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Estimate of bed load transport and scour depth in Kwadna watershed in Minna, Niger State, Nigeria

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Knowledge of sediment transport has been used to determine whether erosion or deposition will occur beneath the hydraulic structures, especially the magnitude of this erosion or deposition, and the time and distance over which it will occur. This paper, utilizes the stream gauging by wading method in estimating the bed load transport and scour depth in Kwadna Basin. The estimate of bed load transport enhances the understanding and design of the hydraulic structures overlying water bodies. The current meter was used in measuring stream flow velocity in three critical points along the Kwanda stream. The measurement was used to derive an equation for depth of scour and the rate of erosion after a period of time. Laboratory tests such as sieve analysis and specific gravity were carried out on the samples obtained from the field which showed that the sediment is poorly graded gravelly sand material. The results of the laboratory tests as well as the stream flow parameters of the stream were used to compute the expected volumetric total sediment load transported daily as 889.33 m^3/day with annual value of 338347.158 m^3/year. Kwadna stream bed material had a geometric mean particle size, D_{50}, of 0.993 mm and consequently, the river transported bed material of larger diameter which explains why there are more deposits of sediments in the basin. The depth of scour for points 1, 2 and 3 after 365 days of high peak rainfall were estimated to be 1.0238, 1.7753 and 1.7019 m, respectively. The findings of this work will help in selecting suitable cross sections for the river structures having observed problems arising from sediment transport and deposition so as to reduce the sediments negative impacts on such structures.

Key words: Kwadna Basin, river sediment, stream gauging, bed load transport, scour depth.

INTRODUCTION

Incessant flow in rivers is affected, in one way or another by sedimentation (Nazir et al., 2016). Sedimentation which comprises non-artificial processes of erosion, sediment transport and deposition, has occurred throughout geologic time (He et al., 2018). Sediment is any particulate material that can be conveyed by water movement and which unavoidably, is dumped as a deposit of dense particles on the bed of a body of water. They are also grouped as pollutants if present in enormous amounts (Kalev and Toor, 2018). Sediment

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transport is aided by water, wind and gravity. It arises on land due to wind action while gravity contributes to transporting these particles on hilltops and cliffs (Gabet and Mendoza, 2012). It occurs sufficiently in streams and rivers due to fluid motion. According to Tian et al. (2016), interest in sediment transport mostly began in economic valuation of flood and erosion control and also from financial gain derived from extraction of crude and other minerals. Based on the mode of transport, sediment load can be grouped into bed load and suspended load (Béjar et al., 2017). According to Béjar et al. (2017), bed load is the sediment load transported close to the stream or river bed where particles move erratically by rolling, sliding, or jumping. Eaton and Rosenfeld (2016) reported that turbulent flow in stream supports suspended load throughout the water column where sediment is swept along at about the local flow velocity.

In modern times, culverts, bridges, dams and other marine hydraulic structures have been built for many purposes and advantages. Culverts are tunnels built to allow flow of fluid from one location to another. Sometimes they are used as bridges as in the case of bridge culverts. Bridge culverts serve both the function of a typical culvert and provide a way across an obstacle such as a stream. Sediment aggradation or degradation occurs in streams in the presence of streamflow which would in turn affect the hydraulic structure overlying it (Cocchiglia et al., 2012; Ho et al., 2013; Iwuoha et al., 2016). Sediment aggradation could lead to acceleration and blockage of the culvert barrel. Conversely, sediment degradation can result in scouring of river channels and erosion of river beds, reducing nutrient input which can affect the ecosystem negatively (Miao et al., 2016). The natural size and form of river beds has changed over time to allow the quantity of sediment transported through the channel. Squires (2014) opined that sediment removal could cause a lot of havoc to natural habitats, plants, animals and even human beings. He also noted that sediment can disturb river flow, capacity and stability causing excess erosion. When sediment degradation occurs, the stream collects sediments off its bed to try to adjust to a uniform flow rate. This result in erosion and increase in deposition downstream locations. In turn, this would reduce the stream capacity and that of the nearby structure significantly. When sediment is eroded from the bed and bank, the erosion process is termed scour.

Scour most likely occurs in alluvial waterways with erodible beds and banks. Typical bridge and culvert scour occurs throughout times of high flows. Since culverts act as obstructions to stream flow unlike bridges, thereby accelerating such flow, this causes turbulence at the base of the culvert and suspending additional particles. Consequently, this results in greater sediment transport and degradation. If a lot of sediment is removed, the construction may collapse due to flood-initiated sediment transport. Flood-initiated sediment transport happens to be the most frequent reason of hydraulic structure failure in Nigeria. Therefore, the relevance and importance of managing sediment transport and deposition cannot be over-emphasized, particularly in a highly erodible watershed like Kwadna Basin in Gidan Kwano area of Minna Niger State with so much loose soil materials and gully incisions. This study, therefore, utilizes particle size distribution data to estimate the percentage of total sediment load which is bed load to quantify the amount of bed load transported in Kwadna basin.

MATERIALS AND METHODS

Description of the study area

The study area is Kwadna catchment which lies within Gidan Kwano Inland Valley located between Latitude 9° 5000' and 9° 5625'N and Longitude 6° 373' and 6° 4375' E (Figure 1) and host community to the permanent site of Federal University of Technology, Minna, Nigeria. Kwadna Stream is one of the streams located in Kwadna Catchment area with a basin of 30.79 km^2. The soil type on the study area was in a textural class of gravelly sand up to the depth of 80 to 90 cm (Adesiji et al., 2016). The area is characterized with low and erratic rainfall of between 1000 to 1200 mm as total annual rainfall with peaks in July and August. Maximum daytime average temperature is about 35°C in the months of March and April while a minimum average temperature of about 24°C is recorded in the month of December and January. The mean annual temperatures are between 32 and 33°C. The region cascades within the guinea savannah vegetation encompassing several species of shrubs and high forest plants along the streams and depressions. The area also comprises of short grasses of heights ranging from 3 to 4.5 m and trees of up to 15 m high. Gidan Kwano comprises low-lying topographies and a small number of placid hills. The southern and central fragments of the area are characterized by comparatively levelled terrain underlain by biotite hornblende granite as proven by petrographic analysis (Amadi et al., 2011). The central portion is significant for its irregular uneven and undulant lands which is most likely accountable for the copious outcrop in this region.

The study area's elevation is between 190 and 230 m above sea flat in the west and descents to some extent to approximately 220 m in the North-Eastern part. The central part is substantial for its irregular rugged and heaving landscape which is possibly accountable for the prolific rock outcrop in this part. A lot of these outcrops ensue as moderately low-hills and ridges with enormous masses of fragmented granite boulders.

Field data collection

River survey, flow measurement and field data collection provide the basic physical information such as sediment characteristics, flow velocity, channel width and depth and stream discharge which are needed for the planning and design of hydraulic structures. Three different critical locations along the stream length were chosen for this study. The measurements were done between July 1 and August 13 which covers 12 days of substantial rainfall depth. The surface width of the stream was determined linearly by two individuals positioned at opposing edges of the stream. The flow velocity was measured with the aid of a current meter by the stream gauging approach using Gore and Banning (2017) approach. Additionally, the stage (depth) of the stream flow at the three critical points was measured using a calibrated steel rule. With the aid of a

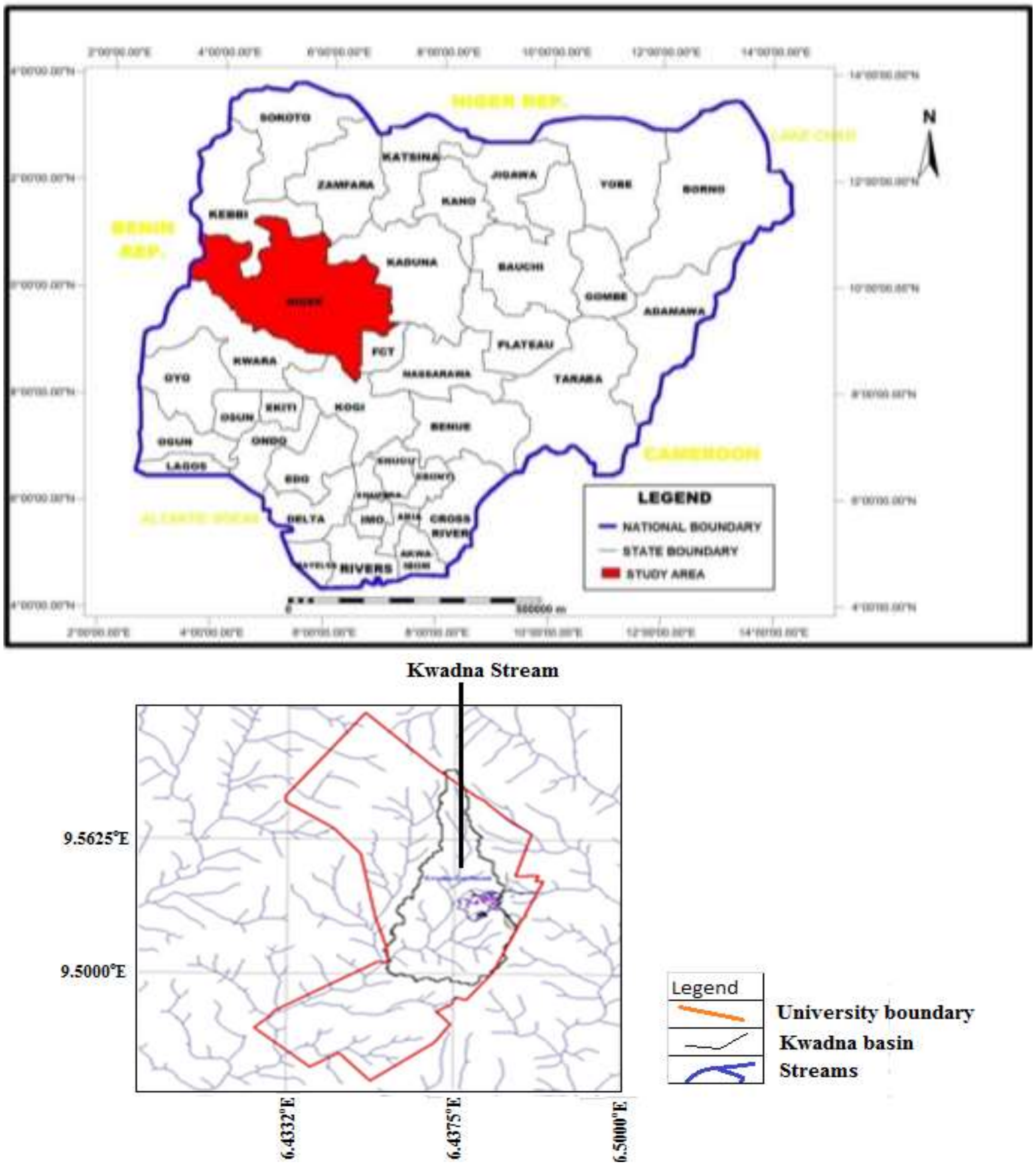

Figure 1. Location of study area showing Kwadna basin.

measuring tape, the culvert geometry was measured. Stream gauging by wading is utilized in this study due to the shallowness of the stream. It is realized by moving through the water body to take measurements of the stream flow. The channel cross-section was divided into 10 'segments' also called verticals from where the measurements of profile-average velocities were made. The current meter is placed at the two-tenth depth and the eight-tenth depth of its stage for velocity measurement. Both velocities are recorded and the average velocity of that section is determined by adding the two and dividing by 2. The discharge was calculated from the measured profile velocity obtained from the current meter for each segment. This procedure was repeated for each of the 12 days of the field work.

Sediment sampling

The most accurate means of sediment sampling is the use of a sediment sampler (Walling, 2017). The bed material samplers designed by the US Federal Interagency Sedimentation Project are expensive and not readily available in the country. As a result of this, an improvised sediment sampler was used in this study to take bed material samples. The sampler was used to acquire bed load on each of the 12 days which were later taken to the laboratory for specific gravity test, sieve analysis and to determine the sediment load transported from the bed on each day. Three critical points at the base of the culvert in the stream were selected and depths of these three points were taken on each of the 12 days of high precipitation to determine the rate of erosion of the river bed.

Quantifying sediment transport loads

Engelund Hansen’s Total Load Equation (1967) (Equation1) was used in the measurement of the sediment transport load. The equation was developed by equating the work done by the drag

Table 1. Specific gravity of sediment sample.

Variable	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12
Mass of glass jar, m_1 (g)	116.6	116.5	116.7	116.6	116.6	116.7	116.6	116.8	116.6	116.5	116.6	116.5
Mass of glass jar + sample, m_2 (g)	147	150.5	148.5	146.6	141.1	135.2	146.8	145.8	150.6	168.9	154.6	171.6
Mass of glass jar + sample. m_3 (g)	425.43	426.11	425.83	424.5	421.984	418.092	424.857	424.446	427.572	439.326	429.215	439.66
Mass of glass jar + water, m_4 (g)	406.5	406.6	406.4	406.5	406.8	406.6	406.5	406.6	406.5	406.7	406.6	406.6
$(m_2 - m_1)$ (g)	30.4	34	31.8	30	24.5	18.5	30.2	29	34	52.4	38	55.1
$(m_4 - m_1)$ (g)	289.9	290.1	289.7	289.9	290.2	289.9	289.9	289.8	289.9	290.2	290	290.1
$(m_3 - m_2)$ (g)	278.43	275.61	277.33	277.9	280.884	282.892	278.057	278.646	276.972	270.426	274.615	268.06
$(m_4 - m_1) - (m_3 - m_2)$ (g)	11.47	14.49	12.37	12	9.216	7.008	11.843	11.154	12.928	19.574	15.385	22.04
$Gs = (m_2 - m_1)/(m_4 - m_1) - (m_3 - m_2)$	2.65	2.43	2.57	2.5	2.63	2.64	2.55	2.6	2.63	2.6	2.47	2.5

forces of the flow to the potential energy gained by the properties as they move up the face of the dune. The form of the equation used is:

$$G = K \frac{0.05WV^2h^{1.5}s^{1.5}}{(s-1)^2 D\sqrt{g}} \quad (1)$$

where:
G = volumetric sediment transport load
k =calibration coefficient (=1 for standard equation)
w = width of flow
v = water velocity
h = flow depth
S = water surface slope
s = specific gravity of sediment
D = sediment diameter
g = acceleration due to gravity

The total sediment load, denoted as G is dimensionally homogenous. It comprises the amount of factor used to multiply discharge to compute sediment load over a period. The factor 0.05 in the equation was set using empirical data. The proposed applicability of the Engelund-Hansen equation is $\sqrt{\frac{D_{75}}{D_{25}}} < 1.6$ and for a mean diameter > 0.15 mm. G is dimensionally homogenous.

Laboratory analyses

Specific gravity and particle size distribution tests were carried out on the samples collected from the study area. Samples were collected for the 12 rainy days the study covers. For particle size distribution, sieve analysis was employed for this study as most fluvial sediment particles diameter fall within the range specified for sieve analysis. Oven-drying method was used where the representative sample of 200 g materials was weighed and poured in a set of U.S. Standard Sieves. The complete set of sieves was placed in a mechanical shaker for thorough shaking. The sediments retained on each sieve were weighed and recorded. From the records, particle graduation curves were plotted to find out their particle's sizes and percentages. For specific gravity, samples were collected for each of the 12 rainy days and were estimated based on ASTM D 854-00 approach.

RESULTS

Specific gravity and sieve analysis tests

The specific gravity values range from 2.43 to 2.64 which are within the range of specific gravity values for gravelly sand (Table 1). Hence, the bed load is gravelly sand. The use of Engelund-Hansen's total load equation (1967) is justified in the case since the average specific gravity of 2. 57 falls within the range of sediment samples containing both bed and suspended loads.

Particle sizes distribution of the sediment sample is shown in Figure 2. The figure shows that the sample comprises mainly of sand particles of about 96.78% (that is, 0.075 < 2 mm), 14.33% passing the 0.425 mm sieve and 3.22% fines content (that is, percentage passing no. 200 sieve) which shows it has clean sands with little or no fines. Under the Unified Soil Classification System (USCS) the sediment is designated poorly graded gravelly sands (SW) as less than 5% passes the no. 200 sieve.

$$Cc = \frac{D50}{D10} = 1.7291 \ (1 \le 1.7291 \le 3) \text{ Okay}$$

$$Cu = \frac{D30^2}{D10 \times D60} = 3.807$$

The distribution indicates a relative size of both granular and finer particles, justifying the fact that the sample is of total load, that is, it consists of both suspended loads and bed loads.

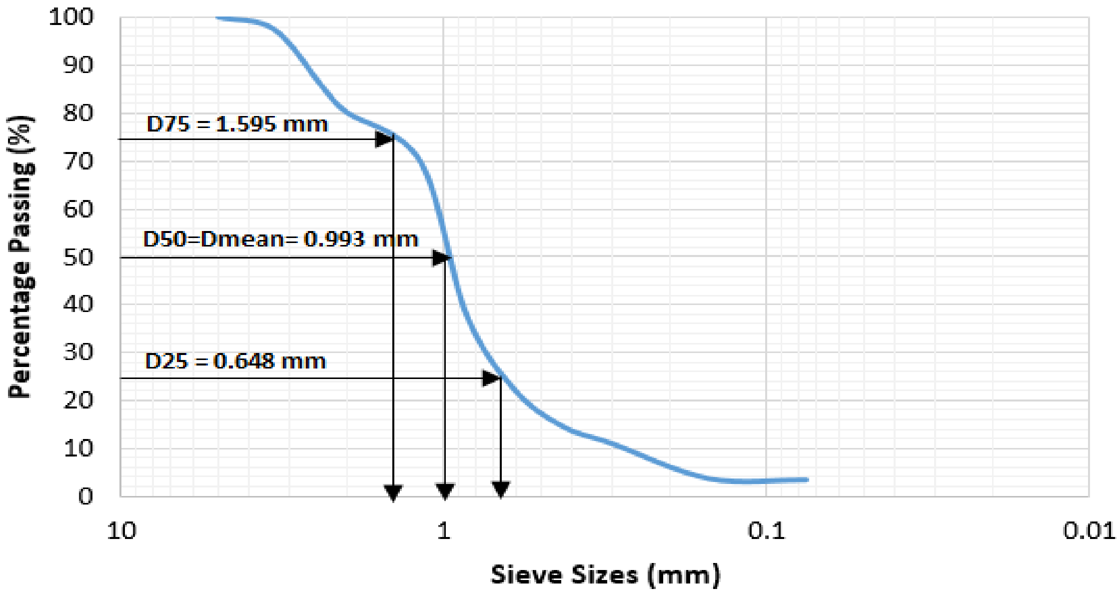

Figure 2. Particle size distribution curve.

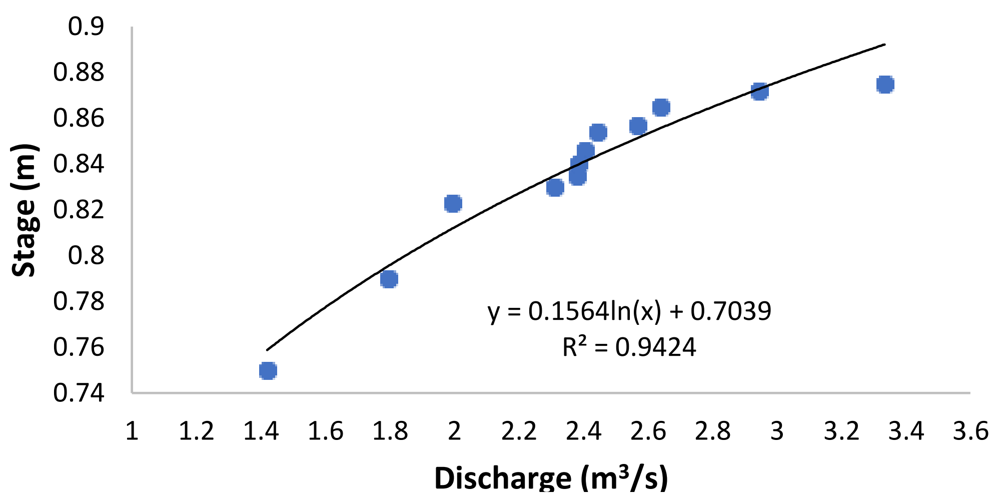

Figure 3. Stage-discharge rating curve of Kwadna Stream.

From Figure 2, the proposed applicability of the Engelund-Hansen equation is confirmed as:

$$\sqrt{\frac{D_{75}}{D_{25}}} = \sqrt{\frac{1.595}{0.648}} = 1.56889 < 1.6$$

D_{mean} = Mean diameter = 0.993 > 0.15 mm.

Description of rating curve

The discharge measurements obtained using current meter method at the gauging stations covering various stages of the stream were used to produce a curve as shown in Figure 3. This represents the rating curve of the stream in the study area which is plotted on either rectangular coordinate or logarithmic plotting paper. The coefficient of determination (R^2) for the logarithmic plot was observed to be 0.9424. The figure clearly underscores accurate information about stage and discharge of the Kwadna Stream and its importance for various hydrological applications such as water resources planning, reservoir operation, sediment handling. The developed stage-discharge relationship can thus be used for computing flow discharge in the Kwadna Stream for any measured stage.

Table 2. Scour depth at critical points.

S/N	Date	Total days	Rainfall (mm)	Discharge (m^3/s)	Point 1			Point 2			Point 3		
					Scour depth (m)	Amount eroded (m)	Cumulative eroded (m)	Scour depth (m)	Amount eroded (m)	Cumulative eroded (m)	Scour depth (m)	Amount eroded (m)	Cumulative Eroded (m)
1	1-Jul	0	13	2.38	0.142	0	0	0.84	0	0	0.1	0	0
2	9-Jul	8	14	2.567	0.384	0.242	0.242	0.859	0.019	0.019	0.332	0.232	0.232
3	11-Jul	10	12	2.311	0.406	0.022	0.264	0.863	0.004	0.023	0.344	0.012	0.244
4	12-Jul	11	10	1.42	0.427	0.021	0.285	0.867	0.031	0.027	0.386	0.042	0.286
5	16-Jul	15	13	2.405	0.513	0.086	0.371	0.872	0.005	0.032	0.411	0.025	0.311
6	21-Jul	20	13	2.639	0.617	0.19	0.475	0.884	0.012	0.044	0.441	0.03	0.341
7	25-Jul	24	13	2.444	0.703	0.086	0.561	0.896	0.012	0.056	0.466	0.025	0.366
8	27-Jul	26	14	1.995	0.741	0.038	0.599	0.9	0.004	0.06	0.481	0.015	0.381
9	31-Jul	30	15	1.796	0.755	0.014	0.613	0.91	0.01	0.07	0.506	0.1	0.406
10	3-Aug	33	14	3.334	0.785	0.044	0.643	0.93	0.02	0.09	0.571	0.065	0.471
11	12-Aug	42	15	2.945	0.82	0.035	0.678	0.942	0.012	0.102	0.6	0.029	0.5
12	13-Aug	43	11	2.385	0.853	0.033	0.711	0.945	0.003	0.105	0.85	0.25	0.75

Measured scour depth of critical depths

The scour depths measured at the three Points 1, 2 and 3 identified along the stream are presented in Table 2. These include the rainfall depths and discharge recorded within the study period.

Figure 4 shows the increase in scour depth of point 1, 2 and 3 measured at Kwadna Stream over varying periods on days with substantial precipitation. For Point 1, a best fit second order polynomial curve with R-squared value (0.9956) close to 1 provides an appropriate equation $y = -0.0003x^2 + 0.01312x + 0.1383$ to determine the maximum scour depth after a certain required period. For Point 2, a best fit second order polynomial curve with R-squared value (0.9894) close to 1 provides an appropriate equation $y = 6E\text{-}06x^2 + 0.0022x + 0.8399$ to determine the maximum scour depth after a certain required period. The same was achieved for Point 3 where a best fit second order polynomial curve with R-squared value (0.8622) provides an appropriate equation $y = -3E\text{-}05x^2 + 0.0136x + 0.1798$.

Figure 4 shows the graph of depth of scour of three points on Kwadna Stream. The plot of critical point 1 shows a steady increase in scour depth in its first lower end and then experiences a spike in the middle before finally, becoming gradual again at the end. The graph of critical point, unlike the other two, displays a rather slower rate of increase in scour depth. The plot of critical point 3 also shows a faster increase in scour depth than critical point 2 but slower than critical point 1. Figure 5 shows the measurement of scour depth taken for the period the study covers. Point 2 was observed to have highest scour depth relative to Point 1 and 3. It was also observed that the there is increasing trend in scour depth with days which shows the impact of precipitation on scour depth.

Discharge-Scour relationship in Kwadna Stream

Figure 6 shows the line graphs of the scour depth of the three critical points selected near the culvert base in Kwadna Stream against discharge. Close observation shows there is increase in scour depth at the upper middle parts of the line graphs of critical Points 1 and 3. However, Point 3 exhibits a much slower increase rate. It is therefore evident from the figure that more sediments are eroded away with increase in discharge.

Annual total sediment load transport rate

From graph of particle size distribution (Figure 6), the proposed applicability of the Engelund-Hansen equation is confirmed as:

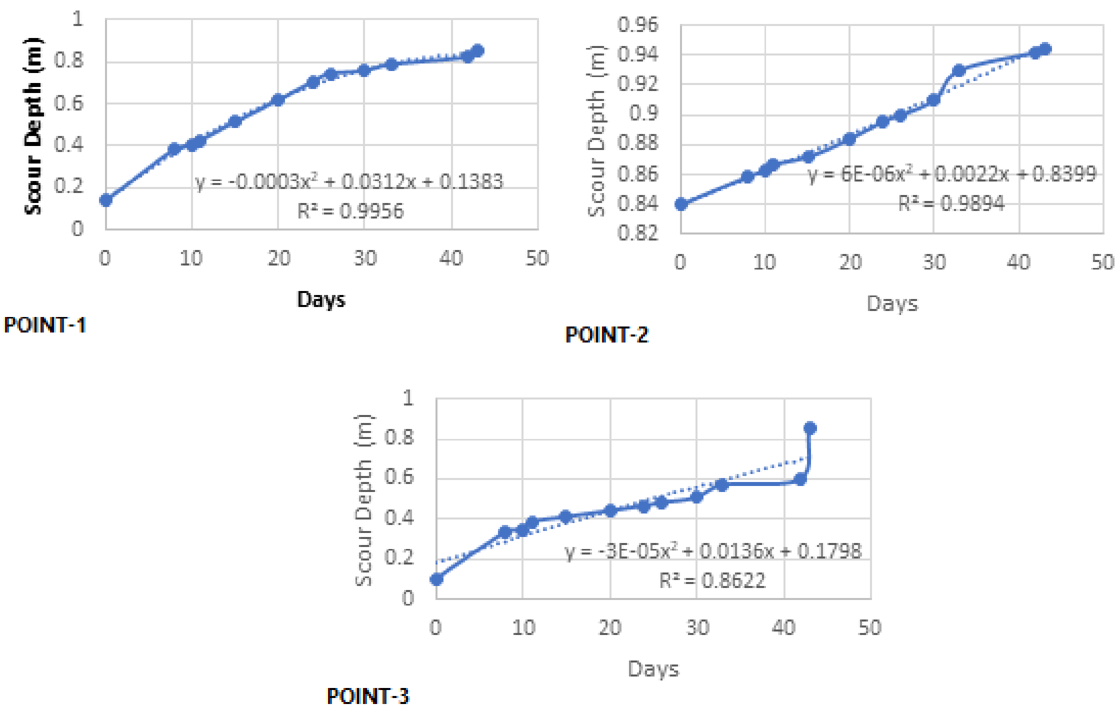

Figure 4. Measured Scour Depth at critical points 1, 2, and 3.

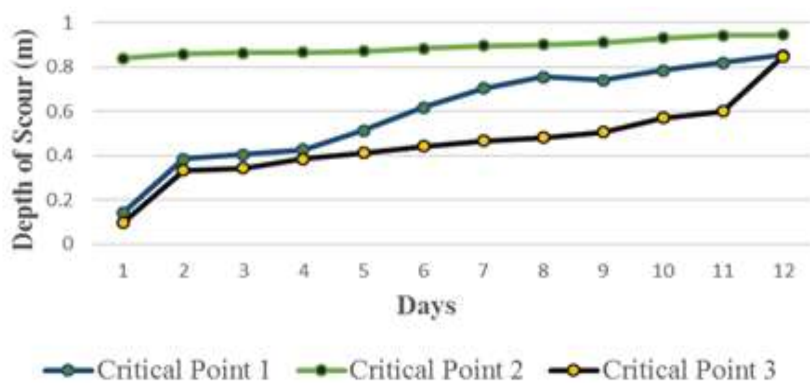

Figure 5. Erosion rate and measured scour depth of critical points.

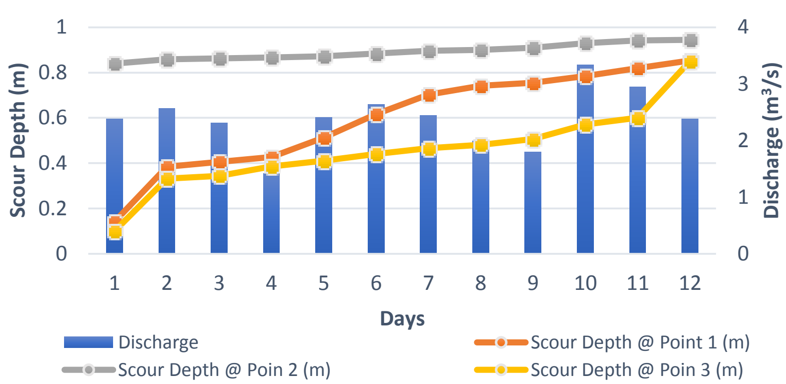

Figure 6. Discharge measurement against scour depth at critical points.

Table 3. Computation of Sediment Load.

S/N	Calibration constant, K	Width of flow, m	Average velocity, m^2/s	Stage	Slope	Specific gravity	Mean sediment diameter, D mm	Acceleration due to gravity	Sediment load, G
1	1	6.2	0.6	0.835	0.006	2.65	0.993	9.81	$4.598 * 10^{-3}$
2	1	6.2	0.622	0.857	0.007	2.43	0.993	9.81	8.762×10^{-3}
3	1	6.3	0.597	0.83	0.0011	2.57	0.993	9.81	1.3334×10^{-3}
4	1	5.7	0.483	0.75	0.0053	2.5	0.993	9.81	1.8011×10^{-3}
5	1	6	0.621	0.846	0.006	2.63	0.993	9.81	5.0632×10^{-3}
6	1	5.8	0.657	0.865	0.0054	2.64	0.993	9.81	1.8418×10^{-3}
7	1	6.5	0.548	0.854	0.0043	2.55	0.993	9.81	2.9066×10^{-3}
8	1	6.4	0.517	0.823	0.0043	2.6	0.993	9.81	2.2616×10^{-3}
9	1	6.2	0.484	0.79	0.0043	2.63	0.993	9.81	1.7400×10^{-3}
10	1	6.6	0.717	0.875	0.0064	2.6	0.993	9.81	8.9472×10^{-3}
11	1	6.6	0.622	0.872	0.006	2.47	0.993	9.81	7.2409×10^{-3}
12	1	6.7	0.575	0.84	0.0054	2.5	0.993	9.81	5.2763×10^{-3}
					Total				5.177×10^{-2}

$$\sqrt{\frac{D_{75}}{D_{25}}} = \sqrt{\frac{1.595}{0.648}} = 1.56889 < 1.6$$

D_{mean} = Mean diameter = 0.993 > 0.15 mm.

Table 3 shows the total load for each of the study period. The table also gives cumulative total load covering the study period which covers 12 days of substantial rainfall. Therefore, from Table 3, average total sediment load transported,

$G_{average}$ = Total load/No. of Days

$\frac{5.177x10^{-2}}{12}$ = 4.314 x 10^{-3} = Average sediment load for the study period

Converting G (m^3/s) to m^3/year, we multiply G by the equivalent number of seconds in a year:

G_{annual} = G × Q × 3600 × 24 × 365

Where:
G = volumetric sediment transport load (dimensionally homogenous) and
Q = Discharge

Average discharge for the 12 days = 28.626/12 = 2.386 m^3/s
Daily sediment load, G_{daily} = 4.314 × 10-3 × 2.386 ×3600 × 24 x 30

= 889.33 m^3/day

Annual sediment load transported = 4.314 × 10^{-3} × 2.386 ×3600 × 24 × 365

= 338347.158 m^3/year

With varying discharge, G_{annual} was increased within the range 2.5 $m^3/s \leq Q \leq 5$ m^3/s:

(1) 4.314 × 10^{-3} × 2.5 ×3600 × 24 × 365 = 340115.76 m^3/year
(2) 4.314 × 10^{-3} × 3.0 ×3600 × 24 × 365 = 408138.912 m^3/year
(3) 4.314 × 10^{-3} × 3.5 ×3600 × 24 × 365 = 476162.064 m^3/year
(4) 4.314 × 10^{-3} × 4.0 ×3600 × 24 × 365 = 544185.216 m^3/year
(5) 4.314 × 10^{-3} × 4.5 ×3600 × 24 × 365 = 612208.368 m^3/year
(6) 4.314 × 10^{-3} × 5.0 ×3600 × 24 × 365 = 680231.5 2m^3/year

Scour depth after two (2) years

Minna experiences an average of 126 wet days in a year, the peak of which occurs in the months of July, August and September. Two years from the initial day of scour measurement culminates at

July 1st 2020. Within the two years, Minna would experience 252 wet days in total. The scour depth after two (2) years would be calculated using the equation derived from the critical scour depth of points 1, 2 and 3 respectively.

Point 1

Critical scour depth equation $y = -0.0003x^2 + 0.01312x + 0.1383$
Estimated maximum depth after 1 year (365 days) at point 1 (that is, x = 365) y (1 year) = 1.0238 m

Point 2

Critical scour depth equation $y = 6E\text{-}06x^2 + 0.0022x + 0.8399$
Estimated maximum depth after 1 year (365 days) at point 1 (that is, x = 365)
$y_{(1\ year)} = 1.7753$ m

Point 3

Critical scour depth equation $y = -3E\text{-}05x^2 + 0.0136x + 0.1798$
Estimated maximum depth after 1 year (365 days) at point 1 (that is, x = 365)
$y_{(1\ year)} = 1.7019$ m

DISCUSSION

The specific gravity of the sediment sample obtained from the Kwadna Stream with the range of 2.43-2.65 indicates granular sand at the stream bed. The particle size distribution curve also indicates that the sediment belongs to the SW classification under USCS Classification system. It establishes that the bed material is gravelly sand and poorly graded.

It is observed from the rating curve of Kwadna Stream in Kwadna Catchment that there is a direct increase in discharge with increase in stage (m). Also, the depth of the three chosen critical points exhibits gradual increase in the period the site was visited. Analysis of three critical points and the scour depths observed with time produced 3 polynomial equations which were used to predict the depth of scour after a year. The predicted depths of scour were calculated to be 1.0238, 1.7753 and 1.7019 m for critical points 1, 2 and 3 respectively. Point 2 was observed to produce the highest scour depth which has been attributed to high discharge rate followed by point 3. This, therefore, justifies the impact of discharge on scouring of hydraulic structures bed.

Consequently, it Is observed that the values of daily sediment load by the Kwadna streams is estimated as 889.33 m^3/day with annual value of 338.347 m^3/s. For discharge values of 2.5, 3, 3.5, 4.0, 4.5 and 5.0 m^3/s, annual sediment load along the Kwadna Stream is estimated to be 340115.76, 408138.912, 476162.064, 544185.216, 612208.368 and 680231.52 m^3/s, respectively with the annual sediment load transported increasing with increase in discharge.

Conclusion

The bed load component of the total sediment load transported from the Kubanni Watershed has been evaluated using particle size distribution of the bed materials of the stream in the watershed. Based on the stream gauging and measured scour results, the relationship shows increase in discharge with increase in stage. This increase in discharge occurs due to rise in precipitation amounts in the peak months of July and August. With a recorded precipitation amount of 206.8 mm over 17 days and 271.9 mm over 21 wet days in the months of July and August respectively, it is deduced that the rate of erosion causes very high increase in scour depth.

Based on the results obtained, the following conclusions can be drawn from the study:

(1) Sieve analysis and specific gravity test indicate that the sediment is poorly graded and gravelly sand. This means that the sediment present in the center of the stream, Point 1 is most likely to erode more slowly and provide an armor layer for the finer particles unlike the other two critical points 1 and 3 which are directly below the culvert outlet and would erode material faster.
(2) Annual sediment load for Kwadna Stream exhibit a direct relationship with discharge. This implies that more sediment would be eroded from the culvert base with cumulative increase in discharge.
(3) The total volumetric annual sediment load of 338347.158 m^3/year is transported from Kwadna watershed.
(4) The depth of scour for the critical points 1, 2 and 3 after 365 days of high peak rainfall were estimated to be 1.0238, 1.7753 and 1.7019 m, respectively.
(5) The predicted scour depth estimated at 2 years considering days of peak rainfall goes to show a critical condition. This would displace the average service life of a box culvert (20-30 years).
(6)The study approach could be applied to other catchment areas for estimating bed load in sedimentation studies.

From this study, therefore, the following recommendations are offered:

(i) Real-time scour monitoring methods such as sonar

(acoustic transducer), that will indicate elevation change in stream level and send the information to the data logger when too much sediment is eroded.
(ii) Further studies should be carried out to correctly predict the scour depth and to find techniques to prevent or reduce the scour in a cost-effective manner in order to save the structures from the imminent risk of damage due to scouring.
(iii) The bed load percentage of total load transport in the watershed should be studied periodically as changes in the stream flow hydraulics or basin hydrology influences the amount of bed load transport.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adesiji AR, Jimoh OD, Adeoye PA, Jimoh IO, Gbadebo OA, Saidu M (2016). Groundwater Recharge Estimation and Trend Analysis Using Hydrological and Soil Moisture BalanceModels In Semi-arid Region The Proceedings of the 37th Annual Conference And Annual General Meeting of The Nigerian Institution of Agricultural Engineers, Federal University of Technology, Minna, Niger State. https://www.researchgate.net/publication/320625544_GROUNDWATER_RECHARGE_ESTIMATION_AND_TREND_ANALYSIS_USING_HYDROLOGICAL_AND_SOIL_MOISTURE_BALANCE_MODELS_IN_SEMI_ARID_REGION

Amadi AN, Nwawulu CD, Unuevho CI, Okoye NO (2011). Evaluation of the Groundwater Potential in Pompo Village , Gidan Kwano , Minna Using Vertical Electrical Resistivity Sounding. British Journal of Applied Science and Technology 1(3):53-65.

Béjar M, Gibbins CN, Vericat, D, Batalla, RJ (2017). Effects of suspended sediment transport on invertebrate drift. River Research and Applications 33(10):1655-1666.

Cocchiglia L, Purcell PJ, Kelly-Quinn M (2012). A critical review of the effects of motorway river-crossing construction on the aquatic environment. Freshwater Reviews 5(2):141-169.

Gabet EJ, Mendoza MK (2012). Particle transport over rough hillslope surfaces by dry ravel: Experiments and simulations with implications for nonlocal sediment flux. Journal of Geophysical Research: Earth Surface 117(F1).

Eaton BC, Rosenfeld JS (2016). Mechanisms of flow and sediment transport in fluvial ecosystems: physical and ecological consequences. A Biogeoscience Approach to Ecosystems. Cambridge University Press, Cambridge, pp. 347-382.

Engelund F, Hansen E (1967). A monograph on sediment transport in alluvial streams. Technical University of Denmark 0stervoldgade 10, Copenhagen K.

Gore JA, Banning J (2017). Discharge measurements and streamflow analysis. In: Methods in Stream Ecology 1:49-70. Academic Press.

He B, Qiao X, Li H, Su D (2018). Soft Sediment Deformation Structures Triggered by the Earthquakes: Response to the High Frequent Tectonic Events during the Main Tectonic Movements. Tectonics: Problems of Regional Settings, p. 103.

Ho HC, Muste M, Ettema R (2013). Sediment self-cleaning multi-box culverts. Journal of Hydraulic Research 51(1): 92-101.

Iwuoha PO, Adiela PU, Nwannah CC, Okeke OC (2016). Sediment source and transport in river channels: Implications for river structures. International Journal of Engineering and Science 5:19-26.

Kalev SD, Toor GS (2018). The Composition of Soils and Sediments. In Green Chemistry (pp. 339-357). Elsevier. https://www.sciencedirect.com/science/article/pii/B9780128092705000145

Nazir MHM, Awang S, Shaaban AJ, Yahaya NKEM, Jusoh AM, Arumugam MARMA, Ghani AA (2016). Sediment Transport Dynamic in a Meandering Fluvial System: Case Study of Chini River. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing 136:1, p. 012072.

Squires VR (2014). People and Place as Determinants of Success or Failure to Meet Management Objectives in River Basins. River Basin Management in the Twenty-first Century: Understanding People and Place. CRC Press Boca Raton, pp. 371-396.

Tian P, Zhai J, Zhao G, Mu X (2016). Dynamics of runoff and suspended sediment transport in a highly erodible catchment on the Chinese Loess Plateau. Land Degradation and Development 27(3):839-850.

Walling DE (2017). Measuring sediment yield from river basins. In: *Soil erosion research methods*, Routledge, pp. 39-82.