretch of this river reach, two bands of sediment were identified on the vertical section of the bed load. Although the layers are not distinct, but yet the two layered structure was identified as the most common. However, at certain rear locations, an additional layer was identified. The two common layers are in this work called the top layer and lower layer. Where the third layer appeared, it is then called the middle layer. The particle sizes of the sediment proved that all the layers are made of sand materials of different grain size. The detailed structure of this river reach observed in the field is shown in table 1 below.

Table 1:- Upstream Bed-load Structural Characteristics

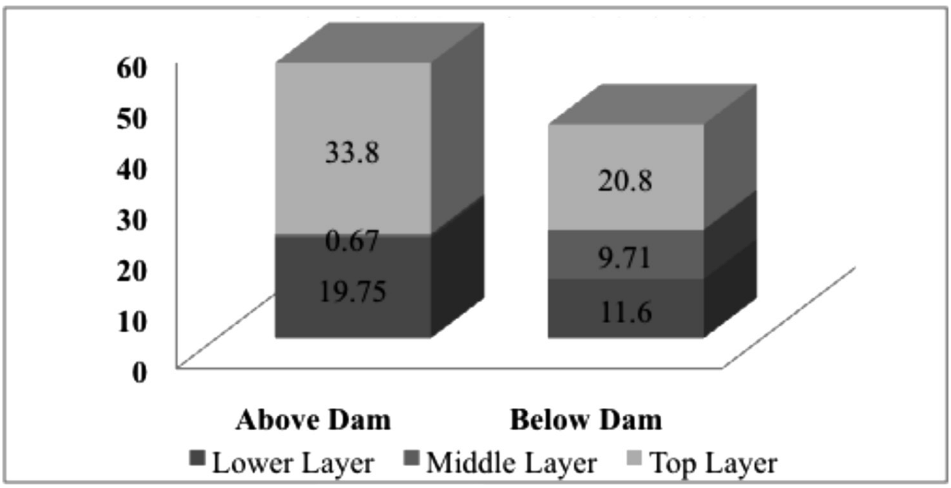
Sample Point	No. of Layer	Thickness of Layer (cm)			Sediment Type and Average Particle Size (mm)		
		Top	Middle	Lower	Top	Middle	Lower
A1	2	**35.3**	**-**	**28.0**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A2	2	**26.5**	**-**	**18.2**	Fine & medium Sand: (0.5-0.125)	Medium Sand (0.50 - 0.25)	Coarse Sand (2.0-0.625)
A3	2	**25.0**	**-**	**12.4**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A4	2	**34.2**	**-**	**20.5**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A5	2	**42.2**	**-**	**08.7**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A6	3	**59.0**	**6.70**	**11.6**	Fine & medium Sand: (0.5-0.125)	Medium Sand (0.5-0.125)	Coarse Sand (2.0-0.625)
A7	2	**28.2**	**-**	**15.8**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A8	2	**33.5**	**-**	**25.2**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A9	2	**28.7**	**-**	**25.5**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
A10	2	**25.6**	**-**	**31.4**	Fine & medium Sand: (0.5-0.125)	No Layer	Coarse Sand (2.0-0.625)
Average	**-**	**33.8**	**0.67**	**19.75**			

Source: Authors Field work

The result shows that the highest thickness of the top layer is up to 59cm found in test point A6 and a lowest thickness of 25cm at A3. These all together yielded an average top layer thickness of 33.8cm. From the result of the lower layer, an average thickness of 19.75cm was realized. There is also a high thickness of 31cm at A10 and a lowest thickness of 8.7cm at A5. This vertical characteristic is also demonstrated on figure 3 below. The table 1 also shows the appearance of a middle layer at A6 test point with a very thin layer of only 6.70cm.

The other section of the table shows the grain size distribution of the sediments by layers. The top layer is dominated by a fine and medium sand particles material, the lower layer is composed of coarse sand material and where a middle layer appears, it is found with a medium grain sand material.

Figure 3: Upstream and Downstream Bed-load Vertical Structral Characteristics



Downstream Bed Sediment Vertical Characteristics

Along this river reach three (3) distinct layers of sediment where identified. These bands of sediments are; fine grained top layer proved to be silt and clay; middle layer which contained coarse sand and gravel and a lower layer containing coarse sand and gravel. This is shown in table 2.

Table 2 :- Below Zobe Dam Bed-load Structural Characteristics

Sample Point	No. Of Layers	Thickness of Layer (cm)			Sediment Type and Average Particle Size (mm)		
		Top	Middle	Lower	Top	Middle	Lower
A1	3	32.3	8.3	6.5	Silt & Clay (0.062-0.0078)	Sand & Gravels (64-2.0)	Medium Sand (0.50-0.25)
A2	3	14.2	11.5	24.8	Silt & Clay (0.062-0.0078)	Coarse Sand (2.0-0.625)	Medium& fine Sand (0.5-0.12
A3	3	23.4	12.2	15.6	Silt & Clay (0.062-0.0078)	Sand & Gravels (64-2.0)	Medium& fine Sand (0.5-0.12
A4	2	22.4	-	23.5	Silt & Clay (0.062-0.0078)	No Layer	Fine Sand (0.25-0.125)
A5	3	18.5	7.45	18.0	Silt & Clay (0.062-0.0078)	Coarse Sand (2.0-0.625)	Medium& fine Sand (0.5-0.12
A6	3	15.5	13.4	4.7	Silt & Clay (0.062-0.0078)	Sand & Gravels (64-2.0)	Fine Sand (0.25-0.125)
A7	3	17.9	6.8	7.2	Silt & Clay (0.062-0.0078)	Gravel (64-2.0)	Medium Sand (0.50-0.25)
A8	3	24.0	12.5	5.0	Silt & Clay (0.062-0.0078)	Coarse Sand (2.0-0.625)	Medium& fine Sand (0.5-0.12
A9	2	23.5	-	4.5	Silt & Clay (0.062-0.0078)	No Layer	Medium& fine Sand (0.5-0.12
A10	3	16.7	5.5	6.2	Silt & Clay (0.062-0.0078)	Sand & Gravels (64-2.0)	Medium Sand (0.50-0.25)
Average		20.8	9.71	11.6			

Source: Authors Field work

The result in the table shows that all of these three layers at downstream river reach are of variable thickness. Figure 3 above illustrates how variable the layers are.

The top layer is also the thickest of the others. It was found with a highest thickness of 32.3cm and a minimum thickness of 14.2cm. The average thickness in the top layer is 20.8cm. The middle layer has an average thickness of 9.71cm; with a highest of 13.4cm and lowest of 5.5cm. The middle layer is the second most variant layer after the top layer. It becomes very thin or found interwoven at certain point because of coarser nature of its particles. The lower layer is the second in thickness with an average of 11.6cm. It has a highest of 23.5cm and a lowest of 4.2cm.

The sediment composition of the layers is also shown in table 4.5. It is clear to see that the top is totally different in grain size composition. The top layer is unique because it is the only layer comprising silt and clay particles. The middle and lower layer resembles each other having sand composition, though the grain sizes are different. The middle layer appears in three different forms; sand and gravel; coarse sand; gravels and in some test points, e.g. A4 and A9, the layer disappeared. The lower layer composed of sand throughout, but of varying sizes, that is median and fine sand particles.

Comparison of Upstream and Downstream Bed Load structural Characteristic

Comparing the results in tables 1 and 2, as well as close observation of figure 3 it clear to resolve that distinct bands are not encountered in the reach downstream; while there are well defined band layers upstream. Another good disparity between the two sets of data is that the entire Bed materials in Upstream are sand materials of different grain sizes, whereas that of downstream comprises very fine material discovered to be silt and clay, and the other two layers composed of sand materials as well as grave materials.

It should also be noted that the top layer of the downstream reach is strongly different from the two other layers likewise with the upstream layers, and that downstream middle and lower layers are closer to the upstream layers than they are to the top layer above them. This implies that the top layer of silt and clay in the downstream reach is the most newly deposited layer and its characteristics of fine material explained the bulk sediment trap action of the reservoir behind the Dam. Thus, it resolved that the Bed load in upstream reach has not changed in any way between the periods before Dam construction and after the dam construction.

Upstream and Downstream Bed Sediment Composition by weight

The analysis of Bed sediment load composition by weight of samples is presented in table 3. The table displays the sediment types identified; their grain size; and percentage composition of each category for both Upstream and downstream of the Dam so as to compare and contrast between the two sets of data.

Table 3:- Downstream and Upstream Zobe Dam Bed-Load Percentage Sediment Composition by Weight (%)

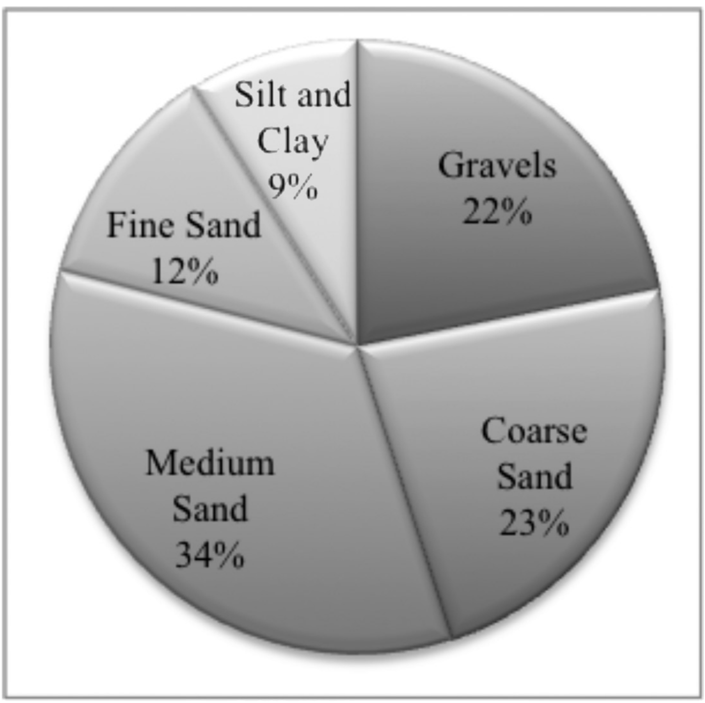
Type of Sediment by sizes	Particle Size (mm)	Percentage Composition by Weight (%)		Variance
		Upstream	Downstream	
Gravel	64 – 2.00	22	26	+4
Coarse Sand	2.00 – 0.625	23	10	-13
Medium Sand	0.50 – 0.25	34	06	-28
Fine Sand	0.25 – 0.125	12	16	+4
Silt and Clay	0.0625 – 0.0078	09	42	+33

Source: Authors Field work

The result in the table illustrate that all the sediment samples taken to the laboratory and analysed fall within highest grain size of 64mm (gravels) and a lowest grain of 0.0078mm (clay material). The table also shows that the bulk of the Bed sediment in Upstream

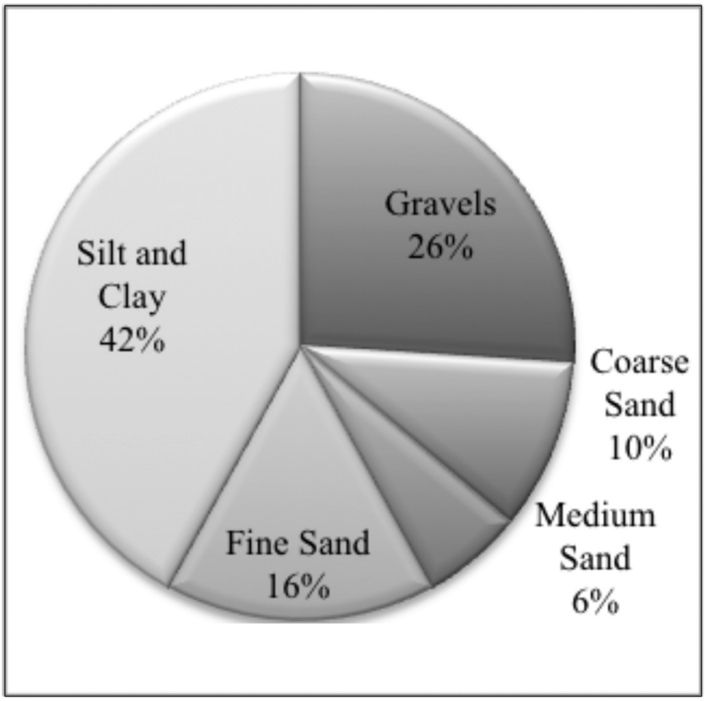
River reach is sand of different sizes. The highest percentage of 34% is found on medium sand particles; this is followed by coarse sand with 23%; then the fine sand with only 12%. All of these range from 0.125mm to 0.50mm. A very small quantity of silt and clay which is only 9% of the total sediment is also found. The proportion of the gravels in the sediments of this river reach is also remarkable by reaching up to 22% of the total Bed load. This is also illustrated in figure 4.

Figure 4: Upstream of Zobe Dam Bed-Load Percentage Sediment Composition by Weight



At downstream river reach also presented in table 3, fine sediment material dominates. This is evident from the highest percentage of 42% with silt and clay and up to 16% of fine sand. Putting this two together, a total of 58percentage is realized. This is on the high side and all within the range of 0.25mm to 0.0078mm. The amount of gravels in this river reach is also noticeable with 26 percent. The other categories of sand particles which are medium sand and coarse sand are given as 6% and 10% respectively. This is also shown in figure 5.

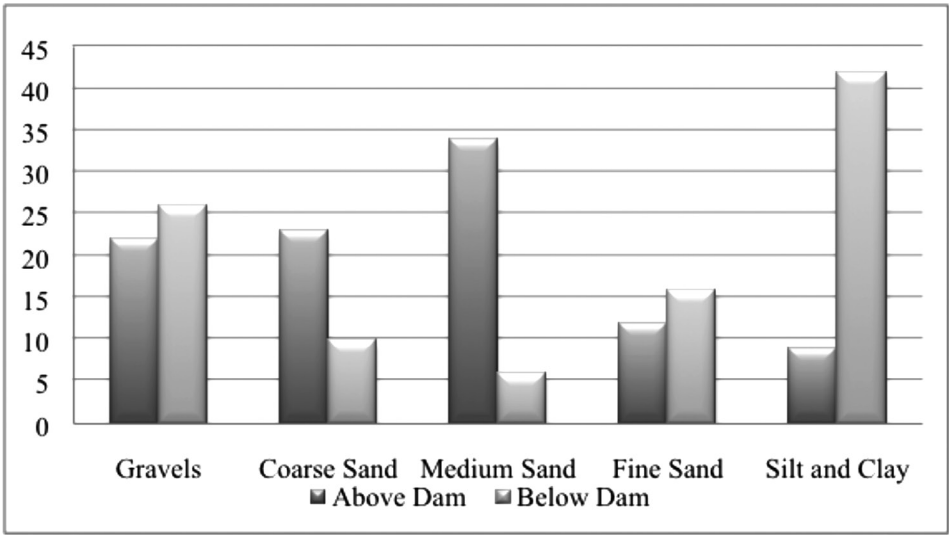
Figure 5: Below Zobe Dam Bed-Load Percentage Sediment Composition by Weight



Comparing the two set of data it is clear to see that the only close relationship that exist is between them is on the amount of gravel with 22% in above and 26% of Downstream. Apart from this all other classes of sediment in the result stand to be significantly different. This is more demonstrated in figure 6.

It is evident in the table that the amount of sand in the Bed load below the Dam is less to that of the Upstream with -28 percent. On the other hand, the amount of fine materials (silt and clay), below the Dam is more than that of the Upstream with up to +33 percent.

Figure 6 : Comparism of Above and Below Zobe Dam Bed-Load Percentage Sediment Composition by Weight



CONCLUSION

Conclusively the action of the Dam and reservoir on downstream river reach can be indicated on Bed sediment characteristics and reliable conclusion could be made from the outcomes. The bulk of sand material transported from the reach upstream of the dam is being trapped in the reservoir and only the fine material is passed through the spill way along with the spilled water to the downstream river reach. Consequently, reducing the overall thickness of the river bed sediment and the addition of the silt and clay layer identified downstream is the major resulted change between Pre and Post Dam construction in the Bed-Load.

It is therefore, recommended that future research should consider a more detailed analysis of Bed-load and all dammed river basins should be studied individually.

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