Sediment Transport Dynamics in a Semi-Arid Reservoir Environment: A Case Study of the Weija Dam

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ABSTRACT

The provision and control of water resources is becoming increasingly expensive with semi-arid regions experiencing significant issues with soil loss, sedimentation, and river erosion. This paper sought to investigate the current rate of sediment transport, capacity and bathymetry of the Weija reservoir by establishing discharge and sediment rating curves at the upstream of the reservoir using empirical equations together with suspended sediment data collected through a one-year (03/2019 - 02/2020) monitoring programme. In realising this, impeller current meters and echo sounders were deployed in the field. Equally, sediment samples were analysed at the laboratory of Water Research Institute, Accra-Ghana. The results indicate minimum and maximum suspended sediment concentrations of 34.67 mg/L and 239.69 mg/L respectively in January 2020 and June 2019. Within the reservoir, the suspended sediment concentrations range from 34.75 mg/L to 124.92 mg/L with gross annual sediment yield estimated at 104,539 t/yr. The current reservoir capacity stands at 86.67x106 m3 indicating a 25% reduction over the designed storage capacity of 116.04 x 106 m3. With increasing changes in land uses, sediment yield is anticipated to worsen within the Weija reservoir and thus the buffer zone policy needs to be enforced to curtail depletion of the reservoir capacity.

Keywords: Bathymetry, reservoir capacity, sedimentation, sediment transport, sediment yield

1.0. INTRODUCTION

Changes in the earth sphere is eminently accelerating owing to rapid development driven by population growth. These developments affect us both positively and negatively depending on how judiciously we manage and utilise our resources. Our negative impacts are largely observed within the hydrologic

These developments affect us both positively and negatively depending on how judiciously we manage and utilise our resources. Our negative impacts are largely observed within the hydrologic cycle and climate change at the extreme. The impact of sedimentation on surface water cannot be over emphasis. Changes in geosphere such as sand winning, irrigated agriculture, damming and mining within developing regions have been established to have severe influence on sediment loading in rivers and streams (Huai et al., 2021). Disintegrated materials (e.g. plant debris, sediments) are transported into ocean floors, streams, reservoirs, lakes and other surface water bodies. Additionally, the product of weathering is carried away from their place of origin into streams, becoming fluvial sediment. Fluvial sediment may be classified according to particle size, specific weight, shape and other characteristics. With respect to transport by water, particle size is the most significant factor.

A stream carrying a capacity load as it approaches a reservoir will deposit the coarsest material where the velocity of the stream is first affected by the reservoir, thus forming a delta. Some fine sediment may be deposited along with the coarse sediment, although most of the fine sediment will be carried further into the reservoir (Stone *et al.,* 2021; Jia *et al.,* 2021). The effects of reservoir sedimentation are felt in many ways, the most obvious being the depletion of reservoir storage capacity due to the accumulation of sediment deposits. The available water supply may also be reduced by increased evaporation losses due to sediment accumulation. Sediment accumulation at the head of a reservoir may cause a delta to be formed, which may soon become coated with various types of vegetative cover resulting in a large increase in transpiration losses (Iradukunda and Bwambale, 2021). On account of excessive sediment load rivers often begin to meander. Meandering rivers in thickly populated river-plain areas may result in the carving out of new channels washing away towns and rich agricultural lands (Iradukunda and Bwambale, 2021). Additionally, sediments may often clog stream channels raising the flood stages leading to bank overflow and subsequently, flooding and damaging surrounding river plain (Mondal *et al.*, 2019). Consequently, sediment transport exerts a considerable influence on the formation of the topography and stratification of the earth's surface (Xia *et al.*, 2021). The diverse anthropogenic activities also impact water quality with the advent of the fluvial processes and affect sediment supply, transport and deposition regimes within the reservoir. The Weija reservoir is a multipurpose dam designed to supply water for domestic, farming and industrial purposes. Currently the dam has average production capacity of 264,430 m^3/day of water of which an average monthly amount of 4.5 Mm^3 is portable and supplied by Ghana Water Company Limited (GWCL) for domestic use.

Over the past couple of years, flooding has plaque the dam and its immediate environment which has become a national problem owing to the increased illegal activities of sand weaning and encroachment of estate developers and farmers. This has resulted in high siltation lowering the volumes of water and holding capacity of the dam. Knowledge of the quantification of sediment deposited in a reservoir is imperative for the effective management of reservoirs and basins. The storage capacity of a reservoir is conceptually divided into several zones based on its required purposes.

The Weija dam reservoir has seen some degree of work being undertaken to characterise its potential and state. Most recently has been the study in trends of the hydrochemistry of the water resources by Mensah-Akutteh et al., (2022). Their research constrained the hydrochemistry of the water resources to be controlled by anthropogenic activities. Ofori et al (2016) also estimated the total annual suspended sediment yield, and annual specific suspended sediment yield to be 5375 tonnes/year and 2.0 t km^{-2} yr^{-1}, respectively. Kuma and Ashley (2008) undertook a study into how much flow comes into the dam and investigated the hydrometeorological characterisation of the dam. This study seeks to estimate the rate at which sediments are deposited into the reservoir by constraining the bed load sediments via PSD as well as determine reservoir volume via bathymetric measure over a well spatially distributed area, which were limitations in the earlier studies. The data generated will serve as a baseline data for future assessments of sedimentation in the reservoir. The outcome will be very helpful in contributing to filling the knowledge gap on the rate of sediment transport into the reservoir to the Densu Basin Management Team (DBMT), especially the Water Resources Commission (WRC) and the Ghana Water Company Limited (GWCL).

2.0. METHODS

2.1. Study Area

2.1.1. Location, Climate and Demographic Characteristics

The Weija reservoir (Figure 1) is formed on the Densu river which lies between latitudes 5° 32’ 30” N - 5° 37’ 30” N and longitudes 0° 20’ 00” W - 0° 25’ 00” W. The Densu river has a length of about 116 km from the Atewa mountains near Kibi where it takes its source. The basin has a catchment area of about 2,600 km² (Figure 1). The reservoir has a surface area of about 30 km^2 with a maximum storage capacity of 115 Mm^3. It receives a mean annual flow of 280 Mm^3 generated from the Densu basin (WRC, 2007). The distance between Ashalaia, the sampling point to the Weija Reservoir is 8 km. The Weija dam, first constructed in 1910, was reconstructed in 1978 following a breach by floods in 1967. The dam is an earth-rock-filled structure with a central gated spillway. The full supply level (FSL) or normal water level (NWL) is about 16 m and maintained at 15m above the mean sea level, respectively (Owusu-Ansah et al., 2019). The reservoir has a surface area of about 33.6 km² with a maximum storage capacity of 116.04 million cubic meters at NWL of 15m. It receives a mean annual flow of 280 million cubic meters generated from the Densu Basin (WRC, 2007).

The rainfall pattern in the basin in bi-modal. The main rainy season is from April to July with the peak in June, whilst the minor season is from September to November. The northern part of the basin falls within the moist semi-deciduous rainforest zone with rainfall ranging between 1,500 mm and 1,650 mm. The central part of the basin falls within the transition of forest and coastal savannah zones, where rainfall ranges between 1,150 mm and 1,500 mm. The southern part of the Basin falls within the coastal savannah where rainfall ranges between 900 mm and 1,150 mm. In the coastal plains of the basin, rainfall is typically less than 900 mm (Ofori *et al.*, 2016). The mean monthly rainfall amounts are particularly slightly less during the major rainy season and slightly higher during the minor season in the latter decade compared to the first period. Suspended sediment discharge increases during high flows (major and minor rainy seasons) compared to low flows (dry season). Temperatures within the basin are characterised by a tropical climate with uniform temperatures throughout the year. Mean annual temperature ranges between 27° C and 32 °C (WRC, 2007).

2.1.2. River Discharge Measurement

River discharge was measured montly at Ashalaja, the hydrological gauged station for one hydrological year (March to February) capturing both dry and rainy seasons which correspond to low and high flows alternating in the river. The river discharge measurement was done using the wading method

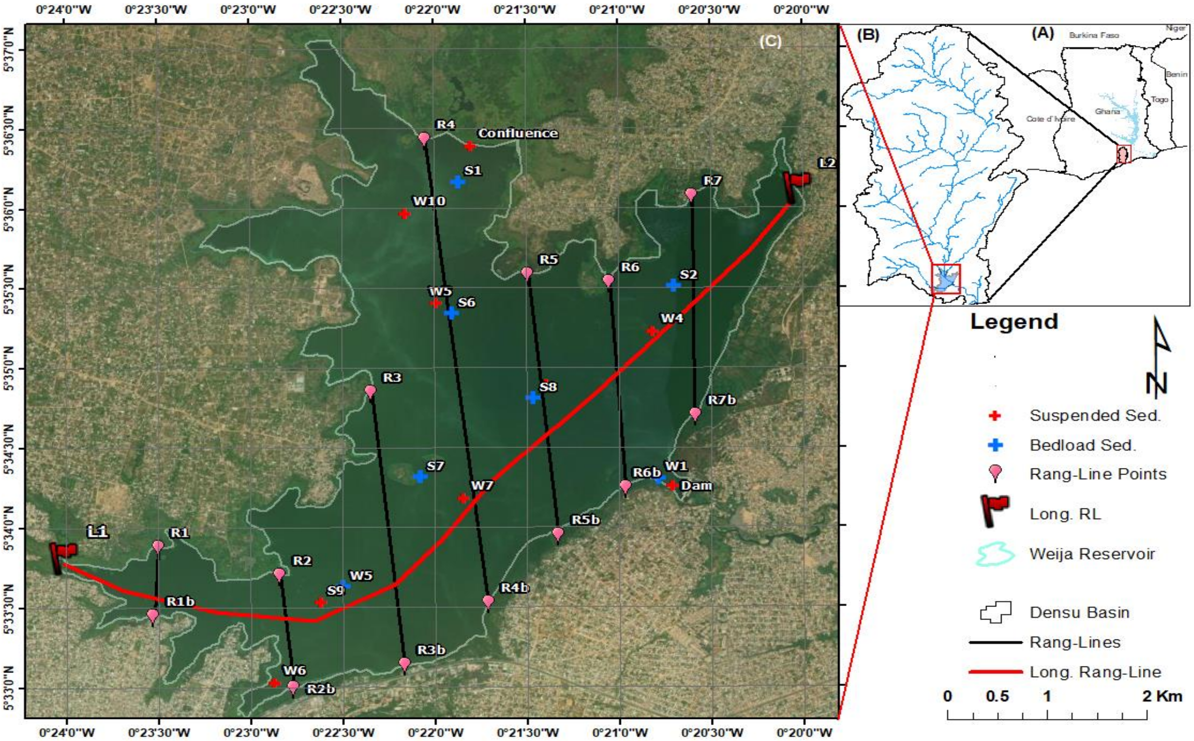

Figure 1: Study area: (a) Inset map of Ghana in West Africa; (b) the Densu River Basin; (c) Detail of the Weija Reservoir with sampling points and transect marked in.

with a graduated wading rod and a current meter. With the river divided into sub-sections based on the depth at each section of the river, discharge measurements were taken at each subsection and the final discharge was computed using the velocity area method. This involves dividing the cross-section into chainages, computing the area, measuring the velocity at each sub-section and determining the total discharge at the entire cross-section using equation (1).

$$Q = \sum_{i=1}^{n} a_i v_i \qquad (1)$$

where Q is the total measured discharge at the river cross-section, a_i is the area of sub-section i, v_i is the mean flow velocity at the sub-section i and n is the number of sub-sections the river section will be divided into. The two-point velocity method was used for high flows, thus 20% (0.2D) and 80% (0.8D) average velocities were measured at each point using the current meter and an echo sounder. The suspended echo sounder was deployed to the surface of the flow to measure the sub-sectional vertical depth. Flow velocities were measured at 0.2D and 0.8D for each subsection of the river, the average of which was multiplied by the cross-sectional area of the section to compute the discharge.

2.1.3. Suspended sediment monitoring and analysis

Suspended sediment samples were collected in triplicates at Ashalaja for twelve consecutive months using a depth-integrating sampler (USDH-48). The samples were taken at the left and right banks as well as the middle of the river's monitoring transect at the sampling site (Figure 1). Laboratory analysis for sediment concentrations was done at the Sediment Laboratory of the Council for Scientific and Industrial Research – Water Research Institute, Accra-Ghana. The oven-dry method was used to determine suspended sediment concentration (SSC). The samples were allowed to settle for 21 days. Samples were prepared and oven-dried at a temperature range of 95 °C and 105 °C to determine the concentration of suspended sediment concentration.

The suspended sediment concentrations in parts per million (ppm) were computed following equation 2 and subsequently converted into milligrams per litre (mg/L) with a conversion factor C in equation 3 (Ofori et al., 2016).

$$ppm = \frac{dryweightofsediment(g)}{netsampleweight(g)} x10^6 \qquad (2)$$

$$mg/L = C \times ppm \qquad (3)$$

The use of the conversion factor (C) in our case was based on the assumption that the density of water is 1.000 mg/L plus or minus 0.005, at a temperature ranging between 0 °C to 29 °C, with specific gravity of 2.65 and dissolved solids (DS) concentration of less than 10,000 parts per million (ppm) (ASCE,2005)

2.1.4. Suspended sediment rating curve

The suspended sediment discharge was computed

The suspended sediment discharge was computed using the relation below in equation 4.

$$Q_s = k \times Q_w \times C_s \quad (4)$$

Where, **Q**$_s$ = suspended sediment discharge in tonne/day,

Q$_w$ = river discharge in m^3/s, C$_s$ is the total suspended sediment concentration in mg/L, **k** = 0.0864, a conversion factor assuming a specific weight of 2.65 for sediment.

The mean monthly and annual sediment discharge were subsequently estimated from the daily mean suspended sediment discharge computed from equation 2, since sediment load is established as a function of water discharge (Akrasi, 2011). Subsequently, a predictive suspended sediment discharge rating curve represented by a power function as shown in equation (5) was developed and used in the determination of total suspended sediment discharge for the Densu River at Ashalaja (Ofori *et al.*, 2016).

$$Q_s = aQw^b \quad (5)$$

Where, **Q**$_s$ = total suspended sediment discharge in tonnes/day, **Qw** = river discharge (m^3/s), **a** and **b** are index of erosion severity (constant) and exponent respectively, obtained by a log-log plot of equation (2). Akrasi (2011) and Kasumi et al., (2014) had indicated that exponents values ranging between 2 and 3 suggest increased sediment load during high flow events. The rating curve was evaluated using a coefficient of determination (r^2) greater than 0.6 (White, 2001).

2.1.5. Bed Load Sampling and Laboratory Analysis

The river and the reservoir bed material were classified in order to establish the soil type and texture of the bed load transport from the main river course to the reservoir as well as determine the proportion of bed load distributed within the reservoir. The Ekman Berg Grabber and US-series bed-material sampler (corer) was deployed to sample the river bed material to be analysed for particle size distribution**,** (Baranya, 2018), in accordance with ISO 772:1977.

2.1.6. Estimating Total Annual Sediment Load and Yield

The river bed at Ashalaja is composed mainly of rocky material, with traces of sand as suspended material. Equation 3 was used in estimating the suspended sediment load at Ashalaja for each month of the study period. The gross annual sediment load from Ashalaja into the Weija Reservoir was computed by the product of the suspended sediment load and the catchment area at the sampling location with its specific sediment load. The highest calculated suspended sediment load in parts per million was less than one thousand, therefore, from Maddock’s classification, between 25% to 150% of sediment suspended load was estimated as the total annual bed load (Wróbel *et al.*, 2023). The annual suspended sediment load transported into the reservoir was then estimated by multiplying the basin catchment area with the basin-specific suspended sediment load. An assumed 25% (least of range) suspended sediment load was added as bed load to estimate the gross annual sediment load, (Cantalice et al., 2015). From the calculation of the total yearly sediment yield at Ashalaja, the specific sediment yield (t/km^2/yr) was calculated using equation (6).

$$SpecificSedimentYield(Y_s) = Sedimentyield\ (t/yr)/Catchment\ area(km^2) \quad (6)$$

2.1.7. Reservoir Bathymetric and Bed Levels Survey

To evaluate the loss in reservoir storage capacity as a result of sediment accumulation, a bathymetric survey was conducted. The range-line method with the moving-boat technique was employed. This method was adopted due to the current size of the reservoir, accuracy for the computation of the changes in storage volume and non-availability of original survey records. The reservoir was mapped into 10 zones. The main reservoir body, its principal tributary arms and dam side were ranged. The reference mark at which the range line was mapped from one bank to the opposite bank could serve as a baseline for future bathymetric surveys by GWCL and WRC. Reservoir bed levels and depth were measured using the echo sounding technique (Wróbel *et al.*, 2023). Sounding from the water surface to the reservoir bed was used to determine the topography of the reservoir bed and hence the depth of the reservoir at each point surveyed.

3.0. RESULTS AND DISCUSSION

3.1.1. Hydro-Meteorological Analysis of the Weija Watershed

The mean monthly rainfall distribution at the synoptic station for Nsawam and Weija for the period 2000 to 2019 were obtained and analysed. This distribution conforms to literature with the wet and dry seasons occurring between April and October (7 months) and November – March (5 months) respectively, with January and December observed to be the driest. Thus, the management of the reservoir must take particular attention to these critical periods in terms of water abstraction for domestic supply and any other purposes.

3.1.2. Suspended Sediment Concentration (SSC)

The trend of the monthly mean suspended sediment concentration (SSC) for the Densu River at Ashalaja during the period of monitoring is presented in Figure 2. In general, it was observed that the fluctuations in river discharges and monthly mean SSC was in response to rainfall trends for the observed hydrological year (Figure 2). There was however, a sharp rise and fall of monthly mean SSC from the start of the rainy season (April to May) and subsequently towards the peak river discharge in

June which corresponds to the peak rainfall month in the basin. The monthly mean SSC ranged from 34.67 mg/L in January to 239.69 mg/L in June with a mean of 82.32 mg/L. The maximum monthly mean SSC was recorded in June and corresponds to the peak of the rainy season in the area (Figure 2). The high amount of rainfall coupled with anthropogenic activities such as sand winning in parts of the basin could explain the high incidence of SSC. During the start of the rainy season, sediment may be readily available for transportation.

3.1.3. Total Annual Suspended Sediment Yield

The estimated daily mean suspended sediment discharges for the major and minor rainfall seasons were 170 tonnes and 677 tonnes respectively compared to 7 tonnes during the dry season (low river discharge). This is consistent with other studies (Akrasi, 2011; Ofori et al., 2016) where suspended sediment discharge increases during high river flows (major and minor rainy seasons) compared to low river discharges (dry season). However, the higher sediment discharge during the minor rainfall season with a peak discharge of about 1,140 tonnes recorded in October, confirms the availability of sediments for transport and also, partly to the increasing rainfall amounts in the latter decade (Figure 2).

In addition, the anthropogenic activities (sand winning, farming etc.) within the basin depletes land cover, causing high discharge due to eroded soil at the start of the raining season.

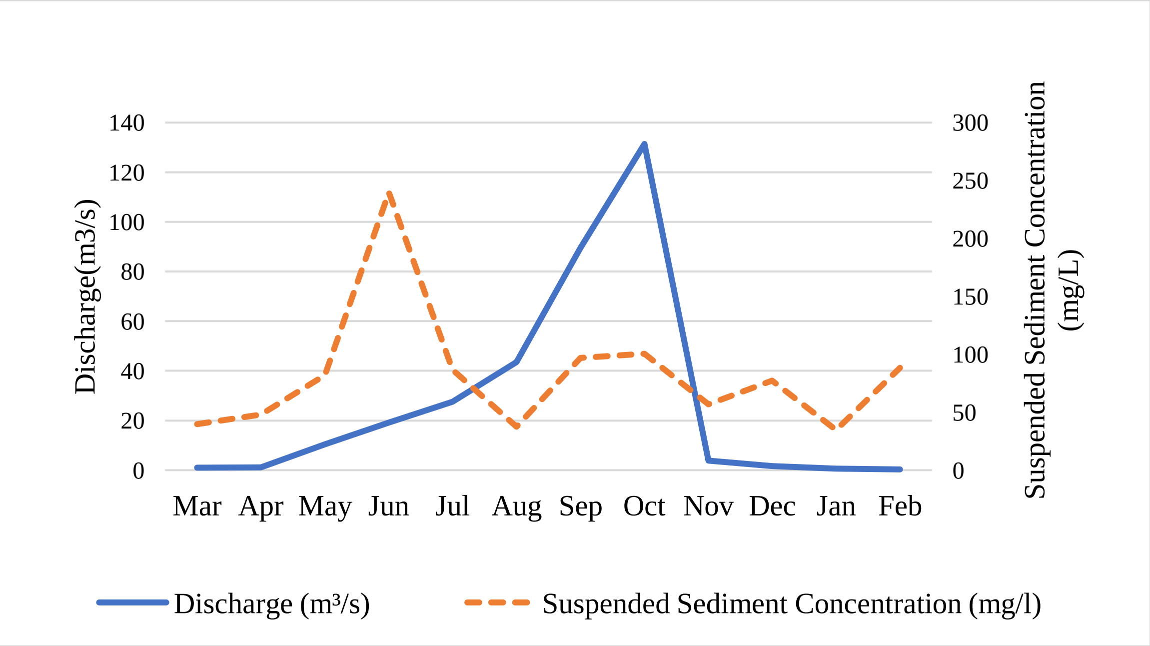

Figure 2: Mean monthly suspended sediment concentration (SSC) at Ashalaja on sampling for the period between 2019-2020

The discharge comes with high energy which transports sediments from uplands, with a resultant increase of sediment load in the river beds and banks. The results of the analysis indicate a gradual increase in SSC from the beginning of the hydrological year (March) and reached its peak in June. The SSC gradually started to reduce from June, this is due to a dilution of the SSC. The daily mean suspended sediment discharge range from about 1. 74 to 1,140 tonnes with a mean of 229 tonnes. The total annual estimated suspended sediment yield was 83,631 tonnes/year with an estimated bed load of 20,908 tonnes/year.

3.1.4. Specific and total sediment yield

The annual suspended sediment and specific suspended sediment yields were estimated to be 83,631 tonnes/year and 40.2 tonnes/km^2/year respectively. The annual suspended sediment and specific suspended sediment yields from this study are relatively higher compared to that of Ofori et a., (2016) (5375 tonnes/year and 2.0 tonnes/km^{-2}/year). The south-western basins increased anthropogenic activities such as illegal small-scale mining (known as *galamsey*) and sand winning coupled with bad farming practices is assumed to be the main sources of high sediment loading (Ofori *et al.*, 2016; Akrasi, 2005). On the contrary, river Pra at Daboase and Black Volta at Bamboi yielded higher annual suspended yield of 189,037 tonnes/year and 5,295,055 tonnes/ year than this study respectively (Ofori et al., 2016). Mention must be made that both watersheds are relatively larger as compared to the Weija. It appears that the relatively high annual suspended sediment yield and annual specific suspended sediment yield are likely due to the failure of IWRM interventions in the basin since earlier studies within the Densu Basin at Mangoase showed relatively lower values.

3.1.5. Reservoir Suspended Sediment Concentration

Suspended sediment concentration measured from the reservoir (i.e estuarine, middle and near dam wall sections) ranged from 34.75 mg/L to 124.92 mg/L (Table 1).

The highest concentration was recorded at the estuarine and the lowest at the dam wall while the intake recorded was 46.21 mg/L. The mean suspended sediment concentration in the reservoir was estimated to be 56.61 mg/L which is relatively high compared to the raw water quality target of 5 mg/L. Suffice to say that the utility provider, GWCL spends a significant amount of money on treating water from the Weija reservoir. Dialogue with the operators of the reservoir suggest that sediment from the cultivated hills around the reservoir, aside that coming from upstream through the main river network and the quarry sites overlooking the reservoir may be a concern. From field observations, the quarry site did not have any water retention or run-off control structures to prevent high sediment-

Table 1: Suspended sediment concentration at the reservoir

Location	Concentrations (mg/L)
1 (Dam wall)	34.75
2 (Intake)	46.21
3 (Estuarine)	124.92
4	52.12
5	50.03
6	38.56
7	52.40
8 (Estuarine)	91.20
9	39.94
10	48.85
11	43.68

-laden run-off water from the sites. It is likely the sediments transported from these sites make up a significant proportion of the total sediment inflow into the reservoir particularly during a rain storm, hence increasing the SSC into the reservoir. This assertion is collaborated in the grain size distribution analysis as samples analysed from Ashalaja and most parts of the reservoir exhibited similar characteristics.

3.1.6. Suspended Sediment Rating Curve

The resultant rating curve relationship fitted to the sediment load data for the Densu River at Ashalaja, as illustrated in Figure 3, is established in the relation as:

$$\mathbf{Q_s = 4.998Q_w^{1.1102}} \qquad (7)$$

The coefficient of determination (R^2=0.9284) indicates that the relationship between sediment discharge and water discharge is a good fit with a strong correlation. Based on the above equation, the total suspended sediment discharge at any point of the river can be determined if the flow rate is known. Sequel to that obtained by Ofori et al., (2016), ($Q_s = 2.939Q_w^{1.0574}$) the index of erosion severity is less than that of this current study, which translates in the observed high suspended sediments within the reservoir. An increase in the exponent in this current study of 1.1102 from that derived by Ofori et al., (b = 1.0574) suggest an increase in the availability of sediments at the upper sections of the catchment in the wake of high discharge rates. Though both studies yielded very good fits for coefficient of determination, the R^2 obtained by Ofori et al., (2016) was slightly lower (0.8404).

The n value is significantly lower than the typical range of 2 to 3 which was reported by (Akrasi, 2005). It is also consistent with similar studies (Akrasi, 2011, Ofori *et al.*, 2016) in the south-western and coastal river basin systems. Fitriana *et al.*, (2021) have indicated that the exponent value between 2 and 3 indicates that sediment load increases mostly with an increase in river discharge or during high flow events. The n value of 1.1102 derived in this study suggests that sediment transport in the basin is largely due to the availability of sediment in the upper catchment of the monitoring point and not just due to high river discharges (Akrasi, 2011; Kasumi et al., 2014). Moreover, the low rating exponents indicate that the gradient of the river morphology is relatively low (Kasumi et al., 2014). The k value was found to be 4.9988 (k >1) and this indicates that some lands within the basin are degraded.

3.1.7. Bathymetry of the Reservoir

In general, surveyed profiles of the reservoir bottom depths ranged from 0.7 – 8.63 m with a mean depth of 5.77 m, varying depths recorded for the different range line (Figure 5). The longitudinal profile depths ranged from 1.05 - 9.30 m with a mean depth of 6.83 m. Dam 1 has a constant depth of 7.62 m. Table 2 shows the maximum, minimum and mean depths for all the bathymetric profiles.

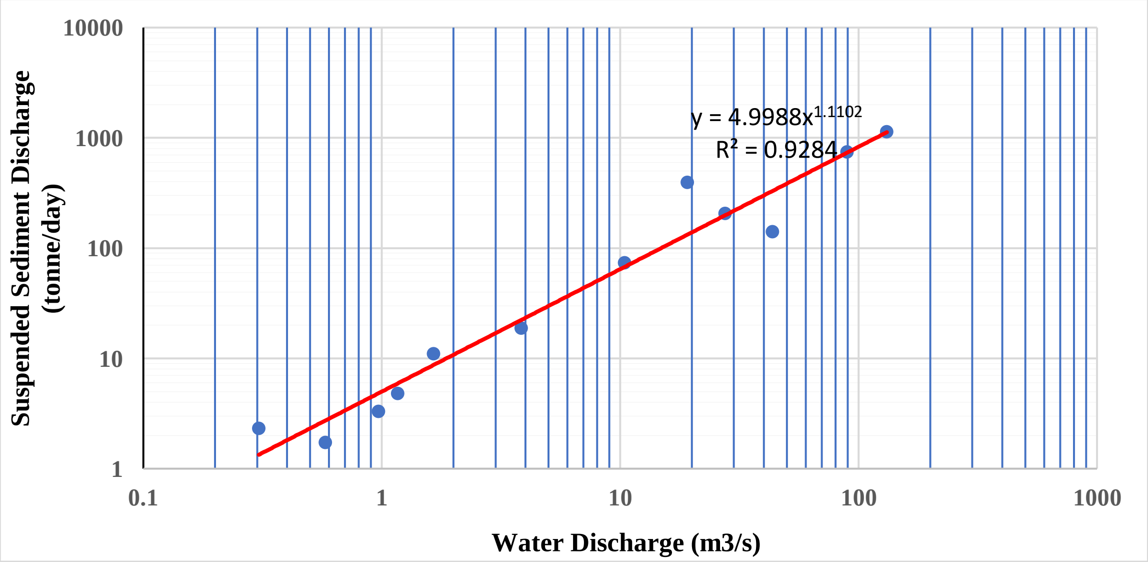

Figure 3: Suspended sediment rating curve for the Densu River at Ashalaja

Table 2: Maximum, Minimum and mean depths of bathymetric profile for the Weija Reservoir

Surveyed profile	Maximum depth (m)	Minimum depth (m)	Mean depth (m)
Range line 1 (R1)	6.32	0.70	3.4
Range line 2 (R2)	7.82	1.70	4.36
Range line 3 (R3)	7.37	1.87	5.76
Range line 4 (R4)	8.25	1.12	4.45
Range line 5 (R5)	8.37	2.12	6.85
Range line 6 (R6)	8.63	1.87	7.12
Range line 7 (R7)	7.00	1.82	4.32
Range line (Long.)	7.30	1.05	6.83
Dam 1	7.62	7.62	7.62
Dam 2	8.12	2.37	7.03

A significant core depth was achieved during the soil sampling. These depths ranged from 0.7 – 1.8 m with soils mainly classified as sandy. These give indications that there are several localised sediment depositions within the reservoir with varying depths at various transects compared to the Normal Water Level (NWL). This reveals a substantive decrease in reservoir depth culminating in the loss of reservoir volume. The soil types at the Ashalaja sampling point of the river as well as the Weija reservoir itself were found to be mostly sand and silt (Figure 4). Figure 4 give a representation of the reservoir bed material characterisation which suggest that the entire reservoir is mainly sandy soil with a fractional percentage of 18.62%, 17.5%, 63.12% and 0.75% for clay, silt, sand and gravel respectively. The particle size distribution analysis within the reservoir were similar except for Point 7 which was sampled at a relatively deeper depth (1.8 m) as compared to the others. Equally, the sample at Ashalaja revealed similar characteristics to that obtained for most parts of the reservoir. Figure 5 shows the bathymetric profile at the Weija Reservoir dam wall. The total width of the dam spillway was 60 m and the water level at the time of the survey was 7.4m and was at its full operational capacity. The profile shows a flat river bed resulting from a preceding spillage four weeks ago that purged the reservoir sediments revealing the signatures of the underlying concrete floor. The spillage flashed all the sediment deposited around the dam wall to its designed bed. Weija Dam uses the Spool valve spillage method to spill the excess water through the bottom of the gate.

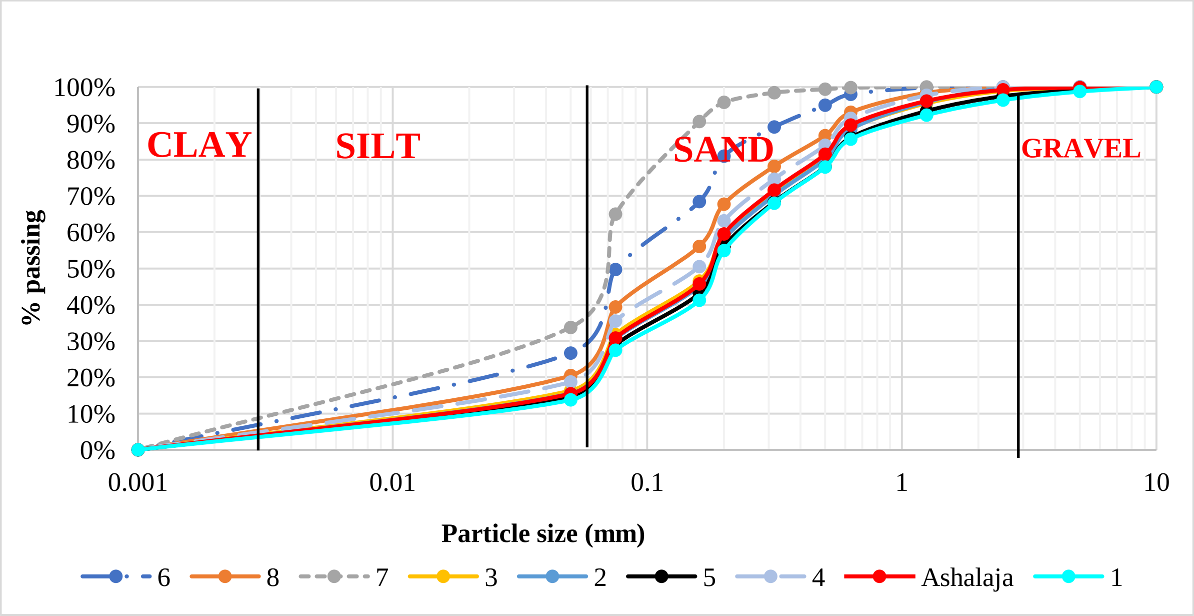

Figure 4: Grading Curve showing the different soil types at Ashalaja and Weija Reservoir

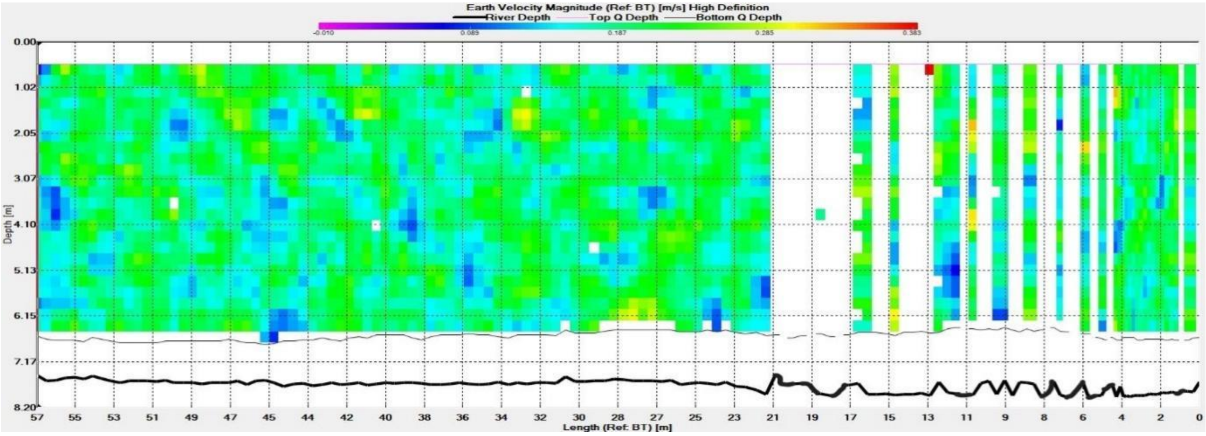

Figure 5: Range-line 7 Bathymetry Profile

3.1.8. Current Capacity of Reservoir

Based on the analysis from the bathymetry survey, the reservoir volume was estimated as 86.67 x 10^6 m^3 with a surface area of 32.319 km^2. Since no work has been done to determine the loss in capacity of the reservoir since its construction, this study compares the initial designed storage capacity of 116.04 x 10^6 m^3 and surface area of 33.6 km^2 to determine the current state of the reservoir in terms of capacity and surface area. Results indicate a loss in the reservoir storage capacity to the tune of 29.371x10^6 m^3 representing 25.31% with a surface area reduction of 1.281 km^2 indicating 3.81%.

The data from this study suggests that the reservoir loses 734,000 m^3 annually, representing 0.734% of its initial capacity (Table 3). The observed trend in loses can be directly linked to the increased annul sediment load accumulation within the watershed. These findings are consistent with other studies by Nagle, (2000) and Palmieri *et al.*, (2001). White, (2001) also found that most of the big reservoirs show various degrees of loss of reservoir storage capacity due to sedimentation globally between 0.5 to 1%. The surface area was also reduced yearly by 32.025 m^2 which represents 0.008% (Table 3).

Table 3: Current reservoir characteristics

Parameter	Value
Designed Storage Capacity (1978)	116.04 x 10^6 m^3
Current Storage Capacity (2019)	86.669 x 10^6 m^3
Change in Storage	29.371 x 10^6 m^3 (25.32%)
Average Annual Loss of Capacity Estimated	734,000 m^3 (0.734%)
Surface Area of Reservoir (1978)	33.6 km^2
Surface Area of Reservoir (2019)	32.319 km^2
Change in reservoir surface area	1.281 km^2 (3.81%)
Annual Surface Area Loss	0.031 km^2 (0.093%)

4.0. CONCLUSION

The objective of this research was to estimate the total annual sediment deposited into the Weija reservoir in the Densu River Basin. The study revealed that the total annual suspended sediment yield was 104,539.17 tonnes/year. This translates into an annual specific suspended sediment yield of 40.2 tonnes/km^2/year, slightly higher than those obtained for other river basins in Ghana. The rating curve established for suspended sediment yield at Ashalaja monitory point had a good fit. The rating equation obtained from this study could be useful in future prediction for sediment transport by comparing with other annual yields to determine the range of yields for a typical wet/dry hydrological year as well as, the average yield over a period which ultimately, can be applied to assess the effectiveness of the IWRM interventions being implemented in the basin. Again, the bathymetric surveyed profiles of the reservoir bottom ranged from 0.7 – 8.63 m with a mean of 5.77 m at its maximum capacity level of 15.8m. The reservoir bed materials in average fraction comprised of clay 19%, silt 18% and sand 63% respectively. In addition, the current reservoir capacity was estimated as 86.67 x 106 m^3 which is 25.32% less than that in 1978 and the surface area was 22.319 km^2 representing 33.57% less since 1978. The study further revealed that the Weija Reservoir loses on average, 734,000m^3 of its storage capacity annually and directly ties in with the observed increase in annual sediment load.

Based on the results obtained from this study, it is recommended that the IWRM interventions being implemented in the basin be intensified to reduce the inflow of suspended sediments into the reservoir. This will safeguard the long-term sustainability of the reservoir for its purpose. It will also limit the activities such as sand winning, farming and restoration of the buffer zones along the river and the reservoir. The reservoir should be de-silted to increase the dwindling storage capacity of the reservoir. In addition, bathymetric surveys should be carried out regularly to know the reservoir capacity as well as a regular update of the rating curve of the reservoir.

AUTHOR CONTRIBUTIONS

Gabriel Appiah – Investigation, writing-original draft, formal analysis; Charles Gyamfi – conceptualization, supervision, funding acquisition, formal analysis, writing-review editing; Obed Fiifi Fynn – Formal analysis, writing- review and editing; Emmanuel K. Opoku-Software, validation, data curation; Frederick O. K. Anyemedu- Supervision, data curation, methodology; writing-review editing; Joseph Turkson-Formal analysis, software.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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