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# 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; Pascod, 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

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mutagenic, carcinogenic and teratogenic effects Friberg *et al.*, 1986). Lead is potentially hazardous to most forms of life and is considered toxic and relatively accessible to aquatic organisms (USEPA, 1986a). Low Pb concentrations affect fish by carrying the formation of coagulated mucous over gills and subsequently over the entire body and thus cause the death of the fish due to suffocation (DWAF, 1996b).The chronic effects of Pb on man include neurological disorders, especially in the foetus and children (Fatoki *et al* ., 2002).

Some physicochemical parameters including pH, temperature and hardness in water affect the water chemistry of metals in aquatic ecosystems. For instance, pH can affect the dynamics of metals in aquatic ecosystems. The pH determines the chemical species of many metals and thereby alters their availability and toxicity in aquatic environments (DWAF, 1996b). Metals such as Al, Cd, Ni and Zn may have increased detrimental effects at low pH. Water hardness is an important factor influencing metal toxicity in aquatic systems. For example, Pb absorption and lethal concentration of Cd in aquatic organisms is dependent on water hardness and type of test animal (DWAF, 1996a).

Although, water is commonly employed as a pollution indicator of trace metals, sediment can also provide deeper insight into the pollution state of a water body. Sediment has been described as a sink or reservoir of contaminants including trace metals, where they concentrate according to the level of pollution (Becker *et al.*, 2001; Onyari *et al.*, 2003).

The focus of this study was on the Mokwé Lagoon, located between the outskirts of Nungua, Accra and the catchment areas of the Sakumo Lagoon. The lagoon, although relatively a small one, used to be a highly productive aquatic environment with an intensive fishery. It was very dependable and supported the livelihood of many people because it was a habitat for ecological and economic important fish species (Denyoh, 1982). Over the years, the water quality problems of the lagoon have intensified in response to increased growth and concentration of population in addition to growth of small-scale industrial activities in the catchment areas. The continued dependence on some fisheries resources by the Nungua inhabitants makes the Mokwé Lagoon an interesting object for study. Little information about the physico-chemical properties of the lagoon exist (Kwei, 1976). What is lacking is knowledge of trace metals distribution in the water and bottom sediment of the lagoon. In recent times, public health on trace metals in seafood and drinking water have been of concern to many local scientists hence leading to many studies in ponds, rivers, seas and lagoons (Serfo-Armah *et al.*, 2000; Boadu *et al.*, 2001). This study therefore serves to provide baseline data on some physico-chemical parameters as well as the levels and distribution of trace heavy metals (Cd, Cr, Ni, Pb and Zn) in the water and sediment of the lagoon, which are essential for determining the water quality status of the lagoon. In order to evaluate metal levels and distribution in the sediment, different metal assessment indices were applied. The indices used were geoaccumulation index, enrichment factor, contamination factor and Pollution Load Index.

## 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$^{o}$N and 5.37$^{o}$N and Longitudes 0$^{o}$ 02'E and 0$^{o}$ 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 lagoonal 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 (1$^{st}$, 3$^{rd}$ and 5$^{th}$) 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

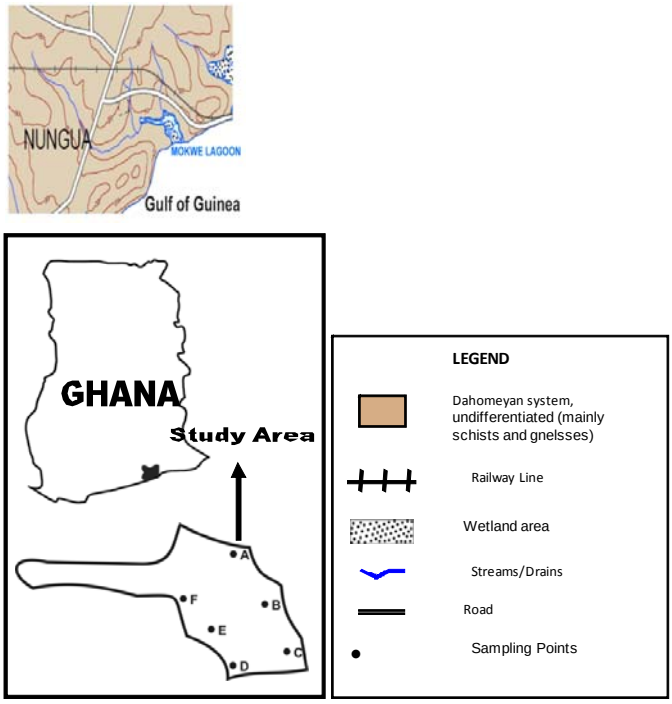


Fig. 1: Drainage map of Mokwé lagoon. Inset: Ghana map and sampling locations

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/$^{o}$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 $cm^3$ 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 $K^+$, $Mg^{2+}$ and $Na^+$ ions. Chloride ($Cl^-$) ions concentration in the water samples was ascertained by titration of the water sample against 0.1 M.

$AgNO_3$ solution using 0.27 M $K_2CrO_4$ as indicator. Sulphate ($SO_4$) ions in the water samples were converted to barium sulphate ($BaSO_4$) 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 $Na_2SO_4$ solution. The nutrients ($NO_3$, $NO_2$ and $PO_4$ 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 $m_l$ of 37% HCl, 6 $m_l$ of 65% $HNO_3$ and 0.25 mL of 30% $H_2O_2$ 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 was done for the sediments.

The concentrations of $SO_4^{2-}$, $NO_3$ $N^{-3}$ and $PO_4$ 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 provide 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 32.3ºC with an average of 31.3ºC. 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 (31.3ºC) was slightly out of the range of 25 to 30ºC needed by fish to grow well (Abulude *et al.*, 2006). Thus, temperature could be one of the physicochemical parameters that were causing the dwindling of fishery resources in the lagoon.

Dissolve Oxygen (DO) levels varied between 2.08 and 3.65 mg/L. When DO is below 2 mg/L, many aquatic organisms perish. Low DO levels result from biological respiration and decomposition processes which reduce the concentration of DO in water bodies (Cunningham and Saigo, 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 µS/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 µS/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 µS/cm, but many exceed 1000 µS/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

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

| Sites | Water depth (cm) | Trans-parency (cm) | pH | Temp (ºC) | DO (mg/L) | Cond (µS/cm) | Sali-nity (ppt) | TDS (mg/L) | Total alkalinity (mg/L) | Total hardness (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 40.6 | 34.8 | 7.36 | 32.1 | 2.35 | 19820 | 11.77 | 9920 | 1520 | 1932 |
| B | 67.4 | 41.2 | 7.84 | 30.8 | 2.60 | 19250 | 11.41 | 9640 | 1040 | 1900 |
| C | 58.2 | 36.6 | 7.22 | 29.5 | 2.08 | 19010 | 11.26 | 9520 | 800 | 1848 |
| D | 81.1 | 39.4 | 7.97 | 31.0 | 3.19 | 19360 | 11.49 | 9690 | 960 | 1980 |
| E | 82.2 | 40.4 | 7.34 | 32.3 | 3.37 | 19970 | 11.88 | 10000 | 880 | 2000 |
| F | 81.6 | 38.5 | 7.04 | 31.8 | 3.65 | 19600 | 11.61 | 9800 | 820 | 1952 |

| Sites | $Na^+$ (mg/L) | $Mg^+$ (mg/L) | $K^+$ (mg/L) | Cl (mg/L) | $HCO_3^-$ (mg/L) | $SO_4^-$ (mg/L) | $NO_3^-$ (mg/L) | $NO_2^-$ (mg/L) | $PO_4^-$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| A | 31.3 | 19.7 | 11.2 | 5991.1 | 707.6 | 5.89 | 0.38 | 0.006 | 0.312 |
| B | 66.5 | 31.2 | 11.2 | 2179.9 | 727.1 | 5.71 | 0.47 | 0.005 | 0.212 |
| C | 157.8 | 82.6 | 15.2 | 2183.7 | 732.0 | 9.20 | 1.25 | 0.006 | 0.342 |
| D | 82.7 | 44.4 | 11.2 | 2112.8 | 727.1 | 9.47 | 0.35 | 0.005 | 0.352 |
| E | 701.4 | 282.3 | 63.6 | 2179.9 | 751.5 | 9.81 | 0.68 | 0.009 | 0.365 |
| F | 880.0 | 294.6 | 64.5 | 3133.8 | 727.2 | 8.96 | 0.53 | 0.007 | 0.371 |

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

| | Cd | | Cr | | Ni | | Pb | | Zn | |
|---|---|---|---|---|---|---|---|---|---|---|
| Element/ sites | Water | Sed. | Water | Sed. | Water | Sed. | Water | Sed. | Water | Sed. |
| A | 0.002 | 0.20 | 0.022 | 308.0 | 0.010 | 16.10 | 0.005 | 1.08 | 0.015 | 32.40 |
| B | 0.002 | 0.20 | 0.010 | 4.69 | 0.010 | 16.30 | 0.005 | 0.79 | 0.017 | 32.50 |
| C | 0.002 | 0.20 | 0.058 | 60.20 | 0.038 | 36.60 | 0.005 | 0.50 | 0.023 | 1.470 |
| D | 0.004 | 1.09 | 0.010 | 1681.0 | 0.066 | 13.40 | 0.014 | 0.50 | 0.025 | 29.20 |
| E | 0.002 | 0.20 | 0.024 | 1.00 | 0.010 | 504.0 | 0.016 | 4.46 | 0.005 | 77.50 |
| F | 0,002 | 0.20 | 0.016 | 343.11 | 0.010 | 1.00 | 0.005 | 29.20 | 0.005 | 25.50 |

women and bottle-fed infants (Kempster *et al*., 1997; Kelter *et al*., 1997). $NO_3^-$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 $NO_2^-$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 $NO_2^-$N varied between 0.005 and 0.009 mg/L with mean concentration of 0.006 mg/L. The concentrations of both $NO_3$-N and $NO_2^-$N, according to McCutcheon *et al*. (1989), were not alarming and that the lagoon was free 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, $PO_4^-$P concentrations range from 0.005 to 0.020 mg/L (Chapman, 1992). In pristine waters, $PO_4^-$P concentrations may be as low as 0.001 mg/L (Karikari *et al*., 2007). Levels of $PO_4^-$P 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 $PO_4^-$P 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 to 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 (Pascod, 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

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 hexevalent 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

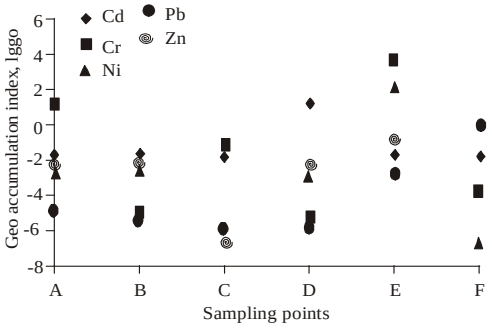


Fig. 2: Geo-accumultion of heavy metals among the sampling sites

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:

$$\frac{(\frac{M}{Fe})sample}{(\frac{M}{Fe})Background}$$

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

Table 3: Minimum, maximum, mean concentration, average shale (µg/g dry wt.) and enrichment factor of heavy metals in sediments of Mokwe lagoon

| Metal | Min | Max | Mean | Average shale | Enrichment factor |
|---|---|---|---|---|---|
| Cd | 0.2 | 1.09 | 0.348 | 0.3 | 39.33 |
| Cr | 1.0 | 1681.0 | 399.65 | 90 | 148.31 |
| Fe | 1388 | 1493 | 1413 | 47, 200 | - |
| Ni | 2.0 | 504.0 | 97.90 | 68 | 47.89 |
| Pb | 0.5 | 29.20 | 6.088 | 20 | 10.43 |
| Zn | 1.47 | 77.50 | 33.10 | 95 | 11.63 |

Table 4: Contamination factor of heavy metals and Pollution Load index of sampling zones in the Mokwe lagoon

| Sites | Cd | Cr | Ni | Pb | Zn | PLI |
|---|---|---|---|---|---|---|
| A | 0.67 | 3.42 | 0.24 | 0.05 | 0.34 | 0.39 |
| B | 0.67 | 0.05 | 0.24 | 0.04 | 0.34 | 0.16 |
| C | 0.67 | 0.67 | 0.54 | 0.03 | 0.02 | 0.30 |
| D | 3.63 | 0.04 | 0.20 | 0.03 | 0.31 | 0.20 |
| E | 0.67 | 18.67 | 7.41 | 0.22 | 0.82 | 1.76 |
| F | 0.67 | 0.11 | 0.13 | 1.46 | 0.35 | 0.35 |

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).

$$Igeo = \text{Log2 } (Cn/1.5Bn)$$

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 (06) 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:
CF = Cmetal /Cbackground

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times ..... Cn)}$$

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; $1 \leq CF < 3$ means moderate contamination; $3 \leq CF \leq 6$ 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 otherhand, 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 expect 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 (Odiete, 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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## REFERENCES

Abulude, F.O., O.O. Fapohunda and B.E. Awanlenhen, 2006. Determination of some heavy *metals in Procambaris clakii, Paleanon* sp., *Macrobrahium vollenhovenii* and *Penaeus notalis* from the Coastal Water of Ondo State, Nigeria. J. Animal Vet. Adv., 5(1): 38-41.

Adaikpoh, E.O., G.E. Nwajei and J.E. Ogala, 2005. Heavy metal concentration in coal and sediment from Ekulu in Enugu, coal city of Nigeria. J. Appl. Sci. Environ. Manage., 9(3): 5-8.

Adaikpoh, E.O., G.E. Nwajei and J.E. Ogala, 2005. Heavy metal concentration in coal and Sediment from River Ekulu, Coal City of Nigeria. J. Appl. Sci. Environ. Manage., 9(3): 5-9.

Addo, M.A., 2002. An assessment of aspects of environmental impacts of the proposed West African gas pipeline project in Ghana. M.Phil. Thesis, Dept. of Environmental Science Programme, University of Ghana, Legon, Ghana, pp: 115-116.

Alabaster, J.S. and R. Lloyd, 1980. Water Quality Criteria for Fish. 2nd Edn., Butterworth, London.

Awofolu, O.R., Z. Mbolekwa, V. Mtshemia and O.S. Fatoki, 2005. Levels of trace metals and sediment from Tyume River and its effects on an irrigated farmland. ISSN 0378-4738-Water SA, 31(1): 87-94.

Becker, A., W. Klock, K. Friese, P. Schreck, H.C. Treutler, B. Spettel and M.C. Duff, 2001. Lake suber see as a natural sink for heavy metals from copper mining. J. Geochem. Exploration, 74(1-3): 205-217.

Beseda, V., J. Fumega and A. Vaamond, 2002. Temporal trends in Cd, Cu, hg, Pb and Zn in Mussel from Spanish Noth Atlantic Coast! 1991-1999. Sci. Total Environ., 288: 239-253.

Biney, C.A., 1982. Preliminary Survey of the State of Pollution of the Coastal environment of Ghana. Proceedings. International Symposium on Coastal Lagoons,SCOR/UNESCO, Bordeaux, France, September, 1981, pp: 31-43.

Biney, C.A., 1990. A preview of some characteristics of freshwater and coastal ecosystem in Ghana. Hydrobiologia, 208: 45-53.

Birch, G., 2003. A scheme for assessing human impacts on coastal aquatic environments using sediments. Source.

Boadu, M., E.K. Osae, A.A. Golow, Y. Serfo-Armah and B.J.B. Nyarko, 2001. Determination of arsenic in some water bodies, untreated ore and tailing samples at konongo in the Ashanti region of Ghana and surrounding towns and villages by instrumental neutron activation analysis. J. Radioanalytical Nuclear Chem., 249(3): 581-585.

Boughey, A.S., 1957. Ecological studies of tropical coastline in the gold coast. West Africa J. Ecol., 45: 665-687.

Bower, H.J., 1979. Heavy Metal in Sediments of Foundry Cover Cold Spring, Environment, Science and Technology, New York, pp: 683-687.

Boyd, C.E. and F. Lichtkoppler, 1979. Water Quality Management in Fish pond Culture. Research and Development Series No. 22, Auburn University, Auburn.

Chakravarty, M. and A.D. Patgiri, 2009. Metal pollution assessment in sediments of the Dikrong River, NE India. J. Hum. Ecol., 27(1): 63-67.

Chapman, D., 1992. Water Quality Assessment: A Guide of the Use of Biota, Sediments and Water in Environmental Monitoring. University Press, Cambridge, pp: 585.

Chapman, P.M., 2000. The sediment quality triad: Then, now and tomorrow. Int. J. Environ. Pollut., 13: 351-360.

Chiba, M. and R. Masironi, 1992. Toxic and trace elements in tobacco and tobacco smoke. Bull. WHO, 70(2): 269-275.

Cunningham, W.P. and B.W. Saigo, 1995. Environmental Science, A Global Concern. 3rd Edn., WNC Brown Publishers, Country.

Dallas, H.F. and J.A. Day, 1993. The Effect of Water Quality Variables on River and ecosystem. Water Research Commission Report No.TT61/93. South Africa.

Delince, G., 1992. The Ecology of the Fish Ecosystem with Special reference to Africa. Kluwer Academic Publishers, London.

Denyoh, F.M.K., 1982. Coastal Aquaculture: Development Perspective in Africa Case Studies from other Regions. Coche, A.G., (Ed.), Series Title: CIFA Technical Papers- CIFA/CPCA/TA, AD794/B, pp: 272.

Department of Water Affairs and Forestry (DWAF), 1996a. Water Quality Guideline for Domestic Use. 2nd Edn., DWAF, Pretoria, Vol. 1.

Department of Water Affairs and Forestry (DWAF), 1996b. Water Quality Guideline. Domestic Use. 2nd Edn., DWAF, Pretoria.

Eja, M.E., O.R.A. Ogri and G.E. Ankpo, 2003. Bioconcentration of heavy metal in surface sediment from the Great Kwa Rivers, Estuary, Calabar, S.E. Nigeria. J. Nigeria Environ. Soc., 2: 247-256.

Ergin, M., C. Saydam, O. Basturk, E . Erdem and R. Yoruk, 1991. Heavy metal concentrations in surface sediments from the two coastal inlets (Golden Horn Estuary and Izmit Bay) of the northeastern Sea of Marmara. Chem. Geo., 91(3): 269-285.

Fatoki, O.S., N. Lujiza and A.O. Ounfowokan, 2002. Trace metal pollution in Umtata River. Water SA, 28(2): 183-189.

Friberg, L., C.G. Elinder, T. Kjelltroem and G.F. Nordberg, (Eds.), 1986. Cadmium and health: A toxicilogical and epidemiological appraisal. Volume II effect and response. In: Fatoki, O.S., N. Lujiza and A.O. Ounfowokan, 2002. Trace Metal Pollution Umtata River. Water SA, 28(2): 183-189.

Ghrefat, H. and N. Yusuf, 2006. Assesssing Mn, Fe, Cu, Zn and Cu" pollution in bottom sediment of Wadi Al-Arab Dam. J. Chemspeheric, 06: 043.

Gibbs, R.J., 1977. Transport phases of transition metals in the Amazon River. Geol. Soc. Am. Bull., 88: 829-843.

Gordon, C., 1987. The Coastal Lagoon in Ghana. In: Burgis, M.J. and J.T. Symoens, (Eds.), African Wetlands and Shallow Water Bodies. URETOM, 211: 182-197.

HACH, 1992. Water Analysis Handbook. Hach Company, Loveland, Colorado, USA, pp: 4012, 427-8, 537-8.

Herber, F.R., M.A. Verschoor and A.A.E. Wibowo, 1988. A Review of the Kinetics and Kidney Effects of Cadmium-A Recent Epidemiological Studies. In: Fatoki, O.S., N. Lujiza and A.O. Ounfowokan, 2002. Trace Metal pollution in Umtata River. Water SA, 28(2): 183-189.

Hutton, M., R.L. Chaney, C.R. Krishna, M. Murti, A. Olade and A.L. Page, 1987. Group Report. In: Hutchson, T.C. and K.M. Meena, (Eds.), Lead, Mercury, Cadmium and Arsenic in the Environment. John Wiley, New York, pp: 35-41.

Johnson, V.A., 2000. The coastal environmental profile of the anglo beach: Shama District. Thesis, Environmental Science Programme, University of Ghana, Legon, pp: 77-90.

Karikari, A.Y., K.A. Asante and C.A. Biney, 2005. Water Quality Characteristics at the Estuary of Korle Lagoon in Ghana. Unpublished paper. CSIR-Water Research Institute, P. O. Box M32, Accra-Ghana.

Karikari, A.Y., J.K. Bernasco and E.K.A. Bosque-Hamilton, 2007. An Assessment of Water Quality of Augaw River in South-Eastern Coastal Plain of Ghana. Unpublished Paper. CSIR-Water Research Institute, P.O. Box M32, Accra-Ghana.

Katz, S.A. and H. Salem, 1994. The Biological and Environmental Chemistry of Chromium. VCH, New York.

Kelter, P.B., J. Grudman, D.S. Hage and J.D. Carr, 1997. A discussion of water pollution in the us and mexico with high school laboratory activities for analysis of lead, Anthrazine and nitrate. Chem. Educ., 74(12): 1413-1418.

Kempster, P.P., H.R. Van Vliet and A. Kuhn, 1997. The Need for Guideline to Bridge the Gap between Ideal Drinking Water Quality Which is Practicable. Water SA, 23(2): 163-167.

Kenneth, H., 1990. Official Methods of Analysis of Association of Official analytical Chemists International. 15th Edn., AOAC Inc., Virginia, USA, Vol. 1.

Kjellstroem, T., 1986. Intai-itai Disease. In: Friberg, L., C.G. Elinder, T. Kjellstroem and G.F. Nordberg, (Eds.), Cadmium and Health. A Toxicological and Epiodermiological Appraisal Effect of Response. CRC Press, Boca Raton, Florida, 2: 257-290.

Kothai, P., P. Prathibha, I.V. Saradhi, G.G. Pandit and V.D. Puranik, 2009. Characterization of atmospheric particulate matter using pixe technique. Int. J. Environ. Sci. Eng., 1(1): 27-30.

Kwei, E.A., 1976. Biological, chemical and hydrological characteristics of coastal lagoons of Ghana, West Africa. Hydrobiologia, 56: 157-174.

Lau, S., M. Murtedzaa and S. Sabtuta, 1996. Heavy metal in sediment as a tracer for sources of pollution in Sg. Saawak, Malaysia. J. Analytical Sci., 2(2): 365-371.

Loska, K., J.J. Cebula, J. Pelczar, D. Wiechhla and J. Kwapulinski, 1997. Use of enrichment and contamination factors together with geoaccumulation indexes to Evaluate the content of Cd, Cu and Ni in the Rybnik water reservoir in Poland. Water Air Soil Pollut, 3: 347-365.

Loska, K., D. Wiechula, B. Barska, E. Cebula and A. Chojnecka, 2003. Assessment of arsenic enrichment of cultivated soils in Southern Poland. Pol. J. Environ. Stud., 12 (2): 187-192.

Luoma, S.N. and G.W. Bryan, 1981. A statistical assessment of the form of trace metals in oxidized estuarine sediments employing chemical Extractants. Sci. Total Environ., 17: 165-196.

McCutcheon, S.C., J.L. Martin and T.O. Barnwell, 1989. Water Quality. In: Maidment, D.R., 1993. Handbook of Hydrology. McGraw-Hill, INC, NY, Sigapore, Sydney. 11.48-11.50.

Mckenzie, H.A. and L.E. Symthe, 1998. Quantitative Trace Analysis of Biological Material. Elsevier, Ansterdan.

Mengel, K. and E.A. Kirkby, 1982. Principles of Plant Nutrition. 3rd Edn., Int. Pot. Inst. P.O. Box CH-3048, Worblaufen-Bern., Switzerland, pp: 655.

Merian, E., 1991. Metals and their Compounds in the Environment. Occurance, Analysis and Biological Relevance. UCH, Weinhelm-New York-Basel Cambridge. In: Fatoki, O.S., N. Lujiza and A.O. Ounfowokan, 2002. Trace metal pollution in Umtata River. Water SA, 28(2): 183-189.

Mmolawa, K.B., S. Likuku and G.K. Gabontloeloe, 2011. Assessment of heavy metal pollution in soils along major roadside areas in Botswana. African J. Environ. Sci. Tech., 5(3): 186-196. Muller, G., 1969. Index of geo-accumulation in sediments of the Rhine River. Geo. J., 2(3): 108-118.

Nasr, S.M., M.A. Okbah and S.M. Kasem, 2006. Environmental assessment of heavy metal pollution in bottom sediment of Aden port, Yemen. Int. J. Ocean Oceanography, 1(1): 99-109.

Odiete, W.O., 1999. Environmental Physiology of Animals and Pollution. Diversified Resources Ltd., Lagos, pp: 261.

O'Flaherty, E.J., 1995. Chromium Toxicokinetics'. In: Asonye, C.C., N.P. Okolie, E.E. Okenwa and U.S. Iwanyanwu, 2007. Some physico-chemical characteristics and heavy metal profile of Nigerian Rivers, Streams and Water Ways. African J. Biotech., 6(5): 617-624.

Onyari, M.J., A.W. Muohi, G. Omondi and K.M. Mavuti, 2003. Heavy metals from Makupa and Port-Reitz creek system: Kenyan coast. Environ. Inter., 28(7): 639-647.

Pane, E.F., J.G. Richrd and C.M. Wood, 2003. Acute water borne nickel toxicity in the rainbow trout (Oncorhychus mykiss) occurs by respiratory rather than ionoregulatory mechanism. Acquatic Toxicology, 63(1): 65-82.

Pascod, M.B., 1992. Wastewater treatment and use in agriculture, irrigation and drainage. In: Godwin, A.A., K. Singh, S. Balerea and S. Kokot, 2007. Exploratory multivariate modeling of the physico-chemical properties of surface water and groundwater. J. Hydrology, 336(1-2): 115-124.

Praveena, S.M., A. Ahmed, M. Radojevic, M.H. Abdullah and A.Z. Aris, 2007. Factorcluster analysis and enrichment study of mangrove sediments-an example from Mengkabong, Sabah. Malaysian J. Anal. Sci., 11(2): 421-430.

Praveena, S.M., A. Ahmed, M. Radojevic, M.H. Abdullah and A.Z. Ris, 2008. Heavy metals in mangrove surface sediment of mengkabong lagoon, Sabah: Multivariate and geoaccumulation index approaches. Int. J. Environ. Res., 2(2): 139-148.

Ramadan, A.A., 2003. Heavy Metal Pollution and Biomonitoring Plants in Lake Manzala Egypt. Pak. J. Biol. Sci., 6(13): 1108-1117.

Rao, J.D. and A.B. Saxena, 1981. Acute toxicity of mercury, zinc, lead cadmium, manganese to the *Chironomus sp*. Inter. J. Environ. Stud., 16: 225-226.

Rast, W. and J. Thornton, 1986. Trend in eutrophication research and control. Hydrol. Proc., 10: 295.

Salnikow, K. and E. Denkhaus, 2002. Nickel essentiality, toxicity and carcinogenicity. Crit. Rev. Oncol/ Haematol, 42(1): 35-56.

Samir, M.N., A.O. Mohamed and M.K. Shaif, 2006. Environmental assessment of heavy metal pollution in bottom sediments of aden port, Yemen. Inter. J. Ocean Oceanogr., 1(1): 99-109.

Serfo-Armah, Y., B.J.B. Nyarko, E.K. Osae, D. Carboo, S. Anim-Sampong and F. Seku, 2000. Rhodophyta seaweed species as bioindicators for monitoring toxic element pollutants in the marine ecosystem of Ghana. J. Water Air Soil Pollution, 127: 243-253, 2001.

Seshan, *et al*., 2010. Geochemical and statistical approach for evaluation of heavy metal pollution in core sediments in southeast coast of India. Int. J. Environ Sci. Tech., 7(2): 291-306.

Simex, S.A. and G.R. Helz, 1981. Regional geochemistry of trace elements in Chesapeake Bay. Environ. Geo, 3: 315-323.

Skidmore, F., 1964. Toxicity of zinc compounds in a quatic animals with special reference to fish. Q. Rev. Biol., 39: 277-248.

Spear, P.A., 1981. Zinc in the aquatic environment: Chemistry and toxicology national research council of Canada associate committee on scientific criteria for environmental quality. Report NRCC No. 17589, Ottawa. In: Fatoki, O .S., N. Lujiza, and A.O. Ounfowokan, 2002. Trace Metal pollution in Umtata River. Water SA, 28(2): 183-189.

Standard Methods for the Examination of Wastewater, 1999. American Public Health Association, American Water Works Association, Water Enviornment Federation.

Teo, K.C and J. Chen, 2001. Determination of cobalt and nickel in water by atomic absorption spectrometry after cloud point extraction. Anal. Chim. Act., 434(3): 325-330.

Tomlinson, D.C., J.G. Wilson, C.R. Harris and D.W. Jeffery, 1980. Problems in the assessment of heavy metals levels in estuaries and the formation of a pollution index. Helgol. Wiss. Meeresunters., 33(1-4): 566-575.

Tsuchiya, K., 1978. Cadmium studies in Japan. A Review In: Fatoki, O.S., N. Lujiza and A.O. Ounfowokan, 2002. Trace metal pollution in Umtata River. Water SA, 28(2): 183-189.

Turekian, K.K. and K.H. Wedepohl, 1961. Distribution of the elements in some major units of the earth's crust. Geo. Soc. Am. Bull., 72(2): 175-192.

United States Commission on Ocean Policy (USCOP), 2007. Pollution of Water Bodies in Addressing Coastal Pollution. Preliminary Report. Retrieved from: http://www.oceancommestom.gov/document/ preliminary/chapter14.pdf, (Accessed on: September 31, 2007).

United States Environmental Protection Agency (USEPA), 1986a. Quality Criteria for Water. Office of Water Regulation and Standards, Washington DC, pp: 20460.

United States Environmental Protection Agency (USEPA), 1986b. Quality Criteria for Water. Office of Water Regulation and Standards, Washington DC, USEPA-40015-86- 001, 256.

Voznaya, F.N., 1983. Chemistry of Water and Microbiology: Mir Publishers, 2 Pervy Rizhsky Perevlok, I-110, GPS, Moscow, 129820 USSR. In: Abdo, M.H, 2005. Physico-Chemical Characteritics of Abu Za'Baal Pond, Egypt. Egyptian J. Aquatic Res., 31(2): 1-15.

World Health Organization (WHO), 1988. Environmental Health Criteria No 61, Chromium. IPCS, World Health Organization, Geneva.

World Health Organization (WHO), 1996. Guidelines for Drinking-Water Quality. 2nd Edn., Vol. 2. Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Zabetoglou K. D Voutsa, C Samara, 2002. Toxicity and heavy metal contamination of surficial sediments from the Bay of Thessaloniki (Northwestern Aegean Sea) Greece. Chemosphere, 49:17-26.