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# Sedimentation and sediment core profile of heavy metals in the Owabi reservoir in Ghana

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## Abstract

Tropical reservoirs are important for numerous socioeconomic and ecological reasons, including water supply, fishing and flood control. These functions are easily compromised, however, when reservoirs undergo accelerated sedimentation with increased inputs of chemical contaminants. The present study applied the concept of sediment core analysis to evaluate the sedimentation rate in Owabi Reservoir, which has served as a source of drinking water supply in Kumasi, Ghana, for nearly a century. The temporal variation of contamination from heavy metals was also assessed over this period. The sedimentation rate for Owabi Reservoir was estimated to be 6.82 mm/year, suggesting a relatively low rate of sedimentation, which is ecologically healthy in preventing a rapid loss of reservoir water volume. Heavy metal concentrations in the sediment cores taken from the reservoir reflected varying degree of contamination from the 1930s to 2010s. The concentration of iron (Fe) (1,560–1,770 mg/kg) was found to be the highest among the metals in the sediment core, while mercury (Hg) concentration (0.01–0.04 mg/kg) was the lowest. Lead (Pb) contamination peaked in the 1980s. Arsenic (As) and mercury (Hg) contamination exhibited more recent peaks in the 2000s, coinciding with recent widespread issues of artisanal and small-scale gold mining (ASGM) in Ghana. Thus, even though ASGM activities are known to occur in remote districts, releases from such activities might eventually contaminate reservoirs designated as urban drinking water supplies.

KEYWORDS
chemical contamination, Owabi, reservoir, sediment core

## 1 | INTRODUCTION

The environmental quality of a lake is intricately related to many different physical, chemical and biological factors occurring simultaneously at any given period of time, including such factors as rainfall cycles, watershed characteristics, lake basin shape and depth, the lake water itself and bottom sediments (Holdren, Jones, & Taggart, 2001). These physical and chemical factors can in turn support a community of biological organisms unique to lakes. While the same basic physical, chemical and biological processes occur in reservoirs and natural lakes, the age, morphology, location of the drainage basin and hydrological characteristics make them unique ecosystems, which needs to be understood in managing specific lakes.

The present study focused on the Owabi Reservoir, constructed nearly a century ago by damming the Owabi River in 1928 in Ghana (Akoto, Gyamfi, Darko, & Barnes, 2017). It was initially the sole source of treated water for the Kumasi metropolis in the Ashanti Region of Ghana until 1971, when the Barekese Dam was constructed (Domfeh, Anyemedu, Anornu, Adjei, & Odai, 2015). The Owabi Reservoir currently provides about 20% of Kumasi's potable water (~3 million gallons/day). In addition to being a water supply reservoir, the reservoir also is relied upon for fisheries and crop farming. It is uniquely located in a wildlife sanctuary, the only inland wetland in Ghana (Nunoo, Agbo, & Ackah, 2012). The Owabi Reservoir drains many streams, prominent among them being the Owabi, Akyeampomene, Akuosu, Sukobri and Punpunase rivers (Akoto, Bruce, & Darko, 2008). These rivers flow through the rapidly urbanizing agricultural village of Atafoa, as well as high population density areas such as Bremang, Suame, Bohyen and Abrepo (Akoto & Abankwa, 2014; Akoto et al., 2008; Badu, Wemegah, Boadi, & Brown, 2013). Rapid urbanization and industrial development in these areas have resulted in some serious concerns for the environment and the quality of the lake water, considering that such issues might escalate the cost of water treatment and the health of the reservoir.

Typical issues confronting the management of tropical reservoirs and lakes include eutrophication, chemical contamination and sedimentation (Cooke, Welch, Peterson, & Nichols, 2016; Lewis, 2000; Nagle, Fahey, & Lassoie, 1999; Thornton, 1987). Increased sedimentation can lead to a decreased water volume in a lake, with attendant undesirable effect on its sustainability and functionality in supporting aquatic life and providing potable water. The process of sedimentation results in the sinking of particles (silt; chemicals; algae; animal faeces; dead organisms) through the lake water column, accumulating in the lake bottom. When the water column is studied, therefore, it provides an understanding of transient events in a reservoir at that particular point in time. When the accumulated sediment is studied, however, it facilitates our understanding of the behaviour of a reservoir over several years. Sediments generally act as a major sink of such pollutants as heavy metals, persistent organic pollutants (POPs) and pesticides. Thus, the sediments can be viewed as providing an environmental record of pollutants, as well as being useful for retrospectively establishing the pollution history of an area. Sediments accumulate gradually in a waterbody, with older sediments being locked up in deeper layers, while recent sediments accumulate in the upper layers (Hogarh, Adu-Gyamfi, Nukpezah, Akoto, & Adu-Kumi, 2016). Thus, a sediment core provides a good spectrum of pollution dynamics in a watershed over time (Spencer & MacLeod, 2002). This fact is important to help understand historical antecedents that might have triggered prevailing environmental issues, allowing management options to be properly designed to deal with similar situations in the future.

Accordingly, the present study evaluated the rate of sedimentation in the Owabi Reservoir, assessed contamination from heavy metals in sediment core segments and elucidated the contamination history in the Owabi Reservoir catchment. Multivariate technique was applied to explore potential source factors of the heavy metal contaminants in order to inform pollution prevention activities for sustainable management of the reservoir.

## 2 | METHODOLOGY

### 2.1 | Study area

The present study was conducted at the head-pond of the Owabi Reservoir (6.74°N and 1.70°W), located within the Owabi Wildlife Sanctuary in the Ashanti Region of Ghana (Figure 1). Owabi Reservoir is about 23 km northwest of Kumasi, the second largest city in Ghana. The Owabi Sanctuary is the only inland wetland in Ghana. Owabi Reservoir was created by damming the Owabi River

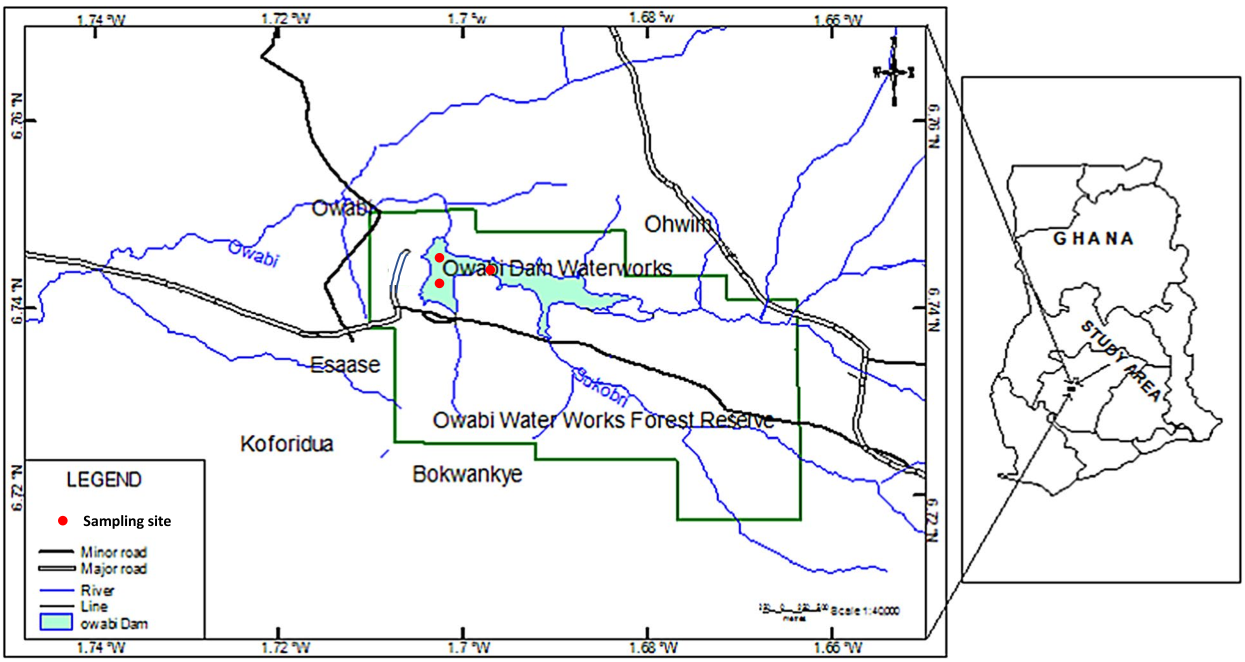


**FIGURE 1** Location of Owabi Reservoir in Ghana

in 1928 for water treatment purposes (Ghana Water Company, personal communication). The reservoir is about 22 ft (6.7 m) deep and covers an area of 2.03 ha with seven streams draining into it (Nunoo et al., 2012). The Owabi Sanctuary surrounds the reservoir. The Owabi Reservoir Water Treatment Plant is among the oldest water treatment plants in Ghana.

### 2.2 | Measurement of average reservoir depth

The approach to determining the sedimentation rate was based on changes in the depth of the reservoir over time. The average depth of the reservoir when it was constructed in 1928 was 6.8 m (680 cm). The current average depth was measured applying a Depth Sounder device (Hondex Digital Depth Sounder), which functions by sending a laser beam from the water surface to the reservoir bottom. The beam is then reflected back to the device, and the distance travelled is estimated as the depth. Measurements were taken at 99 different points, with the objective of taking close to a hundred measurements across the surface of the reservoir head-pond and the average value subsequently estimated. The annual sedimentation rate in the reservoir head-pond was then estimated as follows:

$$\left(\text{Initial depth} - \text{Current depth}\right) / \text{Age of Lake} \quad (1)$$

Thus, the annual rate of sedimentation is calculated as 6.8 m − current depth)/(2016–1928).

### 2.3 | Sampling and processing of sediment cores

Three sediment core samples, each ~1.5 m in length, were taken from the Owabi Reservoir head-pond, utilizing a PVC corer. Corers containing the sediment cores were kept in an upright position for water to drain off gradually. It took two to three months (between May and July 2016) for the cores to dry and harden sufficiently to be cut into slices. One metre of each sediment core was sliced into disc sections. The first 30 cm of each core (from the top) was cut into 2 cm slices. The remaining 70 cm of the core was cut into 5 cm slices. Thus, each core was cut into 15 discs of 2 cm slices and 14 discs of 5 cm slices. The discs were air-dried for one month (August 2016), allowed to harden and then pulverized with a mortar and pestle.

### 2.4 | Heavy metals and organic matter analyses

One gram (1 g) sample of air-dried, pulverized sediment was digested with 3 ml of concentrated nitric acid ($HNO_3$) in Folin-Wu tubes in an electrically heated block for 1 hr at 145°C. Four millilitres of $HClO_4$ was added, and the mixture heated to 240°C for an additional hour. The mixture was allowed to cool for about an hour, with the addition of about 20 ml of Milli-Q water. The mixture was then filtered, and the filtrate was made up to 100 ml with Milli-Q water. Determination of heavy metals, including cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb) zinc (Zn) and a metalloid (arsenic; As), was conducted utilizing Atomic Absorption Spectroscopy (AAS). Standard reference material (ISE 999) was analysed alongside each sample for quality control purposes. The detection limits of the various heavy metals were as follows: As (0.03 ng/g), Cd (0.8 ng/g), Cr (3.0 ng/g), Cu (1.5 ng/g), Fe (5 ng/g), Hg (0.009 ng/g), Ni (6 ng/g), Pb (15 ng/g) and Zn (1.5 ng/g). Analysis of organic carbon was based on the Walkley and Black method (Allison, 1965).

### 2.5 | Statistical analysis

Concentrations of heavy metals in sediment core were expressed as mean ± standard error of mean (*SEM*) among the three cores. The dataset was subjected to principal component analysis (PCA) to explore the possible source factors underlying the dataset.

## 3 | RESULTS AND DISCUSSION

### 3.1 | Rate of sedimentation of Owabi Dam head-pond

The current average depth of the Owabi Dam head-pond was estimated to be 6.20 m. When this value was substituted into Equation (1), the rate of sedimentation was estimated to be 0.00682 m/year (that is, 6.82 mm/year). The rate of 6.82 mm/year suggests sedimentation in the Owabi Dam head-pond has proceeded at a relatively slow pace, which is ecologically healthy for prolonged use and sustainability of the reservoir. This certainly has contributed positively to keeping the dam functional for water supply purposes over the past 88 years without having to be dredged. As the reservoir is located in a wildlife sanctuary, it is likely that the surrounding vegetation has helped retard erosion of sandy materials and debris into the head-pond, consistent with the observation that vegetation cover has been found to reduce overland flow during rainstorms and has a positive impact in reducing erosion and its attendant sedimentation issues (Prosser & Williams, 1998). Previous studies, for example, suggest that when forest cover is removed through such events as natural fires (Prosser & Williams, 1998), or anthropogenic activities such as clearing of land for mining (Hogarh et al., 2016), such disturbances have led to increased sedimentation rates. In the mining district of Bibiani in Ghana, the sediment yield to Lake Amponsah was found to be average 1.76 cm/year, which is two orders of magnitude greater than the rate for Owabi Reservoir (Hogarh et al., 2016). Given the benefit of forest cover for reduced sedimentation and sustainable use of Owabi Reservoir, it is important the wildlife sanctuary is protected against loss of vegetation cover.

### 3.2 | Sediment core profile of heavy metals

#### 3.2.1 | General trends in heavy metal concentration

The general trends of heavy metal contamination observed for Owabi Reservoir are summarized in Figure 2, ignoring time-specific

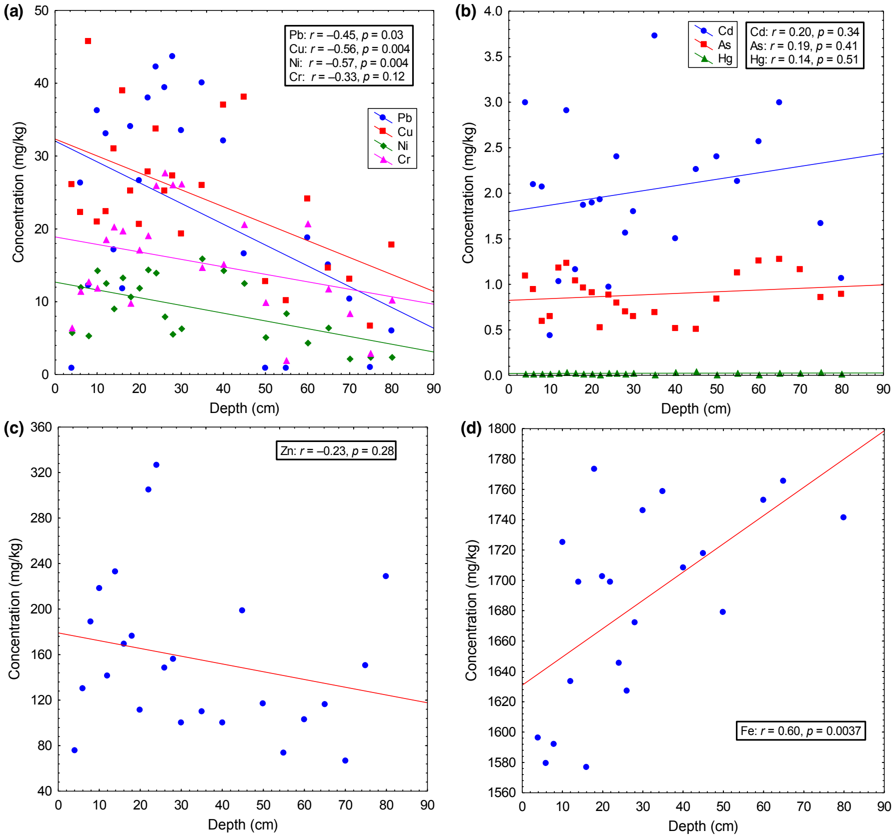


**FIGURE 2** General trends of heavy metal concentrations in Owabi Reservoir

variations in this case. Generally, the concentrations of Pb, Cu and Ni moderately declined with increased depth of the sediment core ($r$ = 0.45, 0.56 and 0.57, respectively; Figure 2a), suggesting relatively increased contamination from the respective metals in recent times. The Cr and Zn concentrations also appeared to decline with depth, although the associations were not statistically significant ($p$ = 0.12 and $p$ = 0.28, respectively; Figure 2a, c). Similarly, ignoring time-specific variations, the association of Cd, As and Hg concentrations with sediment core depth was not statistically significant ($p$ = 0.34, 0.41 and 0.51, respectively; Figure 2b). However, the Fe concentrations exhibited a fairly strong correlation with sediment core depth (Figure 2d), meaning older sediments contained relatively greater quantities of Fe than recent sediment. This might be attributable to a gradual erosion of Fe from adjoining laterite soils over the years such that, with time, the quantity of Fe ending up as part of sediment from eroded soils has declined.

### 3.2.2 | Time-specific variations in heavy metal concentration

At the estimated sedimentation rate of 6.82 mm/year, the 2 and 5 cm core discs were equivalent to ~3 and 7 years of sedimentation, respectively. These were used to construct the sediment core profiles of heavy metal contamination in Owabi Reservoir (Figure 3). Pb contamination increased between the 1940/1950s and 1980s, from about 1.0 ± 0.52 mg/kg to about 45 ± 23 mg/kg, after which the Pb concentrations decreased progressively over time, to ~2.5 mg/kg in the 2010s (Figure 3). The gradual decrease in the Pb concentration from the 1970s appeared to have coincided with various national, regional and global initiatives that sought to ban the use of lead in such applications as in paints and gasoline (Bodel, 2010; Fowler, 2008; Lah, 2011; USEPA, 1992). The various international legislations restricting lead application culminated in a decline of lead-containing products globally. Imports of such products into developing countries like Ghana also declined prior to an eventual ban on leaded gasoline in most African countries between 2003 and 2006 (UNEP, 2004). For the present study, which was conducted close to the city environment, the Pb in sediment cores apparently decreased from the 1990s to 2010s. Compared to earlier studies of the mining environment (Hogarh et al., 2016), Pb exhibited a gradual increase in sediment cores across this time period, presumably due to localized influences from the mining environment.

The arsenic concentration in the sediment initially declined from ~1.3 ± 0.04 mg/kg in the 1930s, to about 0.5 ± 0.14 mg/kg in the 1950s (Figure 3). Thereafter, the As concentration increased progressively to about 1.2 ± 0.18 mg/kg in the 2010s, with occasional declines within the 2000 and 2010 periods. The geology of the Ashanti Region, and most parts of the mining belts in Ghana, is dominated by arsenopyrites, the mineralization of which liberates As (Chudasama, Porwal, Kreuzer, & Butera, 2016). It is also known that excavation activities might expose and liberate heavy metals from soils and rocks (Katsumi, 2015). The excavation processes during the construction phase of Owabi Reservoir in the late-1920s presumably caused liberation of As, resulting in its increased levels in the 1930s.

The As levels in the sediment core subsequently decreased from the 1930s to the 1950s (Figure 3). In the periods following the 1950s, the progressive increase in the As concentrations coincided with the advent of large-scale mining in the Ashanti Region and its environs (Smith, Henry, & Frost-Killian, 2016), with attendant release of As from arsenopyrites rocks into environmental media. The average concentrations of Hg across the sediment core ranged between 0.01 ± 0.001 and 0.04 ± 0.013 mg/kg, without exhibiting any clear trend (Figure 3). The relative concentration of Fe in the sediment was high, ranging between ~1,560 ± 6 and 1,770 ± 11 mg/kg (Figure 3). The high Fe content in the sediment might have originated as run-off from the laterite soil commonly found in the study area. Laterite soils

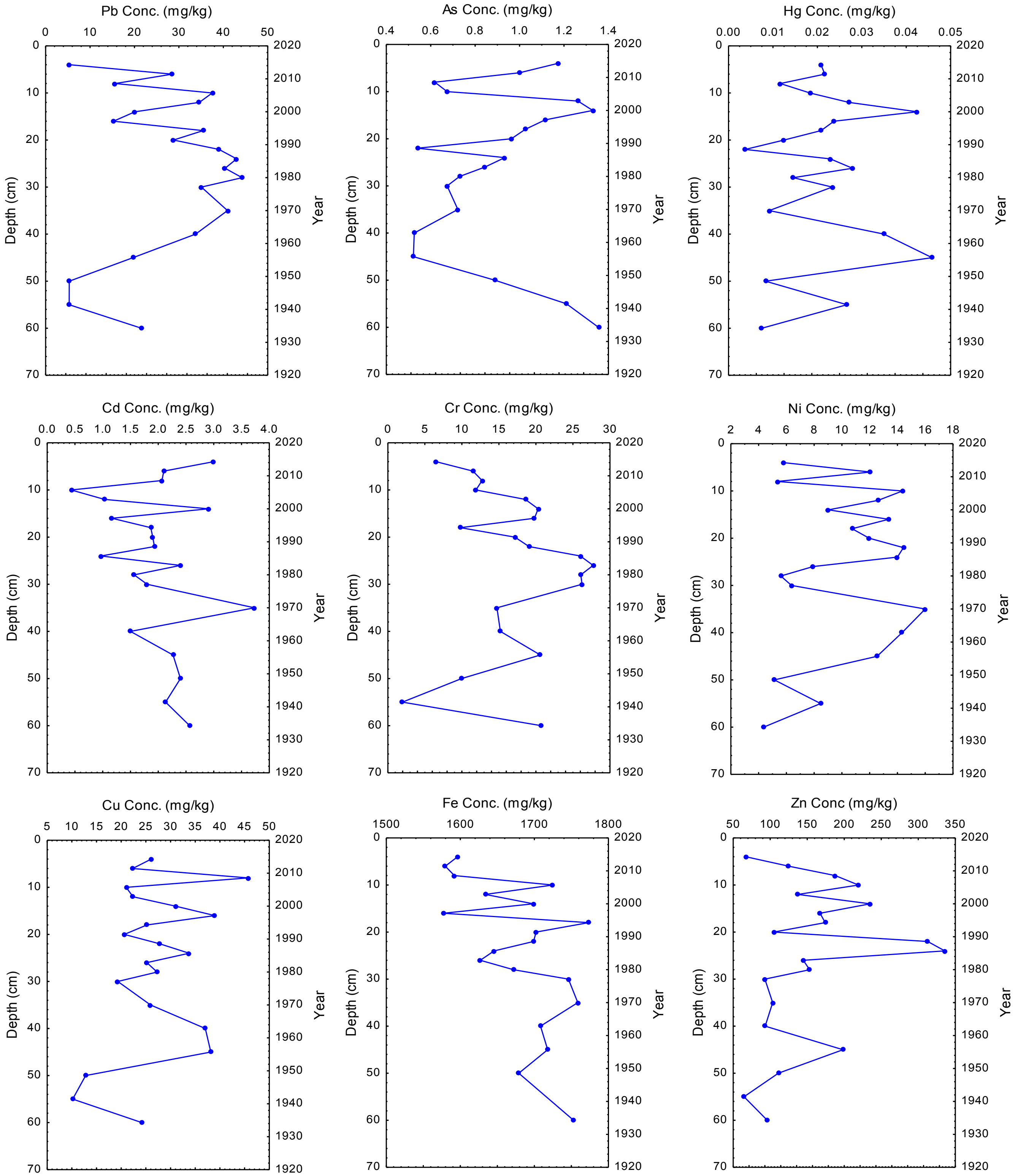


**FIGURE 3** Sediment core profiles of heavy metals in Owabi Reservoir

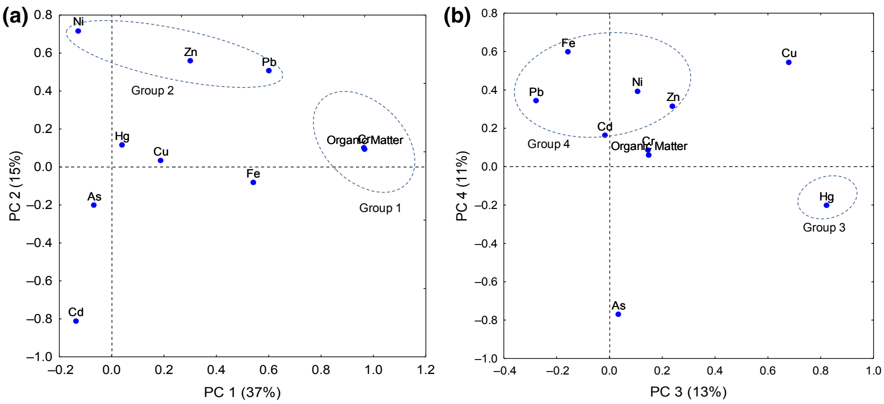


**FIGURE 4** Factor loading plots of heavy metals and organic matter in sediment cores from Owabi Reservoir

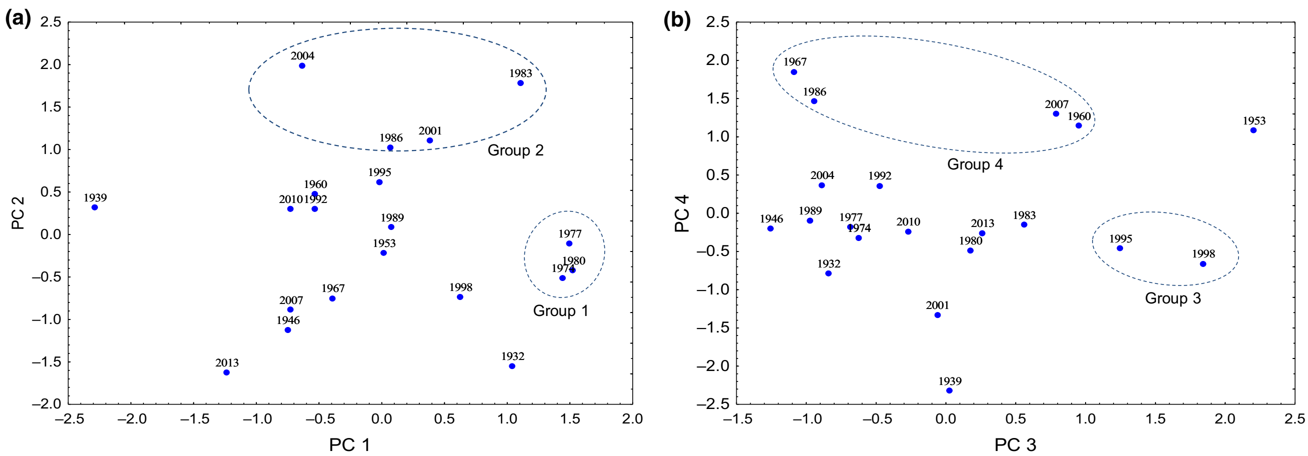


**FIGURE 5** Factor score plots of principal components

typically contain high Fe concentrations (Kamtchueng et al., 2015). There was an overall decreasing trend in the Fe concentration from about 1,750 mg/kg in the 1930s, to about 1,570 mg/kg in the 2010s. The quantity of Zn in the sediment core remained largely within the range of about 70 ± 32 to 230 ± 96 mg/kg for most of the periods, but exhibited an increased concentration to 326 ± 119 mg/kg in the 1980s. The range of Cu concentrations in the sediment between the 1930s and 2010s was ~10 ± 7 to 45 ± 21 mg/kg.

## 3.3 | Source characterization of heavy metals in sediment core

The potential source factors of heavy metals in the sediment core were evaluated with the use of principal component analysis (PCA). Four major principal components (PCs) were extracted as affecting the dataset, altogether accounting for 76% of the total variance. PC1, PC2, PC3 and PC4 accounted for 37%, 15%, 13% and 11% of the total variance, respectively (Figure 4). The PC1 correlated highly with the Cr and organic matter concentration and clustered as Group 1. As Cr is known to bind strongly to organic matter (Gustafsso et al., 2014), PC1 might reflect source factors related to sedimentation of heavy metals via binding with organic matter produced from the decay of plant and animal debris. PC1 was influenced under time periods between the 1930s and 1970s (Figure 3) and might reflect that considerable time was needed for organic matter stabilization and fractionation of highly binding metals. PC2 exhibited a moderate-to-high correlation with Ni, Zn and Pb, which clustered into Group 2 (Figure 4a). From the factor score plot, PC2 related to a more recent time scale from the 1980s to 2000s (Figure 5a). PC2 might indicate vehicular-related emissions/releases source factors, considering that all the metals in Group 2 have been consistently reported in roadside dust (Adamiec, Jarosz-Krzemińska, & Wieszała, 2016; Amusan, Bada, & Salami, 2003; Lu, Wang, Lei, Huang, & Zhai, 2009; Mmolawa, Likuku, & Gaboutloeloe, 2011). It is also noted that leaded fuel was used in Ghana until 2003 (UNEP, 2004), coinciding with the time periods revealed under the factor score plot for PC2 (Figure 4a). The metals grouped into PC1 and PC2 generally can be associated with current or previous applications in the automobile industry and might suggest contamination emanating from this industry. Indeed, major tributaries of the Owabi River (e.g., the Akuosu–Punpunasi–Sukobri tributary) flow through a large enclave of automobile workshops at Suame Magazine near Kumasi (Akoto & Abankwa, 2014), which is reportedly very polluted with automobile wastes products with severe impacts on the Akuosu–Punpunasi–Sukobri tributary, which drains to the Owabi Reservoir (Akoto, Bruce, & Darko, 2010; Frimpong, 2011). Waste oil, batteries, discarded worn-out brake pads and various metal scraps are among the wastes from the automobile workshops, being notable source factors of such metals as

Pb, Ni and Zn, which clustered under PC2. Another common practice in this enclave is spray painting of vehicles, considered a major emission factor of a metal like Cr, which is found in car paints and which clustered under PC1.

PC3 correlated highly with Hg (Group 3; Figure 4b) and appeared to be a contemporary issue since it coincided with quite recent time scales in the 1990s (Figure 5b). PC4 exhibited a moderate-to-high correlation with Fe, Ni, Pb, and Zn (Group 4; Figure 4b) and might depict an association of specific metals in sediment with Fe-oxides (Yu, Tsai, Chen, & Ho, 2001), suggesting mobilization and sedimentation of those metals via Fe-oxide formation. A clear observation on the factor loadings plots is that As did not correlate with any of the principal components, presupposing the As source factor was different from the other elements and, as previously expressed, geological factors might account for the As contamination (Figure 4).

## 4 | CONCLUSION

The rate of sedimentation in Owabi Reservoir was relatively low. As it is located in a wildlife sanctuary, the surrounding vegetation helped retard direct erosion of sandy materials and debris into the reservoir. The average concentrations of metals in the sediment core were in the following order: Fe > Zn > Cu > Pb > Cr > Ni > Cd > As > Hg. Major source factors for most of these metals included wastes inputs, especially from automobile workshops, along key tributaries of the Owabi Reservoir. Arsenic contamination was thought to be related to geological factors, considering the existence of arsenopyrite rocks in the region. The sedimentation processes of the metals appeared aided by binding with organic matter, particularly for Cr, and via Fe-oxide formation, particularly for Pb, Ni and Zn. It is concluded from the results of the present study that sustainable management of Owabi Reservoir for water supply would require specific interventions to reduce contaminant inflows from tributaries draining to the reservoir.

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