Assessment of Water Quality and Heavy Metal Levels in Water and Bottom Sediment Samples from Mokwé Lagoon, Accra, Ghana


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Abstract: The current study deals with the physicochemical characteristics of water samples from the Mokwé Lagoon in addition to trace heavy metals (Cd, Cr, Ni, Pb and Zn) in the lagoon water and bottom sediments. The results indicated relatively high ionic content which was reflected in high conductivity, total dissolved Solids, alkalinity, hardness and chloride levels; and low nutrient content. The trace heavy metal levels in the lagoon water were found within good range of international guideline limits for natural waters. In contrast, the metallic levels in the sediment were high. The levels of metal contamination and distribution in the sediment samples were assessed using geoaccumulation index, enrichment factor, contamination factor and pollution load factor. The metal index analysis indicated high enrichment of the metals (especially Cr and Ni) which reflected anthropogenic effects of contamination attributable to several sources. The study calls for constant environmental monitoring to forestall any heavy metal hazard which could be detrimental to the aquatic ecosystem of the lagoon.

Key words: Enrichment factor, Mokwe lagoon, nutrients, Pollution Load Index, trace heavy metals

INTRODUCTION

In recent times, Ghanaian coastal lagoons have been confronted with serious environmental challenges which have been identified as a cause of their degradation and their consequent to reduction in their fishery productive capacity. Therefore water quality monitoring and evaluation of the ecological integrity of coastal wetlands have become the concern of the Ghanaian scientific community. Increased rate of urbanization, industrialization and other forms of modernization have plagued the productive capacities of coastal water bodies in general to the extent of threatening their existence to sustainable limits. For instance, the concentration of human activities in the coast combined with streams and storm waters flowing from far inland are the primary causes of nutrient enrichment, toxic chemical contamination, sedimentation and other problems that plague coastal waters. Water enriched with nutrients could lead to a host of ecological and economic impacts including fish kill due to oxygen depletion, loss of important and coastal habitats and changes in marine biodiversity (USCOP, 2007).

The physical, chemical and biological characteristics of water may be affected by trace heavy metal pollution. Physicochemical analysis of the water is therefore useful in determining the quality and nature of water (Voznaya, 1983). The accumulation of metals in an aquatic environment has direct consequence on man and the ecosystem (Fatoki et al., 2002). Interest in metals like Zn and Cu which are required for metabolic activities in organisms lies in the narrow “window” between their essentiality and toxicity (Skidmore, 1964; Spear, 1981). Others like Cd and Pb exhibit extreme toxicity even at trace levels (Merian, 1991; DWAF, 1996b). Cd has been found to be toxic to fish and other aquatic organisms (Rao and Saxena, 1981; Pasco, 1992). The effect of Cd toxicity in man includes kidney damage (Friberg et al., 1986; Herber et al., 1988) and pains in bones (Tsuchiya, 1978; Kjellstroem, 1986). Cd also has...
MATERIALS AND METHODS

Study area: The hydrographic area of the Mokwé Lagoon is located within the Accra Plains of Ghana and is enclosed between Latitudes 5.36°N and 5.37°N and Longitudes 0°02′E and 0°03′E (Fig. 1). It lies about 6 km east of Accra and has an approximate surface area of 4 ha (Boughey, 1957). The main drains of the lagoon, believed to originate from the Akwapim Mountains, passes through many residential communities including Nungua. To the East, the catchment of the lagoon overlaps with that of the Sakumo Wetland (a Ramsar Wetland). There is virtually no major industrial development in the area. However, small-scale industrial activities including batik and “tie-and-dye” making are some economic activities carried out in the catchment area. The lagoon is surrounded on two sides by major roads with high vehicular traffic. In addition, a vehicular workshop and car washing bays are situated within the immediate catchments. Vehicular emissions of lead compounds into the atmosphere can be transported into the lagoon through deposition on the streets and urban run-off. Furthermore, tons of solid wastes are generated daily from residential areas and deposited in the main drains very close to the lagoon. At present the main economic activity in the lagoon environment is fishing, especially of lagoon crabs.

Sampling and analysis: Water and sediment samples were collected simultaneously at each selected for site for three days (1st, 3rd and 5th) during the first week in April 2009, a period that coincided with the end of the dry season and the beginning of the raining season (April-June). The daily duration of sampling was from the hours (06:30 to 15:30) representing time interval of 4½ hours between each observation. Six sampling sites were strategically selected to account for all the main drains hosted by the lagoon, after two continuous days of reconnaissance survey prior to sampling. All the sampling sites were concentrically carried within the main body of the lagoon (Fig. 1). At each sampling location, two water samples (for the physico-chemical analysis) were taken just below the surface into 1 L high-density polyethylene containers equipped with screw caps and labeled according to the sampling site. For the purpose of preventing the trace metals from being oxidized, one of
the bottles was fixed with dilute nitric acid. The samples were placed in an ice-chest and later refrigerated in the laboratory prior to analysis.

Some physicochemical parameters (pH, temperature, electrode potential, transparency and water depth) were determined in-situ on the field. Temperature, pH, and electrode potential were determined immediately after sampling using a Fisher Scientist Accumet Portable AP6 pH/mV/°C Meter. Water transparency was determined using the sacchi-disc. The depth of the water column was determined by means of a cylindrical rod calibrated along its length in centimeters. In the laboratory, a Seven Multi-Mettler Toledo was used in the determination of the conductivity and salinity. Total Dissolved Solids (TDS) was determined gravimetrically by filtering 100 cm³ sample through a weighted filter paper followed by evaporation and ignition (Kenneth, 1990). Total alkalinity was determined by titration using methyl orange indicator with 0.2 M HCl as acid. Dissolved Oxygen was determined using Winkler’s Modification Method (Standard Method, 1999). Flame Emission Photometric Method (Standard Method, 1999) was employed to evaluate the water concentration of K⁺, Mg²⁺ and Na⁺ ions. Chloride (Cl⁻) ions concentration in the water samples was ascertained by titration of the water sample against 0.1 M AgNO₃ solution using 0.27 M K₂CrO₄ as indicator. Sulphate (SO₄) ions in the water samples were converted to barium sulphate (BaSO₄) suspension under controlled conditions. The resulting turbid solution was established by spectrophotometer at maximum absorbance of 420 nm (USEPA, 1983). The concentration of the sulphate ions was then determined from a calibrated curve prepared from standard Na₂SO₄ solution. The nutrients (NO₃, NO₂ and PO₄) contents of the water samples were determined with the aid of spectrophotometer using the Cadmium Reduction Method (HACH, 1992).

For the sediment samples, three replicates of the surface substratum at each sampling site were collected using a Petite Ponar Grab Sampler. The samples were emptied into polyethylene bags and stored in a separate ice-chest and transferred to the Chemistry Department of GAEC. The samples were air dried and sieved in 500 µm mesh. 1.5 g of the fine sediment were weighed into Teflon vessels and 3.0 ml of 37% HCl, 6 ml of 65% HNO₃ and 0.25 ml of 30% H₂O₂ were added and thoroughly mixed. The mixtures were then digested in ethos 900 microwave digester for 26 min. The digested samples were allowed to cool in a water bath for 30 min and the concentrations of the Cd, Co, Cr, Ni, Pb, and Zn were determined using Varian AA.240FS atomic absorption spectrometer. For heavy metal analysis of the water samples, 5 mL of the water samples, blank and standards were measured into individual Teflon vessels. The sample preparation for the determination of heavy metals in the sediments was repeated for the water samples and the heavy metal concentrations were determined just as done for the sediments.

Fig. 1: Drainage map of Mokwé lagoon. Inset: Ghana map and sampling locations
The concentrations of $\text{SO}_4^{2-}, \text{NO}_3, \text{N}^-$, and $\text{PO}_4$ were determined spectrophotometrically in the laboratory using potable HACH DR/890 Datalogging colorimeter. Again, for analytical quality assurance, Standard Reference Material (SRM), Oyster tissue was also prepared and analysed under the same conditions.

For the purpose of convenience, all the results of the analysis were averaged. Hence the results presented represent the mean concentrations of the various parameters for the duration of the study.

**RESULTS AND DISCUSSION**

**Physicochemical characteristics:** Table 1 shows the physicochemical measurements of the water samples from the Mokwe lagoon. The depth of the water column ranged from 40.6 to 82.2 cm with a mean depth of 68.5 cm. The results of the depth of the water column were indicative of the fact that the lagoon is shallow.

The shallow nature is consistent with most characteristics of coastal water bodies in Ghana (Gordon, 1987). The transparency, which provides information on the depth of light penetrating the water column and is a reflection of the effect of various matter suspended in water, ranged between 36.4 and 40.4 cm. The pH ranged between 7.04 and 7.84. According Biney (1982, 1990), most coastal waters in Ghana have low transparencies and are slightly alkaline in nature. A pH range of 6.50-9.00 is an indicator of a good fish population (Alabaster and Lloyd, 1980; Abulude, 2006) and therefore the measured pH was good for the lagoon.

Water temperature recorded during the sampling period ranged from 29.5 to 32.3°C with an average of 31.3°C. However, analysis of variance (ANOVA) revealed no significant differences (p=0.05) in water temperature across the various sites. Temperature is a factor of great importance for aquatic ecosystem, as it affects the organisms, as well as the physical and chemical characteristics of water (Delince, 1992). The average temperature (31.3°C) was slightly out of the range of 25 to 30°C needed by fish to grow well (Abulude et al., 1995). The mean value of 2.87 mg/L recorded by the study was slightly above the minimum required limit, a condition not very suitable for biological processes of the lagoon. The low level of DO recorded can be attributed to less wave action at the period of sampling and the organic load from the receiving drains that are gradually affecting the aquatic life of the lagoon. The levels of total alkalinity and total hardness for good fish culture should fall within 20 to 300 mg/L (Boyd and Lichtkoppler, 1979). The results of the present study fell outside this range. The range of 820-1520 mg/L for total alkalinity and 1932-2000 mg/L for total hardness were recorded for the study. Conductivity of the water samples ranged from 19010 to 19970 $\mu$S/cm and that reflect the amount of charged substances in the water samples. These values far exceeded the local Environmental Protection Agency (EPA) effluent guideline limit of 1500 $\mu$S/cm (Addo, 2002), indicating relatively high salt contents. Similarly, the Total Dissolved Solids (TDS) which give a good indication of the salinity ranged from 9520 to 10000 mg/L. The World Health Organization (WHO) recommends that the TDS should be less than 500 mg/L but pegs acceptable limits for portable water at 1500 mg/L (WHO, 1996). Additionally, TDS in excess of 1000 mg/L are objectionable to consumers and have adverse effects on crop production (Pascod, 1992). There is currently no official guideline as to what is considered safe level for conductivity (Karikari et al., 2007). However, the conductivity of most freshwaters ranged from 10 to 1000 $\mu$S/cm, but many exceed 1000 $\mu$S/cm, especially in polluted waters or those receiving large quantities of land run-off (Chapman, 1992).

The concentrations of inorganic ions (Na$^+$, K$^+$, Mg$^{2+}$, Cl$^-$, SO$_4$ and HCO$_3$) in the water were generally expected to be within their respective WHO limits. Although there were considerable concerns about the level of chloride in water (Abulude et al., 2006), the highest observed level was 5991.1 mg/L. Chloride level in water is a useful measure in a water sample. However, high level is not known to be injurious to water organisms (Abulude et al., 2006). The concentrations of the major cations were generally in the order Na$^+$ > Mg$^{2+}$ > K$^+$. The major anion concentration.

Followed the order Cl$^->$HCO$_3$>$SO_4^{2-}$. The cationic dominance pattern was similar to that of seawater but the anionic dominance pattern was a blend between those of seawater and freshwater as observed by Karikari et al. (2005). The sodium and magnesium content of the samples were within the desirable limits of 200 and 100 mg/L for drinking water respectively (WHO, 1996). WHO has no limit for potassium, which is usually present in water in lower proportion than magnesium.

Nitrates, Nitrites and Phosphorous were the nutrients measured in the water samples. Nitrates and Nitrites are veritable indication of biological pollution in natural waters. They are considered to be non-cumulative toxins (Dallas and Day, 1993). When present in high concentrations, the waters are usually subjected to organic pollution and may give rise to potential health risk particularly in pregnant
women and bottle-fed infants (Kempster et al., 1997; Kelter et al., 1997). NO₃⁻N at elevated concentration is known to result in cyanosis in infants (Karikari et al., 2007). Levels in excess of 5.0 mg/L NO₃⁻N and concentration exceeding 0.50 mg/L NO₂⁻N indicate pollution (McCutcheon et al., 1989). Nitrate levels averaged 0.71 mg/L and varied between 0.35 and 1.25 mg/L, whilst NO₂⁻N varied between 0.005 and 0.009 mg/L with mean concentration of 0.006 mg/L. The concentrations of both NO₃⁻N and NO₂⁻N, according to McCutcheon et al. (1989), were not alarming and that the lagoon was not contaminated from organic waste contamination. Phosphorous is a limiting nutrient for algal growth and therefore controls the primary productivity of a water body (Karikari et al., 2007). It is also an essential nutrient and another indicator of anthropogenic biological pollution. In most natural waters, PO₄³⁻ concentrations range from 0.005 to 0.020 mg/L (Chapman, 1992). In pristine waters, PO₄³⁻ concentrations may be as low as 0.001 mg/L (Karikari et al., 2007). Levels of PO₄³⁻ in this study varied between 0.212 and 0.371 mg/L with a mean concentration of 0.325 mg/L, which exceeds the levels in most natural waters (Chapman, 1992). High concentrations of phosphate are largely responsible for eutrophic conditions in a water body. Eutrophication-related problems in warm water systems occur at PO₄³⁻ concentration ranging from 0.34 to 0.70 mg/L (Rast and Thornton, 1986).

### Heavy metals in water and sediments

Results of trace heavy metal analysis in Mokwé Lagoon water and sediments are presented in Table 2. These results are the means of triplicate measurements. The concentration of Cd in water ranged from 0.002 to 0.004 mg/L while that of the sediment varied between 0.20 and 1.09 µg/g. The range obtained for the water was in good agreement with US EPA tolerance level of <0.01 mg/L for wastewater (USEPA, 1983) as well as 0.05 mg/L Maximum Contaminant level (MCL) for natural waters (USEPA, 1986b). The level of Cd obtained in the sediment samples were within South African Target Water Quality Range (TWQR) for irrigation purposes (DWAF, 1996a). Cd used to be an important factor in aquatic monitoring studies, because it has been found to be toxic to fish and other aquatic organisms (Pasco, 1992). Also Cd has been implicated in endocrine disrupting activities which could pose serious health problems (Awofolu et al., 2005). The high level of Cd in the sediment relative to levels in the water is expected as sediments have been described as a sink or reservoir for pollutants in water (Onyari et al., 2003; Samir et al., 2006). Apart from natural sources like run-off from agricultural fields where phosphate fertilizer might be in use, other sources may include leaching from Ni-Cd based batteries (Hutton et al., 1987). Thus, the multiple locations of automobile washing activities located in the catchment area could pose a potential danger for Cd toxicity.

Lead is a highly toxic metal to man since it causes brain damage, particularly to the young and induces aggressive behaviour (Ramadan, 2003). The major ways of lead toxicity to man are through air respiration (inhalation), water contamination from lead piping and

### Table 1: Physico-chemical parameters measured in the water samples

<table>
<thead>
<tr>
<th>Sites</th>
<th>Water depth (cm)</th>
<th>Transparency (cm)</th>
<th>pH</th>
<th>Temp (°C)</th>
<th>DO (mg/L)</th>
<th>Cond (μS/cm)</th>
<th>Salinity (ppt)</th>
<th>TDS (mg/L)</th>
<th>Total alkalinity (mg/L)</th>
<th>Total hardness (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40.6</td>
<td>34.8</td>
<td>7.36</td>
<td>32.1</td>
<td>2.35</td>
<td>19820</td>
<td>11.77</td>
<td>9920</td>
<td>1520</td>
<td>1932</td>
</tr>
<tr>
<td>B</td>
<td>67.4</td>
<td>41.2</td>
<td>7.84</td>
<td>30.8</td>
<td>2.60</td>
<td>19250</td>
<td>11.41</td>
<td>9640</td>
<td>1040</td>
<td>1900</td>
</tr>
<tr>
<td>C</td>
<td>58.2</td>
<td>36.6</td>
<td>7.22</td>
<td>29.5</td>
<td>2.08</td>
<td>19010</td>
<td>11.26</td>
<td>9520</td>
<td>800</td>
<td>1848</td>
</tr>
<tr>
<td>D</td>
<td>81.1</td>
<td>39.4</td>
<td>7.97</td>
<td>31.0</td>
<td>3.19</td>
<td>19360</td>
<td>11.49</td>
<td>9690</td>
<td>960</td>
<td>1980</td>
</tr>
<tr>
<td>E</td>
<td>82.2</td>
<td>40.4</td>
<td>7.74</td>
<td>32.3</td>
<td>3.37</td>
<td>19970</td>
<td>11.88</td>
<td>10000</td>
<td>880</td>
<td>2000</td>
</tr>
<tr>
<td>F</td>
<td>81.6</td>
<td>38.5</td>
<td>7.04</td>
<td>31.8</td>
<td>3.65</td>
<td>19600</td>
<td>11.61</td>
<td>9800</td>
<td>820</td>
<td>1952</td>
</tr>
</tbody>
</table>

### Table 2: Concentration of heavy metals in surface water (mg/L) and sediment (µg/g) in Mokwe lagoon

<table>
<thead>
<tr>
<th>Element/sites</th>
<th>Cd</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.002</td>
<td>0.20</td>
<td>0.022</td>
<td>308.0</td>
<td>0.010</td>
</tr>
<tr>
<td>B</td>
<td>0.002</td>
<td>0.20</td>
<td>0.010</td>
<td>4.69</td>
<td>0.010</td>
</tr>
<tr>
<td>C</td>
<td>0.002</td>
<td>0.20</td>
<td>0.058</td>
<td>60.20</td>
<td>0.038</td>
</tr>
<tr>
<td>D</td>
<td>0.004</td>
<td>1.09</td>
<td>0.010</td>
<td>1681.0</td>
<td>0.066</td>
</tr>
<tr>
<td>E</td>
<td>0.002</td>
<td>0.20</td>
<td>0.024</td>
<td>1.00</td>
<td>0.010</td>
</tr>
<tr>
<td>F</td>
<td>0.002</td>
<td>0.20</td>
<td>0.016</td>
<td>343.11</td>
<td>0.010</td>
</tr>
</tbody>
</table>

from polluted fish stuff. Lead toxicity is due to its ability to mimic many aspects of metabolic behaviour of Ca and inhibit many enzyme systems (Mengel and Kirkby, 1982). Lead level in the lagoon water varied between 0.005 and 0.016 mg/L and between 0.50 and 29.2 µg/g in sediment. The contamination level of Pb at Site F was higher (29.2 µg/g) than the background level of 20.0 µg/g published by Samir et al. (2006). The level of Pb obtained in the sediment were higher than those in the lagoon water, hence the sediment could be an influencing factor on the level of Pb in the lagoon water with other enhancing factors like pH, since water acidity is known to influence the solubility and availability of metals. The high levels of Pb in the sediments especially at Site F was very worrying as fishery resources including lagoon crabs could pose a potential danger as a result of bioaccumulation of the metal. A prompt investigation should be eminent to alert public awareness to possible health risk in that regard.

The levels of Zn in the lagoon water ranged from 0.005 to 0.025 mg/L with a mean of 0.015 mg/L. The TWQR for Zn in water for domestic supply is 3.0 mg/L (DWAF, 1996a). Hence according to the study there is no detrimental effect for the aquatic ecosystem regarding Zn toxicity. Extensive literature on aquatic toxicity of Zn and especially its toxicity to fish has been reviewed by Alabaster and Lloyd (1980) and by Spear (1981). Zn is unusual in that it has low toxicity to man, but relatively high toxicity to fish (Alabaster and Lloyd, 1980). However, the concentration of Zn in the sediments ranged between 1.47 and 77.5 µg/g with mean value of 33.6 µg/g. Yet the mean Zn contamination level was less than the stipulated background level of 70 µg/g (Samir et al., 2006). Zabetoglou et al. (2002) had reported that concentration of heavy metals in sediment usually exceeds those of the overlying water by 3-5 orders of magnitude. In our case, Zn concentration of the sediment and water ratio was much greater and is in the least order of 60 in magnitude.

Levels of Ni in the lagoon water ranged from 0.010 to 0.066 mg/L with a mean of 0.024 mg/L, whilst sediment concentration of Ni varied from 1.00 to 504.0 µg/g with a mean value of 97.9 µg/g. According to Mckenzie and Symthe (1998) more attention has been focused on the toxicity of Ni in low concentrations for reasons such as the fact that Ni can cause allergic reaction and that certain Ni compounds may be carcinogenic. The typical concentration of Ni in unpolluted waters is given as 0.015 to 0.020 mg/L (Salnikow and Denkhaus, 2002). Our study recorded comparable values to this range, indicating that the lagoon water is yet to get over contaminated with the metal. The high level of Ni in the sediment samples, especially at site E (504.0 µg/g) is of concern since it exceeds the background level of 38.0 µg/g (Samir et al., 2006). Possible contamination of the metal in some traditional fishes cannot be ruled out, since Pane et al. (2003) has reported Ni toxicity in rainbow trout. Although, Ni is considered an essential element to plants and some animals (e.g. Ni is present in the enzyme urease), its essentiality to man is yet to be demonstrated (Teo and Chen, 2001). However, Ni related health effects such as renal, cardiovascular, reproductive and immunological effects have been reported in man. Possible sources of Ni in surface waters include anthropogenic sources such as combustion of fossil fuel (Merian, 1991), disposal of old battery wastes and components of automobiles.

Chromium concentration in lagoon water varied from 0.010 to 0.058 mg/L with an average value of 0.023 mg/L. The World health organization (WHO) has set recommended limit for Cr in drinking water as 0.050mg/L WHO, 1988), and only (16%) of the water samples had Cr levels less than this limit. However, it must be borne in mind that the biological effects of Cr depend on its valency. In the trivalent form, Cr is essential element but in the hexavalent form it is carcinogenic (Chiba and Masironi, 1992). Though an essential trace nutrient and a vital component for glucose factor, Cr toxicity damages the liver, lungs and causes organ hemorrhages ( O’Flaherty, 1995). Katz and Salem (1994) reported that Cr contamination is common in soils and in both ground and surface waters in industrial areas. Although the concentrations of Cr in the sediment according to this study ranged between 1.0 to a high level of 1681.0 µg/g, the area of reference is not heavily industrialized and therefore the high level of contamination in the sediment needs further investigation to locate the source of the high contamination.

Contamination status of bottom sediments: Sediments represent one of the ultimate sinks for heavy metal discharge into the environment (Gibbs, 1977; Luoma and Bryan, 1981). In order to protect the aquatic life community comprehensive methods for identifying and assessing the severity and soil contamination have been introduced over the past decades (Loska et al., 1997; Chapman, 2000; Ghrefat and Yusuf, 2006). In this work, the index of geoaccumulation (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and Pollution Load Index (PLI) have been applied to assess heavy metals (Cd, Cr, Ni, Pb and Zn) distribution and contamination in the sediment samples of the Mokwe Lagoon.

Enrichment factor: As proposed by Simex and Helz (1981), the Enrichment Factor (EF) was employed to assess the degree of contamination and to understand the distribution of the elements of anthropogenic origin from sites by individual elements in sediments. Fe was chosen
Fig. 2: Geo-accumulation of heavy metals among the sampling sites

as the normalizing element while determining EF-values, since in wetlands it is mainly supplied from sediments and is one of the widely used reference element (Loska et al., 2003; Kothai et al., 2009; Chakravarty and Patgiri, 2009; Seshan et al., 2010). Seshan et al. (2010) have indicated that several researchers have also employed Al and Si as reference elements in the calculation of EF. An element also qualifies as a reference one if it is of low occurrence variability and is present in the environment in trace amounts (Loska et al., 2003). In this study, iron was also used as a conservative tracer to differentiate natural from anthropogenic components. According to Ergin et al. (1991), the metal (M) EF is defined as follows:

$$\frac{M_{sample}}{M_{Background}}$$

EF values were interpreted as suggested by Birch (2003) where EF<1 indicates no enrichment; <3 is minor; 3-5 is moderate; 5-10 is moderately severe; 10-25 is severe; 25-50 is very severe; and >50 is extremely severe. The background value is that of average shale (Turekian and Wedepohl, 1961). Elements which are naturally derived have an EF value of nearly unity, while elements of anthropogenic origin have EF values of several orders of magnitude.

The EF for the metals under the current study in the Mokwe Lagoon sediments along with their background values in average shale are shown in Table 3. According to the EF classifications, the metals show severe (Pb and Zn) through very severe (Cd and Ni) to extremely severe (Cr) enrichment. With the exception of Pb and Zn, the values of the metals in the sediment are higher than their background values in average shale. The high levels of the enrichments might be related to anthropogenic effects from several sources. In general, the enrichment of the heavy metal in the present study could be arranged in the descending order as follows: Cr>Ni>Cd>Zn>Pb. The relatively high level Cr and Ni in the sediment could be ascribed to discharges of wastewater from car washing bays along the main drains as well as domestic wastewater.

**Geo-accumulation index:** Geo-accumulation index was used to assess heavy metal accumulation in sediments as introduced by Muller (1969) to measure the degree of metal pollution in aquatic sediments studies (Praveena et al., 2007, 2008; Chakravarty and Patgiri, 2009).

$$I_{geo} = \log_2 \left( \frac{C_n}{1.5B_n} \right)$$

where, Cn is the measured concentration of a heavy metal in stream sediments, Bn is the geochemical background value in average shale of element n and 1.5 is the background matrix correction due to Terrigenous effects. The index of geo-accumulation includes seven grades (0-6) ranging from unpolluted to very highly polluted. The grades are as follows:

0 Uncontaminated
1 Uncontaminated to moderately contaminated
2 Moderately contaminated
3 Moderately to highly contaminated
4 Highly contaminated
5 Highly to very highly contaminated
6 Very highly contaminated

The calculated Igeo values for each metal in the sediment samples among the sampling zones are presented in Fig. 2. It is evident from Fig. 2 that the uncontaminated to moderately contaminated (0<Igeo<1) is observed only at site F by Pb. The Igeo values indicated
moderately pollution at site A by Cr, and at Site D for Cd. Moderately to strongly pollution at Site E was observed for Ni and strongly contamination by Cr for the same site. At all it was Sites B and C which showed no pollution by any metal according to the Igeo calculations based on the use of average shale as background material for the elements. Zn is the only metal which shows uncontaminated status in the sediments of the lagoon under the current study indicating that the source of contamination is from a natural source.

Pollution Load Index: Pollution Load Index (PLI) for a particular site has been evaluated following the simplest method proposed by Tomlinson et al. (1980). This parameter is expressed as:

\[
\text{PLI} = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)}
\]

where CF is the contamination factor, Cmetal is the concentration of pollutant in sediment, Cbackground is the background value for the metal, n is the number of metals. The PLI value >1 is polluted whereas <1 indicates no pollution.

The CF reflects the metal enrichment in the sediment. The geochemical background values in average shale of the trace metals under consideration reported by Turekian and Wedepohl (1961) was used as background values for the metal. The CF was classified into four groups (Nasr et al., 2006; Mmolawa et al., 2011). Where the contamination factor CF<1 refers to low contamination; 1≤CF<3 means moderate contamination; 3≤CF<6 indicates considerable contamination and CF≥6 indicates very high contamination.

Using the CF categories as described, Site B and C showed low contamination for all the metals (Table 4). On the other hand, Site E suffered very high contamination for Cr and Ni respectively and low contamination for Cd, Pb and Zn. However, indicated considerable contamination at Site D and low contamination at all the sites. Site F showed low contamination for all the metals except Pb which displayed moderate contamination.

To effectively compare whether the five stations suffer contamination or not, the pollution load index, PLI, described previously was used. The PLI is aimed at providing a measure of the degree of overall contamination at a sampling site. The last column of Table 4 show results of the PLI for the five metals studied at these various zones.

Based on results presented in Table 4, the overall degree of contamination by the 5 metals is of the order E>A>F>C>D>B. Site E show strong signs of pollution or deterioration of site quality suggesting inputs from anthropogenic sources attributable to increased human activities. The human activities may come about as a result of trapping of lagoon crabs from the adjacent bank of the sampling zone. Sites D and B suggested no overall pollution.

This study has determined the physicochemical parameters and trace heavy metals in water and sediment samples from the Mokwé Lagoon. Some parameters including pH, transparency, major ions and nutrients were found to be at acceptable environmental levels and were consistent with earlier findings in some water bodies in Ghana (Karikari et al., 2007; Biney, 1982, 1990; Addo, 2002; Johnson, 2000). On the contrary, parameters like conductivity, TDS, total hardness and total alkalinity were very high and reminiscent of what Karikari et al. (2007) found for the Korle Lagoon, indicating that the Mokwé Lagoon is polluted.

The presence of toxic metals such as Cd, Cr, Pb and Ni in the water and sediment samples in the Mokwé Lagoon could be detrimental to human beings and aquatic life. Most trace metals are toxic. When metallic toxicants find their way into the human body, they attack proteins, notably enzymes (Adaikpoh et al., 2005). The current observation of more heavy metal contamination in sediment than in the water is in agreement with other studies observed by Bower (1979), Lau et al. (1996), Beseda et al. (2002) and Eja et al. (2003). Sediment is a major repository of metals, in some cases, holding more than 99% of the total amount of metal present in the aquatic ecosystem (Odiете, 1999).

The long term accumulation of toxic trace heavy metals in water and sediment of the lagoon could lead to their bioaccumulation in plants and animals of economic importance, and ultimately transfer to humans and therefore should not be taken for granted. The study calls for a continuous environmental pollution monitoring to check heavy metal hazards and parameters which would pose ecological risk to the lagoon’s ecosystem.

**CONCLUSION**

A critical look at the physico-chemical water quality parameters of the Mokwé Lagoon indicates high ionic content of the lagoon water which is reflected in high conductivity, TDS, total hardness and chloride levels. However, pH, dissolved oxygen and nutrients were within good tested levels for natural waters. In contrast, heavy metal levels in water were less than what was found in the sediment samples. In general, the sediment quality in terms of the heavy metals was unacceptable and could pose a serious risk to the aquatic life of the lagoon in future if nothing is done to check metal accumulation in the lagoon. The application of the four metal indices notably enrichment factor, geoaccumulation index, contamination factor and pollution load index confirms the enrichment of the metals in the bottom sediment. The
indices analysis further indicates that the contamination level was related to anthropogenic effects supposed to have originated from multiple sources. The study is suggests’ constant monitoring of the physico-chemical parameters as well as heavy metal accumulation in the lagoon since anthropogenic activities contributing to the current environmental state of the lagoon are expected to increase.

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