An investigative study on the volume of sediment accumulation in Tagwai dam reservoir using bathymetric and geostatistical analysis techniques

Stephen Olushola Oladosu¹ · Lazarus Mustapha Ojigi² · Victor. E. Aturuocha³ · Chidiogo O. Anekwe³ · Rufai Tanko³

© Springer Nature Switzerland AG 2019

Abstract

Sustainable provision of potable water for domestic, industrial and development purposes in Minna has been elusive over the years due to several factors, including lack of spatial database (locations, depth, area, volume, etc.) and the threat by siltation and land use activities within the corridors of the reservoir area. This paper utilizes the data collected from fieldwork to investigate the volume of sediment accumulated in Tagwai reservoir basin over a period of 31 years since the dam was constructed in 1978. Sediment accumulation study in a dam is one of the useful methods of gathering information needed for its monitoring, maintenance, and sustainability. Leica TC1201 (total station) was used for perimeter survey, while Raytheon DE-119 (echo sounder) was adopted for depth measurement. A comparison was made between the designed reservoir volume ($28.3 \times 10^6 \text{ m}^3$) and the computed volume ($20.4 \times 10^6 \text{ m}^3$). A loss of about ($7.9 \times 10^6 \text{ m}^3$) was recorded. Sediment accumulation gave 0.25 Mm^3 , a spread of about (0.80%) annually. Prediction and error analysis was done using geostatistical methods of Kriging/Co-kriging and Empirical Bayesian Kriging in ArcGIS software. The predicted root mean square errors are 0.0963 and 0.1189 for both methods which presented a good representation while testing with other available methods. It can be concluded that the storage capacity of the reservoir is depleting which has further exacerbated the shortage of water experienced in Minna metropolis therefore, urgent attention for de-silting is highly recommended.

Keywords Bathymetry · Echo-sounder · Dam · Reservoir · Sediment accumulation · Perimeter survey

1 Introduction

A dam is any structure built to store water for later release for various purposes; it could also be for raising the water surface elevation for diversion or navigation, [3, 25, 33, 36]. The stored body of water is referred to as reservoir which can be used for many purposes including municipal and industrial water supply, irrigation, flood damage reduction, and control, hydro-electric power generation, recreation, and for providing downstream minimum flows for

water quality and navigation [2, 12, 32, 33]. The reserving of space in the reservoir to store flood waters will reduce the downstream flood risk, [4, 5, 33, 36], and in its life cycle become a potential sink for upstream sediments.

Dam built across river channel impound water upstream and the natural flow of sediments pattern downstream are altered in the process giving rise to sediments accumulation at the bottom of the reservoir basin [28, 32, 33]; the amount and volume of which can be determined using different methods and/or approaches such as (water

✉ Stephen Olushola Oladosu, olushola.oladosu@uniben.edu; Lazarus Mustapha Ojigi, drlazmojigi@gmail.com; Victor. E. Aturuocha, vingdera@gmail.com; Chidiogo O. Anekwe, chidiogo32@yahoo.com; Rufai Tanko, geocentric2011@gmail.com | ¹Department of Geomatics, Faculty of Environmental Sciences, University of Benin, PMB 1154, Benin, Edo State, Nigeria. ²Department of Geomatics, Faculty of Environmental Design, Ahmadu Bello University, PMB 1008, Zaria, Kaduna State, Nigeria. ³Department of Surveying and Geoinformatics, School of Environmental Technology, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria.

sampling analysis, reservoir sediment probing, integrated bathymetry, geostatistical analysis, GIS, remote sensing etc.) [5–7, 31]. The formation of these sediments may be attributed to factors such poor maintenance culture, indiscriminate disposition of (liquid and solid) wastes, excessive flooding from upstream, overgrazing, lumbering, farming activities etc. [5–7].

During rainfall periods, bare earth (topsoils) are usually washed into reservoir and take different time for the particles to settle down below the reservoir basin with the coarse aggregate settling out first and fine aggregate settling thereafter [20, 33]. Residual from fertilizers applied to aid crop yield in agricultural activities as well as industrial wastes are vital contributing elements to the degradation in the quality of water meant for drinking and domestic purposes which also impact negatively on human health and aquatic living organisms. Therefore, reservoirs in general affect water and sediment cycles of the riverine systems globally [36]. Also according to [36] cited in [26],

...on a global basis, more than 50% of the basin-scale sediment fluxes in regulated basins are potentially trapped in artificial impoundments, with discharge-weighted sediment trapping of about 30% due to large reservoirs and an additional contribution of about 23% from small reservoirs.

Furthermore, an average of 0.5–1% of the volume capacities of small and large reservoirs is lost because of sedimentation in the world annually [21]. Rakhmatullaev et al. [25, 26] also observed that the loss in volume capacity requires an annual replacement cost of about US\$ 13 billion dollars. Also David et al. [9] reported that a compendium on silting of reservoirs conducted using 243 samples around India, through their Central Water Commission (CWC) discovered an annual storage loss of about 0.4% on the average of the initial total volume of impounded water.

Bathymetric surveys are important for many purposes [2–4, 10, 15, 28, 40], while integrated bathymetric survey provides reservoir sedimentation details and much-needed information such as reservoir depth, capacity and bottom topography with great accuracy to optimize reservoir operations.

Reservoir bathymetry are often required for the following reasons among others [2, 3, 10, 21, 24, 32, 34, 40]: (1) to optimize stage/volume curves for routine reservoir survey expedition, (2) to determine the amount of sediment load and yield contributed by the upstream hydrological basin, (3) to help engineers have handy information about what to do if another reservoir is to be design in the same region, (4) to predict sediment spatial distribution pattern within the reservoir in question especially those around useful hydraulic features like the intakes, and (5) to

examine the best methods of sediment prevention and/or sediment removal to be adopted.

Surface erosion, sediment transport, scour, and deposition has been the subject of study by engineers, hydrographers, geologist, and various scientists for centuries, due to their importance to socio-economic development [6]. Most ancient civilization existed along rivers in order to use its water supply for irrigation, navigation, and commercial activities [6].

All rivers carry sediments, due to surface erosion from watersheds or bank erosion along the river course [6]. Understanding the dynamic equilibrium between sediment supply from upstream and a river's sediment capability is paramount to the success of river engineering design, operation, and maintenance [10, 12, 16, 18, 24, 38, 40].

The average annual inflow of sediments into a reservoir together with the total sediment volume accumulated in the reservoir and the distribution of the sediments within such reservoir are important attributes of any reservoir [11, 31, 32]. Engineers built levees along rivers for flood control purposes, while reservoirs ensure water supply and flood control as well as built canal or water supply and navigation [6]. Sustainable use of these hydraulic structures depends on proper understanding of the erosion and sedimentation processes [35] and how to apply them to hydraulic designs. For instance, soil conservation practice, check dams, sediment bypass devices, and sluicing is often used to reduce sediment inflow or remove sediment from a reservoir to prolong the useful life of a reservoir [15, 16, 20, 34, 39] (Fig. 1).

The construction of Tagwai Dam Reservoir after the creation of Niger State on 3rd February 1976 with Minna as the state capital was to support the water and agricultural needs of the growing population in Minna and environs. Therefore, Tagwai Dam Reservoir has been of immense benefit to the urban and rural communities of Minna. However, the sustainable provision of potable water for domestic, industrial and development purposes in Minna has been elusive over the years due to several factors, including lack of spatial database (locations, depth, area, volume, etc.) and the threat by siltation and land use activities within the corridors of the reservoir area [19, 23, 37].

This study, therefore, aims at investigating the volume of sediment accumulated in Tagwai reservoir basin over a period of 31 years since the dam was constructed in 1978, with a view to providing relevant information for reservoir management in order to maximally meet the objectives of its establishment.

1.1 The study area

The study area (Fig. 2) covered the entire reservoir of Tagwai dam with the surface area extending up to

Fig. 1 Reservoir sediment profile with delta and lakebed sediment deposits [16, 33]

Fig. 2 Location of the study area

about 550 hectares, [12]. It is located in Chanchaga LGA of Niger State. The dam lies within latitudes ($9^{\circ}33'59''$ to $9^{\circ}36'07''$) and Longitudes ($6^{\circ}39'20''$ to $6^{\circ}39'58''$). The dam is an earth dam constructed between 20th September 1977 and 1st November 1978 commissioned in 1979 shortly after which Minna became the state capital. The

water of the dam was channeled to the treatment plant at Chanchaga waterworks. The dam is located east of Tunga Goro about 10 km south-east of popular Mobil market and north-east of Paiko. After the dam, there is no continuity in road networks making transportation of agricultural farm products uneasy.

1.1.1 Climatic condition around the dam's area

Information available around the dam's location indicated that the quantity of rainfall ranges from 3.66 mm to 240 mm between the months of May to September when peak rainfall is recorded with respect to temperature variations; November is the hottest period of the year with temperature ranging from 37 to 40 °C in April. The lowest temperature is recorded during the months of December with temperature value of 15 °C while relatively low temperature of between 32 and 35 °C occurs during other months of the year and during these months evaporation values of 61–108 ml are recorded but the highest evaporation rates are between 240 and 250 ml recorded between December and April as a result of the high temperature and low rainfall in the area. Relative humidity around the area between July and August has the highest percentage from 70 to 75% while the lowest is between December and February with percentage range from 16 to 20% [8, 23].

1.1.2 Construction information about Tagwai dam

The construction of Tagwai Dam project was initiated by the Niger State government in 1976, originally conceived to impound water of approximate capacity of $28.3 \times 10^6 \text{ m}^3$ to the teeming population of the state capital and its environs. The dam has a vast catchment area spanning about 110 km². The reservoir has a crest length of 1770 m and crest level of 259 m Niger State Water Board, [22]. Table 1, contains the summary of the other characteristics of the dam.

Table 1 Tagwai dam construction information. Source: [22]

S/no	Name of dam: TAGWAI	Remark
1	Type of dam	Earth fill
2	Average annual precipitation	1270 mm
3	Catchment area	110 km ²
4	Average annual run-off	$25 \times 10^6 \text{ m}^3$
5	Crest length	1770 m
6	Crest level	259 m (O.D)
7	Free board	3 m
8	Maximum flood level	257.5 m (O.D)
9	Full reservoir supply level	256 m (O.D)
10	Crest width	10 m
11	Maximum width of base	150 m
12	Hydraulic height	21 m
13	Maximum structural height	25 m (O.G.L)
14	Dead storage capacity	$1.8 \times 10^6 \text{ m}^3$
15	Dead storage level	245.5 m
16	Active storage capacity	$26.5 \times 10^6 \text{ m}^3$
17	Total storage capacity	$28.3 \times 10^6 \text{ m}^3$
18	Surface area of lake	$5.50 \times 10^6 \text{ m}^2$
19	Total volume of earthwork	870,000 m ³
20	Service spillway length	110 m
21	Service spillway crest elevation	258.3 m
22	Emergency spillway length	170 m
23	Emergency spillway crest elevation	258.3 m
24	Intake tower 2 (24") diameter steel pipe penstocks with guan and control valve	–
25	Commencement date	20/09/1977
26	Completion date	01/11/1978
27	Construction cost	₦6,960,000

2 Materials and methods

2.1 Instrumentation

Equipment used in the field and office work are specified as follows; Leica TC1201 Total Station, Raytheon DE-119 (echo sounder), Hillus Van, Boat carrier, Automatic Level, Garmin 76 Map Cxs GPS receiver, Computer System and Accessories, 25-Horse Power Yamaha Boat Engine etc. Instrument test was carried out respectively for the Boat, Leica TC1201 Total Station, Garmin 76 Map Cxs GPS receiver as well as Kern Automatic leveling instrument to ascertain their optimal performance before using them for data acquisition.

2.2 Testing of boat and bar check for the echo sounder

The type of boat used is a 5 m length by 2.5 m width, an engine boat of 25 horsepower was mounted at the rear

end of the boat as shown in the plate in (Fig. 3). A soft push from the edge of the reservoir to gain depth good enough to prevent the transducer from hitting the ground was sought. After which the engine was powered up and the speed of the boat tested by running a distance of 200 m at 20 km/h, the speed was increased to 30 km/h maintaining the same distance.

The speed of 40 km/h was used for the job, [23]. Four transects were navigated from which the boat was observed and inferred capable of maintaining a straight line viable for the sounding exercise. In order to maintain quality and consistency in pinged depth, calibration of echo sounder is very pertinent because transmitted wave from the equipment through the water column is usually affected by the speed of sound, spreading loss of sound in water, attenuation (absorption of sound in water), volume reverberation etc.

Fig. 3 Left (testing the fiber boat engine); right (transferring level to reservoir's surface)

Fig. 4 Single beam acoustic depth measurement techniques. Source [27]

2.3 Echo sounder principle of operation

$$D = \frac{1}{2} * V * t \quad (1)$$

$$d = \frac{1}{2} * (V * t) + k + dr \quad (2)$$

where D is the depth (from the transducer to the river bottom); V , is the average velocity of sound wave in the water column; t , is the to and fro travel times from the transducer; d , is the corrected depth from reference water

surface; k , is the system index constant; dr , is the distance from reference water surface to transducer (draft) (Fig. 4).

2.4 Bathymetry survey procedure

The procedure we followed was using the portable Garmin 76 Map Cxs GPS receiver to fix the horizontal (X , Y) coordinates values of points while the echo sounder simultaneously records the corresponding depth (Z) values for the fixed points. Kern Automatic level was then used to transfer height from CSN 240S second order control to the reservoir surface and level of water was monitored by

staff gauge planted at the lowest river tide throughout the observation period.

2.5 Perimeter survey procedure

We used a Total Station Leica (TC 1201) and accessories to collect data for delineating the boundary of the reservoir catchment area. Three controls CSN239S, with 3D coordinates values (1,058,406.868mN, 242,003.475mE, 259.600mH), CSN240S, with 3D coordinates values (1,058,432.146mN, 242,598.181mE, 264.600mH) and CSN241S, with 3D coordinates values (1,058,237.476mN, 242,569.449mE, 260.900mH) were found in the vicinity of the dam during fieldwork however, only two (CSN 240S and CSN 241S) passed the integrity (in situ) test. These controls were then used to orient the survey work and sixty-two (62) more controls were established, monumented and coordinated around the dam for the perimeter survey.

2.6 Data acquisition

The echo rolls were interpreted and scaled to extract the depth in meters. The spatial coordinates of the sounding lines were tabulated according to the sequence of sounding lines and fixings. The perimeter and the area of the dam reservoir were determined from the traverse survey computation. About 500 data points were fixed in a near dynamic mode of GPS and resampled to about 1018 x, y, z data points [23]. The leveling was reduced using the method of rise and fall. The volumes of the reservoir water at the date of sounding were computed and compared with those of the maximum/designed capacities using Surfer version 11 Software [30].

2.7 Computation of sediment accumulation volume

Sediment Accumulated Volume (SAV) was computed by subtracting the Designed Reservoir Volume (DRV) from the Present Determined Volume (PDV) from fieldwork. This method was previously used by [1, 2, 28, 37] to find the volume of timeline sediment accumulation in their respective works. Equations (3) and (4) were used for the prediction of the reservoir volume losses and the estimation of the percentage of annual loss of the Tagwai reservoir volume capacity.

$$R_{Annual} = \frac{(V_i - V_f)}{t} \quad (3)$$

$$R\% = \frac{(R_{Annual}) * 100}{V_i} \quad (4)$$

where R_{annual} is the mean annual actual sedimentation volume in ($Mm^3/year$); V_i is the initial reservoir volume in (Mm^3); V_f is the final reservoir volume in (Mm^3); t is the number of years (year) under consideration.

2.8 Geostatistical analysis technique

Geostatistical Analyst in ArGIS software when enabled provides a comprehensive set of tools for creating surfaces that can be further used to give visual impression maps, analyze surfaces, as well as proffer a better understanding of the behaviour of spatial phenomena [11, 13, 17].

2.8.1 Variogram analysis

The variogram has been defined in many books and technical papers and has been adopted for analysis of varied phenomena behavioural pattern including their modeling and predictions [11, 13, 17, 29]. The ArcGIS geostatistical analyst wizard offers a five (5) steps, next-to-finish for (semivariogram/covariance) variable modeling involving searching neighborhood and cross-validation. The outputs of the process are the predicted map, error map, standardized error map, and the QQplot map. While the variogram is a measure of variability which increases as samples become more dissimilar between two different variables, covariance, on the other hand, is a measure of the similarity (correlation) between two different variables. The experimental variogram takes cognizance of the particular vector of separation with respect to an area of interest to compute the average (one-half) of the difference squared in relation to the z-values over all pairs of observations separated by approximately the vector under consideration. The equation involved in this method provided for in [13, 14, 17, 29, 30] is as follows:

$$\gamma(\Delta x, \Delta y) = \frac{1}{2} \varepsilon \{ [Z(x + \Delta x, y + \Delta y) - Z(x, y)]^2 \} \quad (5)$$

where $Z(x, y)$ is the value of the variable of interest at location (x, y) , ε is the statistical expectation operator. $\gamma(\Delta x, \Delta y)$, is a function of the separation between points and not a function of the specific location (x, y) .

The Covariance function for a spatial random process $Z(s)$ observed at two different locations i, j is given by [14, 17, 29] as follows.

$$\text{Cov}[Z(S_i), Z(S_j)] = E[Z(S_i), Z(S_j)] - E[Z(S_i)]E[Z(S_j)] \quad (6)$$

Fig. 5 Linear Variogram model with nugget effect for data set

where $Z(S_i, S_j)$ is the value of the variable of interest at location (i, j) , $\text{Cov}[\cdot]$ Covariance function for a spatial random process $Z(s)$ observed at two different locations (i, j) , $E[\cdot]$ is the statistical expectation operator.

3 Results and discussion

3.1 Variogram analysis result

Variogram is a very useful geostatistical tool for reservoir modeling as a measure of spatial variability by adopting mapping and modeling algorithms. The results of semi-variogram/covariance modelling and cross-validation are presented in Figs. 5 and 9a, b respectively.

Figure 5, shows the linear variogram model with nugget effect consisting of error variance of (1.453) and micro variance of (0), anisotropy ratio of (2) and anisotropy angle of (73.64) for our data set. In Surfer 11 software, the nugget effect is normally partitioned into two sub-components namely: the error variance and the micro variance. Both of which are non-negative and summed up to give the apparent non-zero intercept observed in the figure. The error variance measures the reproducibility of observations.

Figure 6 shows the bathymetric chart of the underwater topography and depth variations, while the 3D surface map for the reservoir and the adjoining catchment areas is as shown in Fig. 7.

Figure 6, shows the bathymetry chart of the reservoir with sounding depths indicated on the scale bar. Contour interval of 0.5 m which gave a good visual impression was adopted. The pattern and volume of sediment trapped in relation to depths in which coarse particles settle down first to form delta while the fine particles proceeded

Fig. 6 Bathymetric chart of Tagwai dam reservoir, near Minna, Niger State

Fig. 7 3D surface map of Tagwai dam reservoir, near Minna, Niger State

Fig. 8 Tagwai reservoir depth profile and trend fitting of 2-period moving average model. A highly correlated result of sediment accumulation for both actual and forecasted sediment load/yield pattern for the reservoir is as presented in figure, for the different sounded depths

further down toward the reservoir head can be studied using the bathymetric chart.

The map in Fig. 8 is the 3D surface map of the reservoir produced from grid file created by the software. It also shows the DTM of the reservoir and the adjoining surrounding, surfer software enables the volume of water present in the reservoir to be computed from the data obtained through fieldwork. The variation in heights from the survey control at the (topsoil) down to the highest depth sounded of 10.60 m (below) the reference water surface at reduced level of 245.534 m is as depicted on the scale bar, below the depth of 10.00 m at (R. L) of 246.134 m is the area where other depths higher than 10.00 m can be found as shown on the scale bar. Note the negative sign on the bar.

3.2 Sediment accumulation volume

In this study, the original reservoir full storage capacity at (256 m OD) designed storage level (Table 1), obtained from [22] gave $28.3 \times 10^6 \text{ m}^3$, while in the computed volume of the current reservoir capacity calculated from the surfer software grid file using kriging method gave $20.4 \times 10^6 \text{ m}^3$. From the foregoing, a loss in capacity of $7.9 \times 10^6 \text{ m}^3$ for 31 years in the reservoir capacity was recorded. The reduction in capacity is about 27.9% of the original volume. The rate of sedimentation is $0.25 \times 10^6 \text{ m}^3$ which is approximately (0.80%) annually.

3.3 Water volume and sediment impact

The impact of the quantity of sediment (i.e. loss of storage capacity) of Tagwai reservoir on the dead storage capacity is obvious. Dead storage is that which refers to

Fig. 9 **a** Left and **b** right, depict the results of semivariogram/covariance modeling (cross-validation) outputs from ArcGIS 10.2 geostatistical analysis carried out. From the figures, the values for mean, root-mean-square, mean standardized, root-mean-square standardized and average standard error were displayed. The outputs of

the prediction are acceptable owing to the fact that the RMS error for the semivariogram is close to zero (0) while the RMSS error is close to one (1) and predictions not deviating far from the measured values, indicated by RMS error and average standard error that are as small as possible as proposed by [13]

Fig. 10 **a** and **b** show the predicted values obtained against the measured values from the statistical analysis using Kriging/Co-kriging **a** ranging between $(-3.29$ to 3.29 and -2.69 to $3.29)$ and Empirical Bayesian Kriging **b** of range $(-3.29$ to 3.29 and -2.69 to $3.29)$ also. **c** and **d** show the clustered representation of error in the measurement using Kriging/Co-kriging **c** ranging between $(-3.29$ to 3.29 and -2.69 to $3.29)$ and Empirical Bayesian Kriging **d** of range $(-3.29$ to 3.29 and -3.93 to $3.93)$. **e** and **f** depict the standardized error versus the normal values using Kriging/Co-kriging **e** of $(-3.29$ to 3.29 and -3.29 to $3.29)$ and Empirical Bayesian Kriging **f** of $(-3.29$ to 3.29 and -3.88 to $3.88)$. Finally, **g** and **h** show the standardized error measurement versus measured values using Kriging/Co-kriging **h** ranging between $(-3.29$ to 3.29 and -3.29 to $3.29)$ and Empirical Bayesian Kriging **g** ranging between $(-3.29$ to 3.29 and -3.88 to $3.36)$. The predictions from the two models gave a similar and good representation of the reality compared to other available methods provided for in software

Fig. 10 (continued)

the volume of the reservoir that is allocated for sediment storage to allow the reservoir to function at an optimal level. Dead storage cannot be emptied by gravity therefore, it prevents complete emptying of the reservoir [28]. The dead storage capacity of Tagwai reservoir is $1.8 \times 10^6 \text{ m}^3$.

The loss of storage is ($7.9 \times 10^6 \text{ m}^3$) which is over three times the dead storage capacity. The difference between sediment volume and dead storage is put at $6.1 \times 10^6 \text{ m}^3$. It can be inferred that Tagwai dam reservoir has lost storage capacity at about four times its dead storage capacity.

3.4 Geostatistical analysis

The results of the geostatistical analysis were carried out using geostatistics analyst toolbox in ArcGIS 10.2 environment on the obtained field data which are presented as follows (Fig. 9).

The semivariogram/covariance cloud gives room to examine the spatial autocorrelation between sample points with assumption that the closer a thing is to another, the similar they are. The importance of cross-validation is to help in making rightful decision on which model provide the most accurate prediction between the measured and predicted values. Two methods (Kriging/Co-kriging and Empirical Bayesian Kriging) are better off than others. Hence the output of the two are presented in Fig. 10a–h.

4 Conclusions and recommendations

The bathymetric survey of Tagwai reservoir was carried out, and the result revealed a loss in water volume totaling about $7.9 \times 10^6 \text{ m}^3$ for the period of 31 years considered in this work as against the original designed capacity of $28.3 \times 10^6 \text{ m}^3$ due to sediment accumulation trapped behind the dam. This obvious discovery will eventually lead to a reduction in reliability of water supply. By reduced reliability, availability of potable water could exacerbate a problem in Minna metropolis and environs. Reservoir sedimentation leads to a decrease in project benefits and causes negative impacts on both upstream as well as downstream inhabitants.

In view of the outcome of this study and the importance of the Tagwai Reservoir for Minna and environs, the following are hereby recommended:

1. Routine bathymetric surveys of the reservoir should be carried out to provide information on the dam's reservoir for sustainable maintenance and management.
2. Indiscriminate waste disposal on both natural and artificial drainage channels and unwholesome agricultural practices around the dam and its catchment should be highly discouraged.
3. Advanced equipment such as the 'Integrated GNSS and Digital Echo-Sounder' should be used for real-time data acquisition and monitoring of the reservoir for better or more accurate results.
4. Data acquired and bathymetric chart produced should be used as a basic spatial database for future research, monitoring, maintenance and management of the reservoir.

Acknowledgements The authors wish to tender their unreserved appreciation to the Director/CEO Lansatech Nig. Ltd, Surv. Ijah Samaila Hassan, Department of Surveying and Geoinformatics Federal University of Technology, Minna and the Niger State Water Board for their respective roles in making the study a success.

Compliance with ethical standards

Conflict of interest The authors declared that there exists no conflict of interest in this work.

References

1. Adediji A (2005) Reservoir sedimentation: the case of Opa Reservoir catchment, Southwestern Nigeria. *S Afr Geograph J* 87(2):123–128
2. Adwubi A, Amegashie BK, Agyare WA, Tamene L, Odai SN, Quansah C, Vlek P (2012) Assessing sediment inputs to small reservoirs in Upper East Region, Ghana lakes and reservoirs. *Res Manag* 14(4):279–287
3. Ajith AV (2016) Bathymetric survey to study the sediment deposit in reservoir of Peechi dam. *IOSR JMCE e-ISSN: 2278-1684, p-ISSN: 2320-334X*, pp 34–38. www.iosrjournals.org. Retrieved 14 Jan 2019
4. Annandale GW (2011) Going full circle. *International water power dam construction*, pp 30–34. Google Scholar
5. Annandale GW (2013) Quenching the thirst: sustainable water supply and climate change, create space. North Charleston, S. C. Google Scholar
6. Chil TY (2006) Reclamation managing water in the west; erosion and sediment manual. U.S. Department of Interior Bureau of Reclamation Sedimentation and River Hydraulic Group. Denver Colorado
7. Chukwu FN, Badejo OT (2015) Bathymetric survey investigation for Lagos Lagoon seabed topographical changes. *J Geosci Geomat* 3(2):37–43. <https://doi.org/10.12691/jgg-3-2-2>
8. Dauda AO, Ojo A, Oyeyinka SA (1998) Feeding habit of *Clarias anguillaris* in Tagwai Reservoir, Minna, Niger State, Nigeria
9. David CF, Pramod N, Manoj K (2017) Estimating reservoir capacity loss from sedimentation. Third national dam safety conference 18–19 February 2017, Roorkee. <https://www.researchgate.net/publication/319928210>. Accessed 20 Jan 2019
10. Dawid S, Michał H, Luisa P, Michael M (2018) Assessment of siltation processes of the Koronowski Reservoir in the Northern

- Polish Lowland based on bathymetry and empirical formulas. *Water* 10(11):1681. <https://doi.org/10.3390/w10111681>. Accessed 14 Jan 2019
11. Deutsch CV (2002) Geostatistical reservoir modeling. Oxford University Press, Oxford
 12. Diego G, Martina B, Massimo R, Gordon G, Nikolai F, Ian GC, Fernando M, Tom B (2017) Linking environmental flows to sediment dynamics. *Water Policy* 19:358–375
 13. ESRI (2010) Introduction to the ArcGIS geostatistical analyst tutorial copyright© 1995–2010 ESRI, Inc
 14. Geoff B. (2005) Introduction to geostatistics and variogram analysis C&Pe 940
 15. George WA, Gregory LM, Pravin K (2016) Extending the life of reservoirs sustainable sediment management for dams and run-of-river hydropower© 2016 International Bank for Reconstruction and Development/The World Bank 1818 H Street NW, Washington, DC 20433
 16. Greg S, Richard DC, Charles H, Rajib AH (2017) Dealing with sediment: effects on dams and hydropower generation. <https://www.hydroworld.com>. Accessed 14 Jan 2019
 17. Gringarten E, Deutsch CV (2001) Teacher's aide variogram interpretation and modeling. *Math Geol* 33:507–534
 18. Imanshoar F, Afshin J, Hossein B, Shatirah A, Babak K, Mohammad RMT, Masoud K (2014) Reservoir sedimentation based on uncertainty analysis. <http://dx.doi.org/10.1155/2014/367627>
 19. Ita EO, Sado EK, Balogun JK, Pandogari A, Ibitoye B (1985) A preliminary checklist of Inland Water Bodies in Nigeria with special reference to lakes and reservoir. Kainji Lake Research Institute technical report series no 14
 20. Johannes K, Bernhard G, Daniel K, Markus A (2017) Effect of bed load supply on sediment transport in mountain streams. *Int J Sedim Res*. <https://doi.org/10.1016/j.ijsrc.2017.03.004>
 21. Mahmood K (1987) Reservoir sedimentation: impact, extent and mitigation. World Bank Publications, Washington
 22. Niger State Water Board (1978) Design properties and dimension of Tagwai dam/reservoir, Minna. Niger State
 23. Ojigi ML, Aturuocha VE, Olushola O, Anekwe CO, Rufai T (2012) Hydrographic survey of Tagwai dam reservoir, Minna, Nigeria. *NJWR, National Resources Institute, Kaduna, Nigeria*. 2(1):48–58. ISSN: 115-9944
 24. Palmieri A, Shah F, Dinar A (2001) Economics of reservoir sedimentation and sustainable management of dams. *J Environ Manag* 61:149–163
 25. Rakhmatullaev S, Antoine M, Marache HF, Huneau MMH (2011) Geostatistical approach for the assessment of the water reservoir capacity in arid regions: a case study of the Akdarya reservoir, Uzbekistan. *Environ Earth Sci* 63(3):447–460. <https://doi.org/10.1007/s12665-010-0711-3>
 26. Rakhmatullaev S, Frederic H, Masharif B, Mikael MH, Philippe Le C (2011) Sedimentation of reservoirs in Uzbekistan: a case study of the Akdarya Reservoir, Zerafshan River Basin. In: Proceedings of the ICCE workshop, September 2009, Hyderabad, India, vol 349
 27. SBADMT (2002) Single beam acoustic depth measurement techniques. <http://www.sqwestinc.com/media/support/depthmeasuringtechniques.pdf>. Accessed 10 Mar 2018
 28. Sheikh DA, Aliyu M (2017) Examining sediment accumulation in Goronyo reservoir, Sokoto State, Nigeria. *IOSR JHSS* 22(8):60–65. e-ISSN: 2279-0837, p-ISSN: 2279-0845. www.iosrjournals.org
 29. Sourav D (2011) Statistical estimation of variogram and covariance parameters of spatial and spatio-temporal random processes. <https://www.escholar.manchester.ac.uk/>. Accessed 26 June 2018
 30. Surfer 11 Self-Paced Training Guide (2012). <http://www.goldensoftware.com/>. Accessed 27 June 2018
 31. Sylvain O (2018) Why and how do we study sediment transport? Focus on coastal zones and ongoing methods. *Water* 10(390). <https://doi.org/10.3390/w10040390>. www.mdpi.com/journal/water. Accessed 14 Jan 2019
 32. Timothy JR, Jennifer B (2017) Dam removal analysis guidelines for sediment—version 1 technical report SRH-2016-38 prepared for subcommittee on sedimentation federal advisory committee on Water Information Bureau of Reclamation Technical Service Center, Denver, Colorado
 33. Timothy R, Sean K, Kent C (2017) Frequently asked questions about reservoir sedimentation and sustainability contribution and review by the sub-committee on sedimentation national reservoir sedimentation and sustainability team
 34. Vahid R, Jude HK, Frank D, Mark EJ, Edward AM, Donald HH, Christian G, Paul ML, Scott WC, Ryan AC, Adam J (2018) Blackwood examining storage capacity loss and sedimentation rate of large reservoirs in the Central U.S. Great Plains. Accessed 14 Jan 2019
 35. Vanmaercke M, Poesen J, Broeckx J, Nyssen J (2014) Sediment yield in Africa. *Earth Sci Rev* 136:350–368. <https://doi.org/10.1016/j.earscirev.2014.06.004>. <http://www.sciencedirect.com/>. Accessed 14 Jan 2019
 36. Vörösmarty CJ, Meybeck M, Fekete B, Sharmad K, Green P, Syvitski JMP (2003) Anthropogenic sediment retention: major global impact from registered river impoundments. *Global Planet Change* 39:169–190
 37. Vulegbo AA, Schoeneich K, Alagbe SA (2014) Assessment of sediment generation from Tagwai drainage basin. *Am Int J Contemp Res* 4(8)
 38. Wisser D, Steve F, Stephen H, Bierkens MFP (2013) Beyond peak reservoir storage? A global estimate of declining water storage capacity in large reservoirs. *Water Resour Res* 49:5732–5739. <https://doi.org/10.1002/wrcr.20452>
 39. Yang CT, Randle TJ, Shiang-kueen H (1998) Surface erosion, sediment transport, and reservoir sedimentation. In: Proceedings of a symposium, Vienna. IAHS Publication no 249
 40. Zarris D, Evdoxia L (2017) Comparative analysis of different reservoir surveying methodologies for the optimum volumetric computation of fluvial sediment deposits. *IOSR J Appl Geol Geophys* 5(3):75–80

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.