Assessment of Chemical Characteristics of Bottom Sediments of Zobe Dam Reservoir, Katsina State, Nigeria

Ibrahim Adesoji A., Jolly Byami A. and Tawey Mam. D

Department of Groundwater, National Water Resources Institute, Kaduna

Department of Geology, Ahmadu Bello University, Zaria

Email: adesojiibrahim@yahoo.com

Abstract

Zobe Dam is one of the silted dams in Nigeria. It is located in the Dustin-ma area in Katsina State northwestern Nigeria. The bottom reservoir sediments of the dam were sampled during the bathymetric studies of the reservoir. The objectives are to: determine the status of mineral elements and their distribution; measure the anomalous elemental concentration, as a tool in search for solid mineral deposits; and determine the usefulness of such sediments when dredged out. A total of 15 samples were obtained and analysed at Federal Steel Council laboratory in Kaduna using a Scanning Electron Microscope which was then transferred electronically to EDX that revealed the elemental constituents of the samples in mg/kg. A total of 27 elements were examined, the order of enrichment is Si > Fe > Al > Hg > K > Pb > Ti > Ca > Cd .... All the elements were several times greater than the world’s mean crustal abundance. The preponderance of these elements could be attributed to the contamination from artisanal mining of polymetallic mineral associations in Jibia, Dandire, Mallam Tanko Kafur, Dutsin-Ma and other areas within the State; as well as the anthropogenic factors like organic fertilizer application by farmers. It is recommended that the erosion of sand into the dam be checked through the planting of trees and other environmental conservation practices.

Keywords: Weathering, Sediments, Reservoir, Crustal abundance, Electron microscope

INTRODUCTION

Earth’s surface is in dynamic equilibrium, as a result of the balance between the internal geologic processes which create earthquakes, volcanic activity, and mountain ranges, and the external geologic processes that are responsible for shaping and modifying land relief, through weathering, erosion, transportation and deposition. The geologic agents of achieving these are the wind, the water, living beings and gravity; and one of the resulting actions is sedimentation. It is a process whereby soil particles are eroded and transported by flowing water or other transporting media and deposited as layers of solid particles in water bodies such as reservoirs and rivers (Tundu et al., 2018). It is a complex process that may include temporary storage of eroded materials on hill slopes, stream courses, and in the long-term deposited in lower courses such as standing bodies of water, known as reservoirs.

Of particular concern are fine-grained silts and clays, which can degrade habitat, clog water supply intakes and fill reservoirs, and often carry phosphorus and/or contaminants harmful to humans and aquatic life (Larsen et al., 2010). It also reflects the quality of surface water as
well as provides information on the transportation and fate of pollutants (Santchi, 1984). Research shows that about 1% of the total reservoir storage capacity of the world reservoirs is lost every year to sedimentation (Mahmood, 1987), and this can affect hydropower production or cause damage to the facility’s mechanical components (Obialor et al., 2019). Reservoirs are designed for the assumption of a 50 - 100-year life span, after which depleted by sediment deposition over time. The amounts of sediment inflows from overland often make the useful life of a dam shorter because sediments are directly discharged into the dam and settled down as the velocity of water reduces near dyke as observed by Morris and Fan (2008). A World Bank study (Mahmood, 1987) illustrated that the average useful life of existing reservoirs in all countries of the world decreased from 100 to 22 years despite their significant contribution to flood control, by temporarily retaining flood water during peak flow, consequently reducing excess surface runoff along the streams contributing downstream (De Coning and Poolman, 2011; Elkhrachy, 2015).

A well-structured reservoir management approach will solve these myriads of reservoir sedimentation/siltation. The methods of managing sediment fall under three general categories: those that divert sediment around or through the reservoir, those that remove deposited sediments, and those that minimize the amount of sediment reaching the facility in the first place (Obialor et al., 2019). The bathymetric survey is one of the methods employed to determine the volume changes caused by sediment deposits in various reservoirs. It allows for measuring the depth of a water body as well as mapping the underwater features (Menna, et al., 2018).

The previous researches available on Zobe dam are on the controlling foundation-related seepages in 1983,1985,1986,2005, and 2009 (ESIA,2020), the efficacy of Zobe dam for hydroelectricity generation, (Nuhu and Abdul,2020), water quality assessment (Ibrahim, et al., 2014; Sadauki et al., 2022), measurement of radiation activity, (Najib et al., 2014; Oluwole et al.,2020). However, the bathymetric study and bottom sediment sampling analysis of the Zobe Dam are the first of its kind since the dam was constructed. This report therefore serves as baseline information for future studies. The objectives of sediment bottom sampling are to: determine the status of metals and heavy metals, as well as solid non-metal distribution in bottom sediments; measure the anomalous elemental concentration of elements, as a tool in studying environmental pollution and search for secondary solid mineral deposits.

**Location of the study area**
The Zobe Dam is situated on the coordinates 12°02'13.769” N, 7°02'75.3.89” E in the Dutsin-Ma local government area of Katsina State of Nigeria (Fig.1a). It is an earth-fill structure with a height of 19 m and a total length of 2,750 m. The dam has a storage capacity of 177 million cubic meters and an irrigation potential of 8,000 hectares. Zobe Dam was conceived in the late 1970s and was planned to supply 50% of drinking water to Katsina State (ESIA Report, 2020), while also supporting irrigation farming in the Dutsinma area and nearby towns and villages along the dam spillway discharge (Fig.1b).

**Geology of the Area**
Dutsin-Ma and its environs are underlain by two formations (Akor et al., 2017): the Illo-Gundumi formation of the Sokoto Basin covers 20% of the total geology of Katsina. The remaining 80% parts of where Zobe Dam is located is underlain by Basement Complex Rocks: the ancient biotite-mica-rich older granites older than 650 million years (commonly called the Pan-African granite suites), and the granite-gneiss-migmatite with minor bandings and augen structures in occasional place types (Kankara, 2020), in association with meta-sediments (Akor et al., 2017). However, within the surroundings of Zobe Dam are exposed lateritic hard pans.
In some parts of the area, the rocks have changed over time as a result of weathering and erosion effects (Kankara, 2020).

**MATERIALS AND METHODS**

**Sample collection**
A total of fifteen samples were collected within the reservoir in December 2021. Their locations are shown in Fig.2. These samples were later grouped as either single or composite samples based on their proximity and tributaries, according to the established network during bathymetric studies. In the end, six samples were analysed, these are ZEB 01, ZEB 05,(as single samples), ZEB 3 representing sample locations 3, 6,8, and 10; ZEB 14 representing locations 14 and 16; ZEB 12, representing locations 11, 12 and 18; and ZEB 22, representing, 22, 23, 28 and 35 (as composite samples). The samples were collected using a fabricated dredger. The wet samples were wrapped into black polythene bags, labelled and transferred to the Federal Steel Council laboratory, Malali in Kaduna, where they were air dried at room temperature (26° - 27°C) for three weeks.

**Laboratory Analyses**
These Samples were then pulverized to a particle size of about 0.15 microns or about 100mesh, using equipment such as a Jaw Crusher, Disc miller, and vibrating cup miller. The samples were later run through a Scanning Electron Microscope (SEM-PHENOM PRO X MODEL). The images are adjusted for sharpness, necessary zooming and refocusing. This was then transferred electronically to EDX (Energy dispersive X-ray spectroscopy) The EDX coupled with Elemental Identification Software automatically characterized the major, minor and trace percentage elemental constituents of the sample. The machine is capable of carrying out elemental analysis of samples and expressing the results in percentage atomic weight, % weight conc., and oxides of the element in % stoichiometry concentration.
RESULTS AND DISCUSSION

Description of Bottom sediment of Zobe Dam
The sediments are silty to fine-grained sands (mostly quartz) and the textures vary from very fine to fine, while the colour is from greyish-black to brown, depending on the location. Those at the periphery of the dam are brown, while those at the centre are greyish to black. The sediments are also rich in organic matter, especially remains of decayed aquatic weeds (mainly Typha grass). The colour could be attributed to an anoxia environment and the presence of organic matter.

Chemical Analysis of Sediment of Zobe Dam
A total of twenty-seven elements were examined from the bottom sediments collected at Zobe Dam, these elements are grouped as Heavy metals; macro and micro nutrients for plant growth; and those that are referred to as commonly found elements in the earth's crust. From the descriptive statistics of the concentration and distribution of these elements (Table 1), it was observed that all the elements present are several times higher than their crustal abundance. Those with relatively lower values of concentration are sodium, 12.7%, Magnesium, 30.7%, and Calcium, 55.8%. This could be due to chemical alteration, as explained by Thomas et al., (1996) that when chemical alteration exceeds mechanical erosion, the most soluble elements are carried in the dissolved phase as ions (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$) and dissolved SiO$_2$, whereas the least soluble ones (Al, Fe, Ti, Mn) remain in the soil which gradually becomes more enriched.
Also, Katsina State is endowed with several solid minerals, these include Nickel, Copper, Cobalt, Vanadium, chromite- a polymetallic association in Jibia and Chromate found with asbestos at Dandire and Mallam Tanko. Tantalite/Columbite occurs in many locations and artisanal mining is being carried out in 15 LGAs, Iron ores occur in 5 locations (Katsina State Investors Handbook, 2016). The weathering and other surficial processes could also assist in the concentrations of these minerals, as well as their associates. Other activities could be attributed to anthropogenic activities, such as agricultural practices. Agricultural activities have caused 70% of water pollution worldwide (Sagasta et al., 2017). Watts (2010) stated that pesticides and fertilizers from agricultural activities have contributed 43% of chemical oxygen demand, 67% phosphorus, and 57% nitrogen from waste to the rivers.

### Table 1: Descriptive statistics of the distribution of elements in the bottom sediment of Zobe dam

<table>
<thead>
<tr>
<th>Element Symbol</th>
<th>Range (Mg/Kg)</th>
<th>Mean (Mg/Kg)</th>
<th>Mean± SD</th>
<th>*Crustal Abundance greater than crustal abundance (Mg/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>320200-94100</td>
<td>359883</td>
<td>±335906.6</td>
<td>277200 129.8</td>
</tr>
<tr>
<td>Fe</td>
<td>167300-81600</td>
<td>214867</td>
<td>±157192.4</td>
<td>5000 429.7</td>
</tr>
<tr>
<td>Al</td>
<td>160000-15400</td>
<td>188600</td>
<td>±165192.4</td>
<td>81300 232</td>
</tr>
<tr>
<td>K</td>
<td>37900-40900</td>
<td>43867</td>
<td>±39352.73</td>
<td>25900 169.4</td>
</tr>
<tr>
<td>Pb</td>
<td>0 - 36700</td>
<td>19700</td>
<td>±5985.19</td>
<td>15 131333.3</td>
</tr>
<tr>
<td>Cu</td>
<td>0 - 5600</td>
<td>933</td>
<td>±1353.19</td>
<td>70 1333.3</td>
</tr>
<tr>
<td>Ti</td>
<td>19800-28900</td>
<td>24767</td>
<td>±21758.57</td>
<td>4400 562.9</td>
</tr>
<tr>
<td>Cd</td>
<td>8200-21600</td>
<td>13088</td>
<td>±8015.56</td>
<td>0.2 6544165</td>
</tr>
<tr>
<td>Ca</td>
<td>16800-23700</td>
<td>20250</td>
<td>±17719.58</td>
<td>36300 55.8</td>
</tr>
<tr>
<td>Ag</td>
<td>10700-18500</td>
<td>13667</td>
<td>±10509.36</td>
<td>0.1 1366670</td>
</tr>
<tr>
<td>Co</td>
<td>0 - 12600</td>
<td>6267</td>
<td>±567.99</td>
<td>23 27246.4</td>
</tr>
<tr>
<td>Mn</td>
<td>2900-14700</td>
<td>6433</td>
<td>±1491.62</td>
<td>1000 643.3</td>
</tr>
<tr>
<td>Zn</td>
<td>0 - 10400</td>
<td>5950</td>
<td>±2019.73</td>
<td>130 4576.9</td>
</tr>
<tr>
<td>Se</td>
<td>3100-10400</td>
<td>6533</td>
<td>±3959.55</td>
<td>0.09 7259256</td>
</tr>
<tr>
<td>Mg</td>
<td>1700-10400</td>
<td>6417</td>
<td>±3378.31</td>
<td>20900 30.4</td>
</tr>
<tr>
<td>Nb</td>
<td>8500-17200</td>
<td>11867</td>
<td>±8851.26</td>
<td>24 49444.5</td>
</tr>
<tr>
<td>Cl</td>
<td>5000-7700</td>
<td>6400</td>
<td>±5514.56</td>
<td>320 2000</td>
</tr>
<tr>
<td>Ni</td>
<td>0 - 10200</td>
<td>4000</td>
<td>±754.68</td>
<td>80 5000</td>
</tr>
<tr>
<td>Y</td>
<td>8200-20800</td>
<td>12217</td>
<td>±7763.05</td>
<td>40 30541.7</td>
</tr>
<tr>
<td>Na</td>
<td>2500-4800</td>
<td>3600</td>
<td>±2616.13</td>
<td>28300 12.7</td>
</tr>
<tr>
<td>As</td>
<td>4800-3400</td>
<td>6383</td>
<td>±4260.4</td>
<td>2 319166.5</td>
</tr>
<tr>
<td>P</td>
<td>1300-3400</td>
<td>2333</td>
<td>±1548.99</td>
<td>1180 197.7</td>
</tr>
<tr>
<td>Cr</td>
<td>0 - 5800</td>
<td>1450</td>
<td>±976.31</td>
<td>200 725</td>
</tr>
<tr>
<td>C</td>
<td>1300-4900</td>
<td>2617</td>
<td>±1389.94</td>
<td>320 817.7</td>
</tr>
<tr>
<td>S</td>
<td>0 - 5900</td>
<td>2133</td>
<td>±371.13</td>
<td>520 410.3</td>
</tr>
<tr>
<td>N</td>
<td>900-2300</td>
<td>1400</td>
<td>±926.71</td>
<td>50 2800</td>
</tr>
<tr>
<td>Hg</td>
<td>0 - 90200</td>
<td>15033</td>
<td>±14664.01</td>
<td>0.5 30066</td>
</tr>
</tbody>
</table>

*Crustal abundance adapted from (Mason, 1952)

Heavy metals that are released and transported from land environments can easily accumulate in the sediment and, under certain conditions, permeate the water layer (Duman...
and Koca, 2004), and this could have severe consequences for the users of such water. For instance, since Cd has bioaccumulation capacity (Norvell et al., 2000), it is one of the most toxic substances for all human populations mostly from plant-derived food and the intake of contaminated food. Moreover, in part of the valley of the River Jinzu in Toyama Prefecture, Japan, paddy-rice-growing soils had been contaminated by a Pb-Zn mine upstream and some of the population suffered death and severe disability from Cd toxicity (Alloway and Steinnes, 1999).

CONCLUSION
The elemental composition of the bottom sediments of the Zobe Dam reservoir analysed using the SEM-EDX technique shows that the reservoir is rich in metallic and non-metallic mineral elements. The order of enrichment is Si > Fe > Al > Hg > K > Pb > Ti > Ca > Cd....All the elements were several times greater than the world’s mean crustal abundance. The preponderance of these elements could be attributed to the contamination from artisanal mining of polymetallic mineral associations in Jibia, Dandire, Mallam Tanko Kafur, Dutsin-Ma and other areas within the State, as well as the anthropogenic factors like organic fertilizer application by farmers. It is therefore recommended that:

- Activities like artisanal small-scale gold mines that use Mercury, Arsenic cadmium and Lead should be seriously monitored to curtail further pollution of the dam;
- The use of cow dung as a remediation of heavy metals like chromium and arsenic should be encouraged especially among farmers, via organic manure, as it has been proven (Mohan and Gupta, 2014) that cow dung can achieve 73.8% removal of chromium from aqueous solution;
- Watershed management concerning planting of trees, to reduce soil erosion and transportation of sand particles should be encouraged in the region.

REFERENCES
Assessment of Chemical Characteristics of Bottom Sediments of Zobe Dam Reservoir, Katsina State, Nigeria


Katsina State Investors’ Handbook, (2016). Mineral inventory of Katsina State, Table 1, p20


