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Table of Contents: Volume 8 Number 1 January, 2014

## ARTICLES

## Table of Contents: Volume 8 Number 1 January, 2014

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*Full Length Research Paper*

# Evaluation of allelopathic effect of *Eclipta alba* (L.) Hassk on biochemical activity of *Amaranthus spinosus* L., *Cassia tora* L. and *Cassia sophera* L.

**Aasifa Gulzar* and M. Badruzzaman Siddiqui**

Department of Botany, Aligarh Muslim University, Aligarh, India.

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**A study was conducted to assess the magnitude of suppressing ability of *Eclipta alba* (L.) Hassk. on some selected weeds of Aligarh namely, *Amaranthus spinosus* L., *Cassia tora* L. and *Cassia sophera* L. The research finding was conducted to evaluate the effect of aqueous leaf leachate and organic fractions of donor plant on biochemical activities (carbohydrate content, chlorophyll content and protein content). The result shows that aqueous leachate and organic fractions reduced the level of biochemical activities. Carbohydrate content was increased in treated plants as compared to control while chlorophyll content and protein content were reduced as compared to the control. Aqueous leachate showed maximum toxicity on weeds than organic fractions. The reduction may be due to the allelochemicals present in *E. alba* leaves.**

**Key words:** Allelochemicals, aqueous leachate, organic fractions, chlorophyll content, carbohydrate content, *Eclipta alba*.

## INTRODUCTION

Weed infestation is one of the major causes of yield reduction in crops. The incidence of allelopathic effect of weeds on growth of crops has become increasingly wide-spread. When the two plant species grow together, they interact with each other by either inhibiting or stimulating their growth or yield through direct or indirect allelopathic interaction (Rice, 1984; Nandal et al., 1994; Abendroth and Elmore, 2007; Kumari et al., 2006). Several reports have documented the deleterious effect of decaying weed residues on the growth and yield of subsequent crops in the field (Guenzi and McCalla, 1966; Shaukat et al., 1985, 2003; Burhan and Shaukat, 1999). The effects of decaying weed residues depend upon the release of allelochemicals from them into the soil. These chemicals may be washed directly from the residues, or may result from microbial activity during decomposition (Putnum and Duke, 1978; Lynch and Cannell, 1980; Kumar et al., 2006). The effect of allelopathic chemicals tends to be highly species-specific (Stowe, 1979; Melkania, 1983). Normally, the effect is harmful, but beneficial effect is also possible (Newman, 1978).

*Eclipta alba* is a small branched annual herbaceous plant, occasionally rooting at nodes, cylindrical or flat, rough due to the presence of white hairs, nodes are distant, greenish but occasionally brownish. The allelopathic potential of *E. alba* has been revealed by many researchers (Yonli et al., 2010; Nisar and Hussain, 1992; Pawinde et al., 2008).

The present study was to evaluate the aqueous leaf leachate and organic fractions effect on biochemical activity of some weed plants (*Amaranthus spinosus*, *Cassia tora* and *Cassia sophera*).

*Corresponding author. E-mail: aasifa4gulzar@gmail.com or aasifa.gulzar@rediffmail.com. Tel: 09760931189.

## MATERIALS AND METHODS

### Collection of material

Leaves of *E. alba* were collected locally from AMU campus, Aligarh. Healthy and freshly collected leaves were surface cleaned, dried and powdered. Seeds of the weed species, *A. spinosus*, *C. tora* and *C. sophera* were collected from the road sides of the Aligarh Muslim University, Aligarh, U.P., India.

### Preparation of leachable allelochemical

Based on the methods devised by Kumari et al. (1985), healthy and freshly collected leaves of *E. alba* were cut roughly into pieces after clearing their surface and their dry weight per unit fresh weight were determined by desiccating the tissue in the oven. The weighed amount of fresh leaf pieces of the plant was soaked in requisite amount of pure water for a period of 20 h at room temperature. It was filtered completely through double layer of muslin cloth followed by Whatman No. 1 filter paper and the requisite concentration was made with distilled water. One half of this filtrate referred to as the aqueous leachates was used, while the other part was chilled and subjected to acid hydrolysis using pre-chilled, 3 N HCl. The precipitates so formed were recovered through centrifugation (2000 rpm). These were washed 5-6 times with pure water. Every time the recovery was made through mild centrifugation. For experimental purpose, requisite amount of the precipitate was dissolved in a few drop of ethyl alcohol and the final volume was made with pure water. A drop of Tween 20 was added to it, to serve as surfactant. This is referred to as aglycone or aglyconic or organic component of aqueous leachates.

### Extraction of organic fraction

The healthy leaves of the donor plant were freshly collected, surface cleaned, then dried under shade and powdered. The powder was immersed in petroleum ether (60-80°C) for 20 h. The liquid was separated residue (marc), through mild centrifugation (500 rpm for 2 min). From the liquid portion the solvent (petroleum ether) was recovered on a hot water bath. Requisite amount of the residue so obtained was weighed and a few drops of xylene, a part from a drop of Tween-20 (to act as surfactant) were added to it. Final volume was made with pure water. This was termed petroleum ether fraction. The marc (residue from petroleum ether suspension) was suspended in methanol for 20 h and filtered, from one half of the filtrate, methanol was covered on a hot water bath. The residue, so obtained was dissolved in a drop of methanol and the final volume was made with pure water. It has been called methanol fraction. From another half of methanol filtrate, the solvent was removed and the residue was partitioned between chloroform and water (1:1 v/v). The two layers so formed were separated in a separating funnel. The chloroform was recovered over a hot water bath. To the requisite amount of residue, a few drops of methanol were added and the final volume was made with pure water. This has been termed as the chloroform fraction. The water from the aqueous layer after separating chloroform fraction was dried under low pressure on a rotary flash evaporator. The solution made with water was termed the water fraction.

### Treatment for mature plants

For the estimation of various macro-molecular content (carbohydrate contents, protein content and chlorophyll content), nine plants of each test plant (*A. spinosus*, *C. tora* and *C. sophera*) were sprayed with 100 ml of the treatment solution per plant daily for five for five days. On the sixth day, the estimation of the carbohydrate content, protein content and chlorophyll content was done from the freshly plucked leaves.

### Determination of carbohydrate content

The methodology employed by Loweus (1952) was followed for this purpose.

### Estimation of chlorophyll content

The total chlorophyll content from leaves of treated or control plants were extracted in Di-methyl sulphoxide (DMSO) following the method of Hiscox and Israelstan (1979). Finely cut uniform discs (100 mg fresh weight) were made from fully expanded leaves of test plants. Dry weight equivalents of each of the treated samples were determined by keeping 100 mg fresh weight discs in an oven. The weighted material (100 mg fresh weight leaf disc) was suspended in 10 ml of di-methyl sulphoxide (DMSO) incubated at 65°C for one hour (the period of incubation was found sufficient for the complete extraction of chlorophyll). The DMSO was recovered by thorough decantation. The final volume was corrected to 10 ml with fresh DMSO.

The extinction of chlorophyll thus recovered in DMSO was measured at dual wave-length of 645 and 663 nm on spectrophotometer against DMSO as blank. The extinction values were read and the amount of chlorophyll was calculated according to the equation given by Arnon (1949), with modification by Hiscox and Israelstan (1979).

### Estimation of total soluble proteins

The method as given by Lowry et al. (1951) was adopted for this purpose.

### Statistical analysis

Each experiment was performed in completely random design block and results were mean of three replicates. All results were statistically analyzed through LSD.

## RESULTS AND DISCUSSION

It is very clear from the result of this experiment that *E. alba* leaves exert a very negative influence on the acid soluble and water soluble carbohydrates of the weeds *A. spinosus*, *C. tora* and *C. sophera*. It is very well depicted that an increased amount of carbohydrates content exerts its influence mainly through its aqueous leachates. Effect of different treatments on carbohydrate content is in the following order AL>CF>PF>WF>MF (Table 1).

An increased amount of carbohydrates points out to the fact that the plant is under stress and it is gathering up its energy reserves to meet any condition of adversity. The results are in line with radish where appreciable increase in the increased concentration of soluble sugars in response to leaf extracts of heliotrope (*Heliotropium foertherianum*) was reported (Abdulghader et al., 2008). Similar increase in soluble sugars of maize in response to leaf extracts of *Acacia* and *Eucalyptus* has been reported

**Table 1.** Effect of aqueous leachates and organic extract fractions derived from the leaves of *E. alba* on total carbohydrate content of the leaves of *Amaranthus spinosus* L., *Cassia tora* L. and *Cassia sophera* L.

| Treatment solution | *Amaranthus sinosus* | | *C. tora* | | *C. sophera* | |
|---|---|---|---|---|---|---|
| | **Acid soluble carbohydrates (mg/gdry wt.)** | **Water soluble carbohydrate (mg/g dry)** | **Acid soluble carbohydrate (mg/g dry wt.)** | **Water soluble carbohydrate (mg/g dry wt.)** | **Acid soluble carbohydrate (mg/g dry wt.)** | **Water soluble Carbohydrate (mg/g dry wt.)** |
| Control | 49.45±0.65 | 52.12±0.31 | 58.47±0.36 | 56.79±0.49 | 52.83±0.57 | 64.83±0.33 |
| Aqueous leachates AL (1% g/ml fresh weight) | 76.45±0.12 | 79.63±0.37 | 65.34±0.15 | 69.11±0.15 | 81.04±0.67 | 80.37±0.52 |
| Petroleum ether fraction PF (0.09w/v) | 67.34±0.15 | 70.11±0.15 | 65.34±0.15 | 69.11±0.15 | 75.31±2.57 | 77.84±2.65 |
| Methanolic fraction MF (0.09% w/v) | 52.63±0.92 | 64.52±0.39 | 51.63±0.92 | 64.52±0.39 | 69.02±1.53 | 81.05±1.14 |
| Chloroform fraction CF (0.09% w/v) | 74.12±0.29 | 82.02±.0.61 | 72.15±0.13 | 70.19±0.92 | 79.32±0.52 | 70.21±0.43 |
| Water fracrtion WF (0.09% w/v) | 64.71±0.54 | 59.45±0.37 | 47.36±0.20 | 61.29±0.38 | 52.21±0.81 | 69.67±2.32 |
| LSD at 5% | 6.28 | 6.59 | 6.55 | 7.39 | 5.96 | 7.10 |
| LSD at 1% | 8.94 | 9.38 | 9.32 | 10.51 | 8.48 | 10.10 |

± Represents standard deviation.

**Table 2.** Effect of aqueous leachates and organic extract fractions derived from the leaves of *E. alba* on total chlorophyll content of the leaves of *Amaranthus spinosus* L., *Cassia tora* L. and *Cassia sophera* L.

| Treatment solution | Total chlorophyll content (µg/mg fresh wt.) | | |
|---|---|---|---|
| | ***A. spinosus*** | ***C. tora*** | ***C. sophera*** |
| Control | 2.85±0.13 | 3.46±0.09 | 3.20±0.11 |
| Aqueous leachates AL (1%g/ml fresh weight) | 1.83±0.16 | 3.20±0.66 | 2.11±0.10 |
| Petroleum ether fraction PF (0.09w/v) | 1.63±0.42 | 2.74±0.04 | 2.01±.0.37 |
| Methanolic fraction MF (0.09%w/v) | 1.64±0.19 | 2.34±0.65 | 2.26±1.75 |
| Chloroform fraction CF (0.09%w/v) | 1.39±0.73 | 1.69±0.03 | 2.61±0.33 |
| LSD at 5% | 0.270 | 0.321 | 0.339 |
| LSD at 1% | 0.384 | 0.456 | 0.482 |

± Represents standard deviation.

(Sahar et al., 2005).

The chlorophyll content was also reduced as compared to the control (Table 2). Aqueous leachate and organic fraction shows different level of inhibition on different weeds. In *A. spinosus,* maximum inhibition was seen in aqueous leachate treatment. The reduction in the chlorophyll content in this experiment may be due to the fact that allelochemicals either inhibit the synthesis of chlorophyll or perhaps they breakdown the chlorophyll molecule by acting on the pyrrolic ring and the phytol chain (Blum et al., 1985; Colton and Einhelling, 1980; Yang et al., 2002, 2006). Hence the allelo-chemicals act by inhibiting the process of photosynthesis which ulti-mately can lead to the death of plant. Allelopathic effect of *Croton bonplandianum* cause reduction in chlo-rophyll content as reported by Sarkar and Chakraborty (2010) on *Triticum uestivam* and *Brassica campestris*; Liu et al. (2009) on *Lycopersicon esculentium* and Abu-Romman et al. (2010) in *Euphorbia hierosolymitana*. Recently, there has been increase in research on the role of the demand for photo-assimilates in regulating photo-synthesis through changes in carbohydrate partitioning and accumulation under stress condition (Paul and Foyer, 2001; Paul and Driscoll, 1997; Nielsen et al., 1998; Osmond et al., 1987; Levitt, 1982).

The decrease in protein content is shown in Table 3.

**Table 3.** Effect of aqueous leachates and organic extract fractions derived from the leaves of *E. alba* on total protein content of the leaves of *Amaranthus spinosus* L., *Cassia tora* L. and *Cassia sophera* L.

| Treatment solution | Total protein content (mg/g dry wt.) | | |
|---|---|---|---|
| | ***A. spinosus*** | ***C. tora*** | ***C. sophera*** |
| Control | 58.17±0.17 | 58.78±2.21 | 55.94±0.99 |
| Aqueous leachates AL (1% g/ml fresh weight) | 32.44±0-73 | 45.52±1.14 | 44.69±0.17 |
| Petroleum ether fraction PF (0.09% w/v) | 34.17±0.76 | 42.62±0.65 | 47.21±0.65 |
| Methanolic fraction MF (0.09% w/v) | 46.24±0.23 | 33.81±0.82 | 35.27±0.19 |
| Chloroform fraction CF (0.09% w/v) | 47.16±0.31 | 48.4±0.84 | 36.27±0.12 |
| Water fracrtion WF (0.09% w/v) | 32.17±0.12 | 39.02±0.32 | 33.93±0.32 |
| LSD at 5% | 3.99 | 4.38 | 4.24 |
| LSD at 1% | 5.68 | 6.22 | 6.03 |

± Represents standard deviation.

Our findings are supported by the results of Duhan et al. (1995) who demonstrated significant decrease in the level of soluble proteins in legume crops in response to *Acaccia nilotica extracts*. Baziramakenga et al. (1997) demonstrated that phenolic acids reduced the incorporation of certain amino acids into proteins and thus reduce the rate of protein synthesis. Maize has been reported to contain 3 phenolic acids (Iman et al., 2006), which might have resulted in decreasing the protein content of soybean leaves. The phenolic acids have been shown to be toxic to activities of many enzymes (Hopkins, 1999).

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*Full Length Research Paper*

# Reginol interpretation of river Indus water quality data using regression model

**Aziz-ur-Rahman and Muhammad Owais Chughtai**

Department of Energy and Environment, Hamdard University, Karachi, Pakistan.

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**Water samples were collected from river Indus over 591 km$^2$ from Kashmor to Keti Bandar/Shah Bandar in the province of Sindh, Pakistan, during 2008 and 2009 on seasonal bases. These samples were analyzed for 12 water quality variables including physical and chemical parameters. Then correlation study was carried out and correlation co-efficient "r" was determined using correlation matrix to identify the highly correlated and interrelated parameters. Regression model were developed to test the significant 'r' and P-value test was carried out to test the significance of the pair of parameters. F-test was also used to examine the joint-effects of several independent variables without taking into account the separate effects of each variable. The comparison of the observed and predicted values of different parameters using regression equation suggested that the regression model provide useful means of rapid and easier monitoring of water quality of a river in a region.**

**Key words:** Regression model, correlation coefficient, river indus, monitoring, physico-chemical parameters.

## INTRODUCTION

Water is undoubtedly the most precious natural resource that exists on our planet. Although we recognize this fact, we disregarded it by polluting our rivers, lakes and oceans. It is the basic duty of every individual to conserve water resources (Jothivenkatachalam et al., 2010; Vega et al., 1998). The riverine system is most important resources of water supply in different countries of the world. At the source of a river, the water is relatively pure as it flows towards downstream. In Pakistan riverine system are getting polluted day by day. A primary reason for this is that all three major sources of pollution (industry, agriculture and domestic) are concentrated along the river belt and work together to reduce water quality which is a cause of alarm.

According to world wide fund for nature (WWF), five rivers in Asia serving 870 million people are among the most threatened in the world, as dams, water extraction and climate change all take their toll. The Indus River is among the top five most threatened river basins. Various studies were carried out to investigate the quality of Indus River water (Sadia et al., 2013; Ali et al., 2004; Tassaduqe et al., 2003; Khuhawar et al., 2000).

The environment, economic growth and development of Pakistan especially in province of Sindh are highly influence by water, it regional and seasonal availability, and quality of surface water and microbiological parameters. A few number of research articles are available regarding the analysis of water quality data using regression techniques (Mulla et al., 2007; Patil and Patil, 2010, 2011; Kumar and Sinha, 2010; Obiefuna and Orazulike, 2010; Mehta, 2010; Sami et al., 2011; Jain and Sharma, 2000; Joarder et al., 2008). These parameters are closely interlinked. All the research so far reported on river water quality of Pakistan based on physico-chemical analysis, no attempt has been made to predict the river water quality by using regression analysis.

In the present study, river water quality was determined by measuring the concentration of some physico-

*Corresponding author. E-mail: azizemaz@yahoo.com. Tel: (+92)0333-2185430.

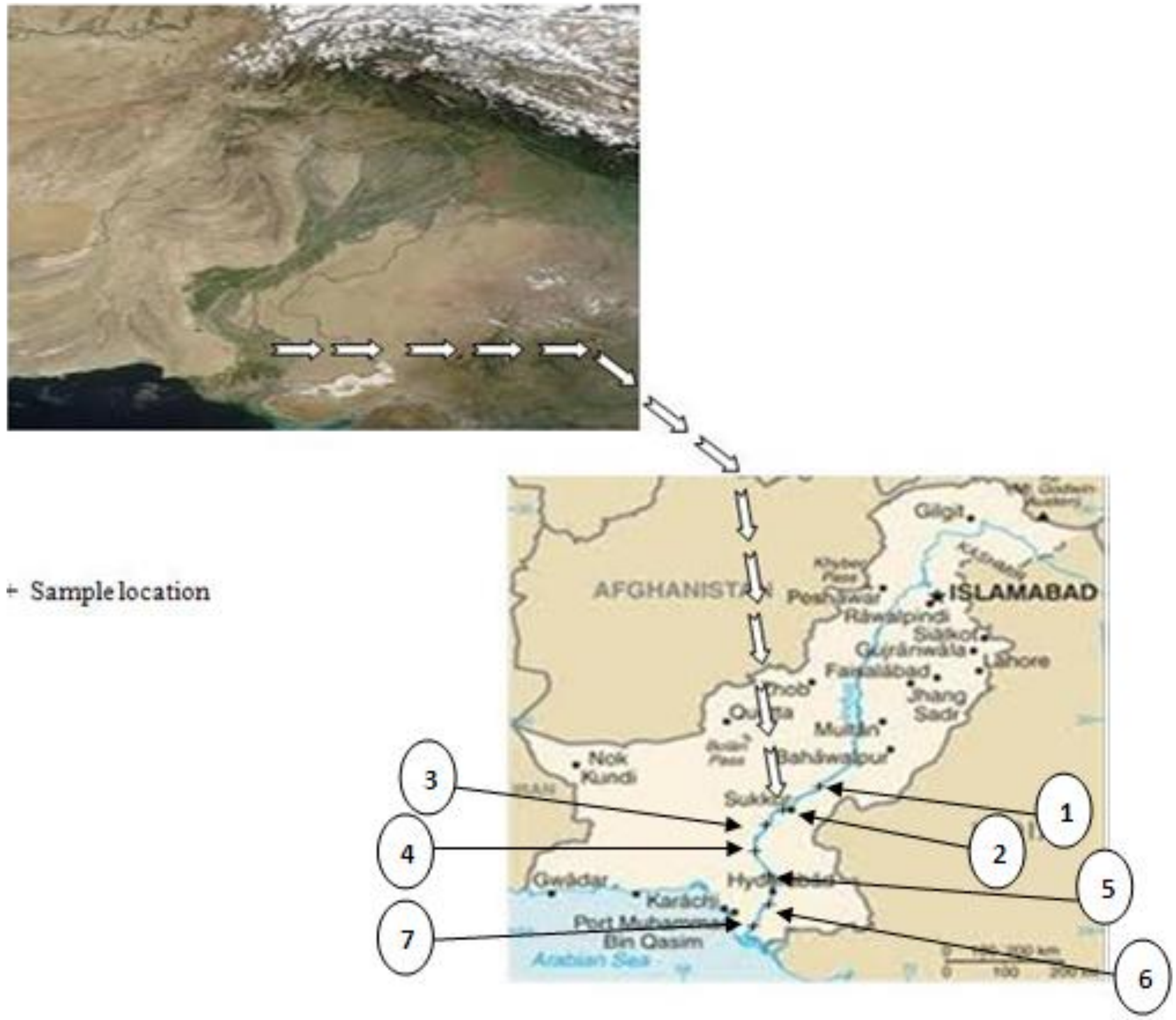


**Figure 1.** Location map. 1. Guddu Barrage; 2. Sukkur barrage; 3. Dadu-Moro Bridge; 4. Indus link 1 km downstream from Latifabad; 5. River Indus after Indus link outfall 6. Kotri Barrage at main bridge; 7. Sajawal bridge.

chemical parameters and comparing them with drinking water standards (WHO). Regression equations for the parameters having significant correlation were used to estimate the concentration of other constituents. Regression model were developed to test the significant correlation coefficient to overall water quality relative concentration of various pollutants in water to provide necessary clue for implementation of rapid water quality management.

## MATERIALS AND METHODS

Water quality parameters of Indus River were monitored at seven different sampling points: Guddu Barrage; Sukkur barrage; Dadu-Moro Bridge; Indus link 1 km downstream from Latifabad; River Indus after Indus link outfall ; Kotri Barrage at main bridge and Sajawal bridge, considering sampling locations (receiving bulk quantity of effluent either by municipal/industrial/agriculture return flow) (Figure 1).

### Chemical analysis

The samples were collected using boat from the middle of the flow within 3-9 inches from the surface of water. Two to four sub samples of equal volume were also collected from vertical section. The samples were mixed well and saved in a 2.5 L glass bottle. The samples were analyzed for physicochemical parameters such as alkalinity, bi-carbonate, calcium, pH, conductivity, total dissolved solid, and total suspended solid, chloride, chemical oxygen demand, biological oxygen demand, sulfate, sodium, potassium and magnesium using standard methods (APHA, 2005). Results obtained were subjected to regression statistical analysis using Statistical Package for social Scientist (SPSS) 14$^{th}$ version.

**Table 1a.** Estimated values of water quality parameters and WHO prescribed limits (pre-monsoon).

| Parameter | ST-1 | ST-2 | ST-3 | ST-4 | ST-5 | ST-6 | ST-7 | St.Dev | WHO limit |
|---|---|---|---|---|---|---|---|---|---|
| Conductivity | 0.381 | 0.323 | 0.323 | 0.417 | 0.380 | 0.396 | 0.494 | 0.059 | 0.3 |
| pH | 7.7 | 7.5 | 7.6 | 7.8 | 7.6 | 7.7 | 7.7 | 0.098 | 7 to 8.5 |
| Alkalinity | 71.5 | 61.1 | 77 | 89 | 91.2 | 45 | 76 | 16.021 | 100 |
| BOD | 28 | 24 | 22 | 33 | 57 | 21.3 | 39 | 12.711 | 06 |
| COD | 67 | 56 | 53.3 | 41.7 | 131 | 50 | 93 | 31.449 | 10 |
| TSS | 324 | 321 | 187 | 63.3 | 167 | 60.3 | 24 | 123.342 | 500 |
| TDS | 220.3 | 200.5 | 224.7 | 233.7 | 237.1 | 207.1 | 287 | 28.372 | 500 |
| $Cl^{-1}$ | 40 | 38.7 | 38.4 | 39.3 | 39.3 | 37 | 50.3 | 4.454 | 200 |
| $HCO_3^{-1}$ | 87.3 | 74.7 | 93.6 | 93.3 | 92.7 | 73.0 | 97.7 | 9.798 | - |
| $SO_4^{-2}$ | 30.3 | 28 | 29.3 | 33.3 | 35 | 37.3 | 53 | 8.520 | - |
| $Ca^{+2}$ | 35.3 | 29.3 | 35.6 | 37 | 37.7 | 37.5 | 40 | 3.358 | 100 |
| $Mg^{+2}$ | 5.2 | 6 | 5.9 | 6.1 | 6 | 2.9 | 8.5 | 1.645 | - |
| $Na^{+1}$ | 21.8 | 22 | 21.6 | 22.1 | 23 | 24.6 | 31.3 | 3.476 | - |
| $K^{+1}$ | 1.9 | 1.8 | 1.8 | 2.2 | 2.2 | 3 | 6 | 1.513 | - |

### Statistical screening

The regression analysis was used to estimate two water quality parameters to describe realistic ground water situations. In addition, this analysis attempts to establish the nature of the relationship between the variables and thereby provides a mechanism for prediction or forecasting (Kumar and Sinha, 2010; Agarwal and Sexena, 2011; Mulla et al., 2007). To find the relationship between two physicochemical parameters X and Y, the Karl Pearson's correlation coefficient, r is used and it is determined as follows:

$$\mathbf{r} = \frac{n \Sigma x y - (\Sigma x . \Sigma y)}{\sqrt{[n \Sigma x^2 - (\Sigma x)^2][n \Sigma y^2 - (\Sigma y)^2]}} \quad (1)$$

where, n = number of data points; x = values of X-variable; y = values of Y-variable.

To evaluate the straight-line by linear regression, the following equation of straight line can be used:

$$Y = a X + b \quad (2)$$

where, Y = dependent variable ; X = independent variable ; a = slope of line; b = intercept on y-axis

$$a = \frac{n \Sigma x y - (\Sigma x. \Sigma y)}{n \Sigma x^2 - (\Sigma x)^2} \quad (3)$$

and

$$b = \overline{y} - a \overline{x} \quad (4)$$

Where, x = arithmetic mean of all values of x; y = arithmetic mean of all values of y.

For good correlation, value of r should be between $-1 < r < 1$.

## RESULTS AND DISCUSSION

The values of physicochemical parameters, standard deviation and WHO prescribed limits are presented in Table 1a and b during pre and post-monsoon, respectively. The relationship between alkalinity with $HCO_3^{-1}$ is highly correlated and with BOD and $Mg^{+2}$ are moderately correlated where as alkalinity is weakly correlated with COD and TDS during pre-monsoon (Table 2a).

The relationship between alkalinity with $Na^{+1}$, $Ca^{+2}$ and TDS during post-monsoon which give correlation co-efficient are equal to 0.448, 0.546 and 0.531, respectively (Table 2b) showing less moderate to moderate as values of 'r' lies between -1 and +1.

The terms alkalinity and hardness are often used interchangeably when discussing water quality. These aggregate properties of water share some similarities but are distinctly different. Alkalinity is a measure of the acid-neutralizing capacity of water.

Alkalinity in most natural waters is due to the presence of carbonate ($CO_3^{-2}$), bicarbonate ($HCO_3^{-1}$), and hydroxyl ($OH^{-1}$) anions. However, borates, phosphates, silicates and other bases also contribute to alkalinity if present. This property is important when determining the suitability of water for irrigation and/or mixing some pesticides and when interpreting and controlling wastewater treatment processes.

In the present study, the alkalinity values were maximum during pre-monsoon. This may be attributed to increase in the rate of organic decomposition during which $CO_2$ is liberated, which reacts with water to form $HCO_3^{-1}$, thereby increasing total alkalinity in pre-monsoon. The increased alkalinity during pre-monsoon was due to the concentration of nutrients in water. The decrease was due to dilution caused by the rainwater during monsoon. Similar observation was reported by

**Table 1b.** Estimated values of water quality parameters and WHO prescribed limits (post-monsoon).

| Parameter | ST-1 | ST-2 | ST-3 | ST-4 | ST-5 | ST-6 | ST-7 | St.Dev | WHO limit |
|---|---|---|---|---|---|---|---|---|---|
| Conductivity | 0.377 | 0.408 | 0.342 | 0.378 | 0.415 | 0.330 | 0.119 | 0.102 | 0.3 |
| pH | 7.8 | 7.8 | 7.8 | 7.4 | 7.6 | 7.3 | 7.4 | 0.219 | 7 to 8.5 |
| Alkalinity | 63.5 | 67.5 | 70.8 | 62.4 | 49.3 | 53 | 75.4 | 9.336 | 100 |
| BOD | 14.3 | 25.2 | 18 | 35.6 | 36 | 15.9 | 9.7 | 10.447 | 06 |
| COD | 38 | 67.3 | 40.3 | 98.3 | 67.7 | 46 | 21 | 25.572 | 10 |
| TSS | 239.7 | 260.3 | 160.3 | 153.3 | 321.3 | 210.3 | 3.3 | 101.735 | 500 |
| TDS | 229.2 | 228.6 | 234.5 | 399.2 | 276.7 | 227.8 | 805.3 | 213.055 | 500 |
| $Cl^{-1}$ | 42.3 | 40.7 | 42.3 | 35 | 81.4 | 35.7 | 35.7 | 16.484 | 200 |
| $HCO_3^{-1}$ | 75.7 | 77 | 80.3 | 82.5 | 97.1 | 80 | 101.7 | 10.239 | - |
| $SO_4^{-2}$ | 40 | 43 | 39 | 38.7 | 89.4 | 34 | 87.3 | 24.262 | - |
| $Ca^{+2}$ | 38 | 37.1 | 38.7 | 36.8 | 37.5 | 42 | 80 | 15.838 | 100 |
| $Mg^{+2}$ | 8.3 | 7.6 | 8.4 | 6.3 | 71.6 | 5.2 | 22.7 | 24.11 | - |
| $Na^{+1}$ | 20.6 | 20.3 | 22 | 19.7 | 45.3 | 18.7 | 129.3 | 40.731 | - |
| $K^{+1}$ | 4 | 2.7 | 3.7 | 18.3 | 15.1 | 3.3 | 6.3 | 6.365 | - |

**Table 2a.** Statistical regression analysis data (pre-monsoon).

| R -Equation | I-Var. | D-Var. | n | r | F value | S.E |
|---|---|---|---|---|---|---|
| Alkalinity =30.650 x pH - 161.720 | pH | Alkalinity | 7 | 0.187 | 0.181 | 17.241 |
| Alkalinity = 0.234x COD+56.499 | COD | DO | 7 | 0.460 | 1.342 | 15.583 |
| Alkalinity = 0.880x BOD + 44.785 | BOD | DO | 7 | 0.698 | 4.748 | 12.569 |
| Alkalinity= - 0.012 x TSS + 74.926 | TSS | DO | 7 | -0.092 | 0.043 | 17.476 |
| Alkalinity = 0.278 x TDS +8.905 | TDS | DO | 7 | 0.493 | 1.607 | 15.267 |
| Alkalinity = 45.23 x Conductivity+55.44 | Conductivity | DO | 7 | 0.166 | 0.141 | 17.307 |
| Alkalinity = 0.841x $Cl^{-1}$ + 38.97 | $Cl^{-1}$ | DO | 7 | 0.234 | 0.289 | 17.063 |
| Alkalinity = 1.391 x $HCO_3^{-1}$ - 48.66 | $HCO_3^{-1}$ | DO | 7 | 0.850 | 13.070 | 9.232 |
| Alkalinity = 0.069 x $SO_4^{-2}$ + 70.55 | $SO_4^{-2}$ | DO | 7 | 0.037 | 0.007 | 17.538 |
| Alkalinity = 1.421 x $Ca^{+2}$ + 21.74 | $Ca^{+2}$ | DO | 7 | 0.298 | 0.487 | 16.754 |
| Alkalinity = 5.952 x $Mg^{+2}$ + 38.450 | $Mg^{+2}$ | DO | 7 | 0.611 | 2.982 | 13.890 |
| Alkalinity = -0.359 x $Na^{+1}$ + 81.512 | $Na^{+1}$ | DO | 7 | -0.078 | 0.031 | 17.497 |
| Alkalinity = -0.531x $K^{+1}$ + 74.404 | $K^{+1}$ | DO | 7 | -0.050 | 0.013 | 17.528 |

**Table 2b.** Statistical regression analysis data (Post-monsoon).

| R-Equation | I-Var. | D-Var. | n | r | F value | S.E |
|---|---|---|---|---|---|---|
| Alkalinity = 11.134 xpH-21.328 | pH | Alkalinity | 7 | 0.262 | .367 | 9.871 |
| Alkalinity = -0.153 x COD +71.379 | COD | DO | 7 | -0.418 | 1.057 | 9.292 |
| Alkalinity=-0.477 x BOD +73.664 | BOD | DO | 7 | -0.533 | 1.989 | 8.650 |
| Alkalinity = -0.067 x TSS + 76.119 | TSS | DO | 7 | -0.735 | 5.868 | 6.937 |
| Alkalinity = 0.023 x TDS +55.142 | TDS | DO | 7 | 0.531 | 1.966 | 8.664 |
| Alkalinity = -54.03xConductivity+81.4 | Conductivity | DO | 7 | -0.588 | 2.645 | 8.271 |
| Alkalinity = -0.341 x $Cl^{-1}$ + 78.395 | $Cl^{-1}$ | DO | 7 | -0.603 | 2.851 | 8.161 |
| Alkalinity = 0.25 x $HCO_3^{-1}$ + 61.024 | $HCO_3^{-1}$ | DO | 7 | 0.027 | 0.004 | 10.224 |
| Alkalinity = -0.010 x $SO_4^{-2}$ + 63.662 | $SO_4^{-2}$ | DO | 7 | -0.026 | 0.003 | 10.224 |
| Alkalinity = 0.322 x $Ca^{+2}$ + 48.880 | $Ca^{+2}$ | DO | 7 | 0.546 | 2.119 | 8.571 |
| Alkalinity= -0.192 x $Mg^{+2}$ + 66.689 | $Mg^{+2}$ | DO | 7 | -0.495 | 1.620 | 8.888 |
| Alkalinity = 0.103 x $Na^{+1}$ + 59.083 | $Na^{+1}$ | DO | 7 | 0.448 | 1.254 | 9.145 |
| Alkalinity = -0.562 x $K^{+1}$ + 67.415 | $K^{+1}$ | DO | 7 | -0.383 | 0.860 | 9.447 |

(Brion, 1973; Wetzel, 1983).

Alkalinity is important because it buffers the pH of water within the system. Without this buffering capacity, small additions of acids or bases would result in significant changes of pH, which could be deleterious for aquatic life. Alkalinity also influences the distribution of some organisms within aquatic systems. The pH range was 7.5 to 7.8 during pre-monsoon and 7.3 to 7.8 during post-monsoon. The pH of most natural waters falls in the 6 to 9 range because of the bicarbonate buffering.

In the present study, the TDS and TSS values were maximum during post-monsoon and minimum during pre-monsoon. High values of TSS during post-monsson may be due to siltation, deterioration, heavy precipitation and mixing runoff rain water which carried mud, sand, etc. Similar observations were made by Jawale and Patil (2009) and Salve and Hiware (2006).

COD is the amount of chemical oxidant required for the oxidation of the organic matter present in the waste. River Indus receives high amount of organic matter which generally originate from domestic and industrial effluents on the bank of Indus River. In the present study, the COD value vary from 41.7 to 131 during pre-monsoon and 21 to 98.3 during post-monsoon. For biodegradation, this organic waste requires oxygen, causing significant depletion of dissolved oxygen in river Indus water. The oxygen depletion not only effect biotic community of the river but also affects the purification capacity. High value of COD indicates that river received high amount of organic matter during pre monsoon. Hence the low value of alkalinity indicates that the compound responsible for decrease alkalinity is working as chemical oxidant for COD and hence significant increase in the value of COD. As regression equation, $Y = 0.477 X + 73.664$ and $Y = -0.153 X + 71.379$ was used to estimate the values of BOD and COD, respectively. It also helps to find the value of BOD/COD ratio to analyze the extent of pollution and biodegradability of water. The high value of BOD suggest that oxygen present in water is consumed by aerobic bacteria which makes fish, blind dolphins and other aquatic species to find it difficult to survive during pre monsoon.

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*Full Length Research Paper*

# Heavy metal bioaccumulation and biomarkers of oxidative stress in the wild African tiger frog, *Hoplobatrachus occipitalis*

**Idowu Emmanuel Taiwo, Amaeze Nnamdi Henry*, Adie Peter Imbufe and Otubanjo Olubunmi Adetoro**

Department of Zoology, University of Lagos, Akoka-Yaba, Lagos State, Nigeria.

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**Human activities can have dramatic effects on animal populations around urban areas with heavy metal contamination being a primary cause of harm. Amphibians, as residents of aquatic systems and with their semi-permeable skin are especially susceptible to heavy metal contamination. To better understand the effect of heavy metals on Wild African Tiger frogs (*Hoplobatrachus occipitalis)* and the resulting production of oxidative stress enzymes, the concentrations of the heavy metals, cadmium (Cd), copper (Cu), iron (Fe), zinc (Zn), lead (Pb) and nickel (Ni) were investigated in the tissues of *H. occipitalis* as well as in water and sediment samples collected from five different locations in Lagos State, Nigeria. The activities of superoxide dismutase (SOD), reduced glutathione (GSH) and level of lipid peroxidation product, malondialdehyde (MDA) were analyzed in the liver of the sampled frogs. Most measured physicochemical characteristics of the water varied significantly across the sampling locations (P<0.05). The levels of metals (mg/kg dry weight) in muscle tissues also varied significantly across the locations (P<0.05) and ranged as follows: Cd: 0.21-5.03, Cu: 0.74-13.40, Fe: 3.19-109.10, Zn: 3.70-120.20, Pb: 0.12-18.24 and Ni: 3.20-7.28. Zn was the most accumulated metal, followed by Fe, Cu and Ni, while Pb was the least. The mean of SOD and reduced GSH in the frogs indicate some responses to oxidative stress which varied significantly among sampling areas (P<0.05). MDA values however did not consistently correlate with either oxidative stress or heavy metal concentrations in the frogs. The water-sediment-tissue analysis for heavy metals demonstrated that the sediment concentrated more heavy metals than water, while the frog tissues accumulated these metals particularly in more polluted areas.**

**Key words:** Heavy metal pollution, bioaccumulation, *Hoplobatrachus occipitalis,* biomarkers, oxidative stress.

## INTRODUCTION

Heavy metal pollution is ubiquitous in our environment (Don-Pedro et al., 2004) and results from diverse activities such as industrial effluents, foundry wastes, wearing of metal parts and equipments, paints, automobiles, mining and rock weathering. These are subsequently deposited on soil surfaces and may be leached through municipal drainages to nearby ponds, streams and rivers which are common amphibian habitats and hiding places. The major concern with heavy metals lies with their acute toxicity and their ability to bioaccumulate in biological systems (Otitoloju and Don-Pedro, 2002a), resulting in a number of deleterious effects such as immunosuppression (Carey and Bryant, 1995), induction of stress proteins (Piano et al., 2004), oxidative stress (Farombi et al., 2007; Soundararajan et al., 2000) histopathologhical damage (Kothari et al., 1990; Andhale

*Corresponding author. E-mail: amaezenh@gmail.com. Tel: +2347066302345.

et al., 2011; Tarasub et al., 2011), disruption of reproductive potential and endocrine disruption (Drevnickand and Sandheinrich 2003; Kasperczyk et al., 2008) and mortality/acute toxicity (Kurdland, 1960; Otitoloju and Don-Pedro, 2002b). Metal are often in ionic forms and their ligands interact with hydrocarbons which makes them bioavailable and able to penetrate body surfaces where they readily pass through phospholipids cell membranes, causing harm due to the inability to metabolize them (Walker et al., 2001). Cooper and Manalis (1983) linked lead, cadmium and mercury with the impairment of pre-synaptic mechanisms such as acetylcholine inhibition in amphibians.

Amphibians living in the fringes of populated cities may come under pressure from a number of anthropogenic factors including pollution from heavy metals. Frogs have a wide variety of diet and live in rugged terrains such as swamps, tree, thickets (Hickman et al., 2008), as well as unkempt lawns and human habitations thus exposing them to polluting activities. A semi-permeable and highly vascularized skin allows cutenous respiration in amphibians (Noble, 1925) and therefore, may confer them with high a propensity to accumulate environmental pollutants in their tissues directly from water and moist surroundings (Willens et al., 2006). It is now commonly speculated that amphibian species may be globally on decline (Wake and Vredenburg, 2008). Their decline and loss of viable populations has been attributed to habitat destruction, introduction of invasive species, over exploitation, emerging diseases, pathogens, climate change and environmental contamination (Becker et al., 2007; Smith et al., 2009; Hayes et al., 2010). Their biology and peculiar habitat selection makes them candi-dates for heavy metal accumulation (Hayes et al., 2010; Hsu et al., 2006). A number of pollutants including heavy metals have been linked with the presence of free radicals which may induce oxidative stress in biological systems (Osuala, 2012). Certain biosynthetic mechanisms, such as induction of low molecular weight proteins exists which have been attributed to the ability to inhibit metal activity and possibly their absorption into the bloodstream of *Rana ridibunda* (Loumbourdis et al., 2007). The presence of these proteins can be a protective mechanism for managing oxidative stress and can confer tolerance to heavy metal pollution.

Some heavy metals are hepatotoxic agents causing liver disorders, largely due to their active metabolites and free radicals (Lygren et al., 1999). These activated radicals bind covalently to macromolecules and induce peroxidative degeneration of the endoplasmic reticulum (ER) lipid membrane, which is rich in polyunsaturated fatty acids resulting in cell damage (Sies, 1985). The release of lipid peroxidation products such as malondialdehyde (MDA), has been established as a useful biomarker in monitoring effects of pollutants such as polycyclic aromatic hydrocarbons, petroleum products as well as heavy metals (Otitoloju and Olagoke, 2011; King et al., 2012; Osuala, 2012). The lipid peroxidative degradation of biomembrane is one of the principal causes of heapotoxicity of heavy metals (Timbrell, 2000). Antioxidants defense system such as superoxide dismutase (SOD), glutathione-S-transferase (GST), reduced glutathione (GSH) and catalase are mobilized to reduce organism susceptibility to the damaging effects of reactive oxygen species (ROS) and free radicals that have been generated by the biodegradation of membranes and biotransformation of metallic moieties (Soundararajan et al., 2009; Sasaki et al., 1997; Azqueta et al., 2009). One of the major classes of antioxidant enzymes characterized in eukaryotic cells is SOD, a family of metalloenzymes which catalyzes the spontaneous dismutation of superoxide anion to hydrogen peroxide and molecular oxygen. SOD is widely distributed in aerobic organisms and plays an important role in the control of radical superoxide levels in the cellular compartments (Sasaki et al., 1997). Glutathione is believed to be the most important protective mechanism, occurring in most cells, especially the liver (Timbrell, 2000). This mechanism detoxify substances by conjugation with GST, conjugation with reactive metabolites or donation of proton or hydrogen atom to free radicals to bring about reduction and hence stop the damaging process of oxidative stress (Otitoloju and Olagoke, 2011). These enzymes are often employed in combinations as biomarkers of stress from free radicals in disturbed and polluted environments (Regoli et al., 2002).

In furtherance of understanding the effects of human activities on animal populations around urban areas, this study seeks to assess the levels of some heavy metals in waters and sediments and their accumulation in the tissues of *Hoplobatrachus occipitalis* within the Lagos metropolis and to determine levels of oxidative stress enzymes with the goal to evaluate their suitability in monitoring the presence of stressors in the urban environment.

## MATERIALS AND METHODS

### Study design

Five Local Government/Local Council Development Areas (LGA/LCDAs): Amuwo-odofin, Ojo, Ikorodu, Badagry and Yaba (Figure 1), spanning the breadth of Lagos State, the commercial capital of Nigeria were selected as sampling locations for this study on a semi-random basis to cover areas of high and low commercial activities and population densities. African Tiger frog (*H. occipitalis*) were sampled once between March and July 2010, a period spanning between late dry season and mid rainy reason depending on accessibility of the area and availability of the frogs, and five individuals were trapped in each occasion for toxicological evaluation.

### Classification of the study sites

The dominant anthropogenic activities observed in the five Local Government Areas are as follows:

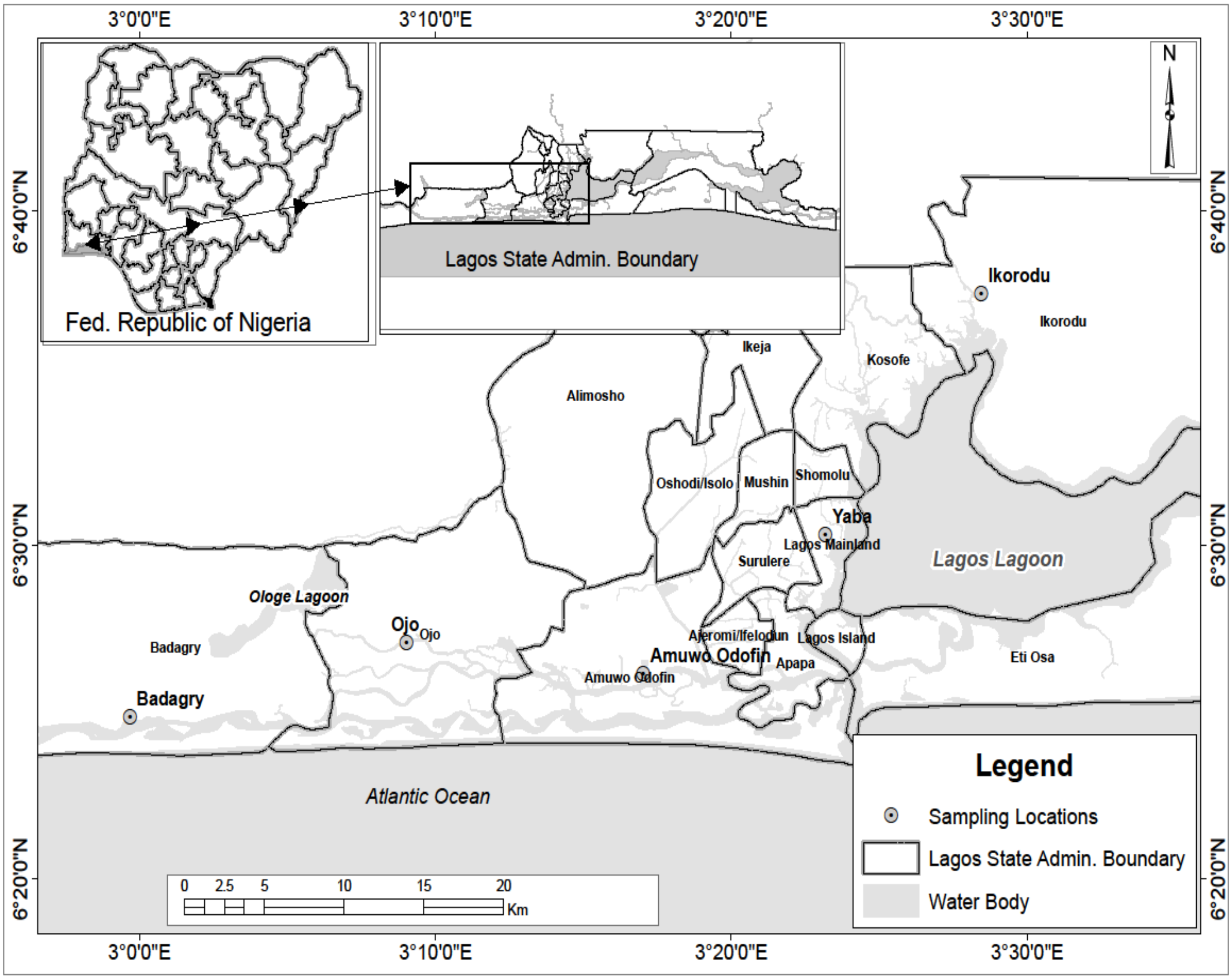


**Figure 1.** Map of sampling locations in Lagos, Nigeria.

Amuwo-Odofin: High population density, high vehicular traffic and large markets. Badagry- Low population density, low level of industrial activities and small markets. Ikorodu- Sub-urban/Rural with moderate population density, low industrial activities, moderate vehicular traffic and medium sized markets.Ojo- High population density, large electronics market, high vehicular traffic, numerous auto-mechanic workshops and open burning of worn-out electronics. Yaba- Highly urbanized, high population density, high vehicular traffic and numerous auto-mechanic workshops.

Efforts were made to select permanent or semi permanent ponds which are far from areas of reach of automobile tires and pedestrians. The ponds were often close to thickets and generally shallow (less than 50 cm).

### Sampling technique

Soil and water were obtained once within the study period from sediment and ponds in each sampling sites, in triplicates and mixed together for each location so as to portray the average conditions in the respective areas. Soil samples were collected using a 10 kg auger in an area of 10 $m^2$ radius while water samples were scooped using new 1 L plastic cans which have been previously unused. Both samples were kept in flasks lagged with ice packs until transferred to the laboratory where they were stored at 4°C prior to analysis.

*H. occipitalis* from each sampling location were caught using sweep nets and transferred to properly aerated cages made from wire gauze, with floors lined with leaves. The frogs were treated humanely according to local ethical standards (University of Lagos) and dissection was carried out in the laboratory to collect liver and muscles for analysis after immobilizing them with cotton wool soaked in chloroform.

### Determination of physico-chemical characteristics of sediment and water

Physico-chemical characteristics of the water and sediment samples were determined *ex situ* in the laboratory at least 48 h after sampling. The pH, electrical conductivity (EC), total dissolved solid (TDS) and dissolved oxygen (DO) were measured with a

Metler Toledo (Model In lab 730), and a Jenway 9720 $DO_2$. Turbidity was determined *ex situ* using HACH DR 2000 direct spectrophotometer method 8237 and then estimated against deionized water as blank at 450 nm. Colour, total suspended solids (TSS), nitrate ($NO_3$-N), phosphate ($PO_4^{3-}$ -P) and sulphate ($SO_4^{2}$) were determined using HACH DR 2000 spectrophotometer. Acidity, alkalinity, chloride ion ($Cl^-$) and biological oxygen demand (BOD) were analyzed volumetrically according to the method described by APHA-AWWA-WEF (2005).

Water samples were incubated in the dark for 5 days at 20°C in BOD bottles so as to determine the BOD in mg/l.

Chemical oxygen demand (COD) was also analyzed *ex situ* by Winkler's titrimetry method (APHA-AWWA-WEF, 2005). Briefly, 5 ml of water samples were measured in a test tube and then followed by addition of 1 ml mercury sulphate, 5 ml $H_2SO_4$ and then 25 ml of $KMnO_4$. The solution was titrated against aqueous ammonium sulphate after being refluxed for 2 h and allowed to cool. Ferroin, an iron complex was used as an indicator of the end point.

#### Determination of heavy metal levels in sediment, water and tissues

Metal levels were evaluated in sediment, water and tissues using techniques employed by Don-Pedro et al. (2004). Fleshy portions of the muscles of frogs were oven dried at 70°C for 1 h and ground to powder in ceramic mortars and 5 g of each sample were made into paste by adding double distilled water. This was followed by digestion using 10 ml of 1 M $HNO_3$ and mild heat until brown fumes appeared. The samples were cooled off, made up to 50 ml in a standard volumetric flask which have been subjected to acid wash to remove any trace of residual metals and then filtered prior to analysis.

Water samples were also digested and prepared using 1 M $HNO_3$ after being evaporated in a heated sand bath (70-80°C) according to the method of APHA-AWWA-WEF (2005). Sediment samples were sieved using a 200 µm sieve and the uniform particles were then digested using established technique (Agemian and Chau, 1976). All three samples were each subjected to Atomic Absorption Spectrophotometer (AAS) using Perkin Elmer series AAS to determine levels of selected heavy metals against known standards of mixed heavy metal elements (SIGMA Aldrich) by comparing absorbance. The samples were run twice and mean was recorded as the concentration of heavy metals in mg/kg in the respective tissue, water and sediment.

#### Determination of heavy metal accumulation

The biota to soil accumulation factor (BSAF) and bio-concentration factor (BCF) were determined as ratio of heavy metals in the bullfrogs to that in the soil and water samples as follows:

$$\boldsymbol{BSAF} = \frac{\textit{Concentration of heavy metal in animal tissue}}{\textit{Concentration of heavy metal in soil sample}}$$

$$\boldsymbol{BCF} = \frac{\textit{Concentration of heavy metal in animal tissue}}{\textit{Concentration of heavy metal in water sample}}$$

#### Measurement of oxidative stress markers

Following dissection, liver samples were stored in the freezer at -20°C prior to biochemical analysis within 48 h. Measurement of oxidative stress markers were based on established methodologies. Superoxide dismutase was determined as described by Sun and Zigma (1978). Reduced glutathione (GSH) was determined according to Sedlak and Lindsay (1968) and lipid peroxidation based on the method of Buege and Aust (1978). The Biuret method was used in determining the total protein levels in liver samples (Gonall et al., 1949).

#### Data analysis

The obtained data for physicochemical properties of water samples and heavy metal concentrations were analyzed using one way analysis of variance (ANOVA) performed with GraphPad Prism 5 software (GraphPad Prism software Inc. La Jolla, CA, USA)®. Significantly different results were established at $P<0.05$.

## RESULTS

### Physico-chemical characteristics of water samples

The results of the physico-chemical assessment of water samples from all the study locations indicates that conditions differ widely between sites, thus reflecting the ecological diversity and differences in anthropogenic pressure in different parts of the City. The physico-chemical characteristics of the sampling ponds are presented with detail in Table 1. The yellowish colouration of the water was due to the muddy and shallow nature of the ponds which are typical of anuran habitats in this area. Turbidity ranged from 0.25 FTU at Ikorodu to 5.0 FTU at Amuwo. Conductivity, TSS and TDS were highest in the ponds around highly urbanized areas such as Amuwo-Odofin, Ojo and Yaba where human activities tend to be high and ponds are located close to human dwellings, markets and industrial sites. This trend was also reflected in the high acidity, COD, sulphate and low pH recorded in most areas particularly around the industrial town of Amuwo. The pond water pH was generally low across the stations, with Amuwo-Odofin and Ojo having particularly low vales of 4.10 and 4.20 respectively while the highest value of 6.10 was recorded at Badagry. This was also expressed in the high level of total acidity across all sampling locations. TSS was above the Nigerian Federal Environmental Protection Agency (FEPA) acceptable limit of 30 mg/l at the three most polluted sites (Amuwo-Odofin, Ojo and Yaba). Ojo and Yaba had the highest nitrate levels: 4.80 and 5.90 mg/l, respectively. Phosphate levels remained <1 mg/L across sampling locations with less urbanized locations of Badagry and Ikorodu having the least values. Incidentally these sites also had high BOD, values which are higher than the FEPA limit of 50 mg/L.

The nitrate levels, however, fell within the national approved limit for water. Measured total alkalinity of the surface water was >20 mg/L in most stations except at Yaba. Dissolved oxygen level was generally low and remained at the <5 mg/L set limit in most cases. Except for DO and BOD, all physiochemical characteristics of the water in the frog habitats, varied significantly ($P<0.05$).

**Table 1.** Levels of some physical-chemical parameters in water from five Local Government Areas of Lagos State (values are mixed triplicates of water samples collected once).

| Parameter | Study location | | | | | FEPA limit |
|---|---|---|---|---|---|---|
| | Amowu-Odofin | Ojo | Yaba | Badagry | Ikorodu | |
| Colour | Yellow | Yellow | Yellow | Yellow | Yellow | NS |
| Turbidity (FTU) | 5.0 | 4.0 | 4.96 | 4.34 | 0.25 | 10 |
| Conductivity (µS/cm) | 1560 | 1780 | 1476 | 225 | 196 | NS |
| Total suspended solid (mg/l) | 110 | 100 | 120 | 85 | 3 | 30 |
| Total dissolved solids (mg/l) | 746 | 570 | 640 | 125 | 96 | 200 |
| pH | 4.1 | 4.2 | 6.8 | 6.1 | 6.6 | 6.0-9.0 |
| Total acidity (mg/l) | 56 | 26 | 38 | 54 | 20 | NS |
| Total alkalinity (mg/l) | 24 | 30 | 16 | 24 | 36 | 20 |
| Chloride (mg/l) | 544 | 610 | 512 | 198 | 44 | NS |
| Nitrate (mg/l) | 2.6 | 4.8 | 5.9 | 3.7 | 2.4 | 10 |
| Phosphate (mg/l) | 0.16 | 0.45 | 0.15 | 0.53 | 0.91 | 5.0 |
| Dissolved oxygen (DO) (mg/l) | 20.0 | 4.0 | 4.2 | 4.2 | 4.0 | 5.0 |
| Biological oxygen demand (BOD) (mg/l) | 86.0 | 76.0 | 80.0 | 36.0 | 15.0 | 50 |
| Chemical oxygen demand (COD) | 172.0 | 184.0 | 96.0 | 135.0 | 32.0 | NS |
| Sulphate (mg/l) | 198.0 | 240.0 | 113.0 | 150.0 | 0.3 | NS |

NS = Not stated; FEPA = Federal Environmental Protection Agency.

### Heavy metal concentrations and bioaccumulation in the tissues of *H. occipitalis*

Heavy metals were ubiquitous, occurring at varying concentrations across the study sites (Table 2). Cadmium (Cd) was detected in the soil, water and sediment at two of the sampling locations (Ojo and Badagry), which lie closest where electronic are sold and worn out parts are dumped openly. The concentration of Cd in the sediment samples from the different sites differed significantly (P<0.05), having a highest concentration of 0.60 mg/kg around the Ojo electronics market; as well as biota to soil accumulation factor (BSAF) of 0.35. Copper (Cu), iron (Fe) zinc (Zn) and nickel (Ni) were detected in the water, sediment and frogs in all the five sample locations. Cu was highest in water at Ojo and lowest at Amuwo-Odofin, while in the sediment it was highest at Ikorodu and lowest at Badagry. The sediment concentrations of Cu, unlike in water and tissue samples was significantly varied (P<0.05) between sampling sites across the Lagos metropolis. Bio-concentration factor (BCF) of Cu was highest at Amuwo-Odofin (236.67) while the highest BSAF of 12 was obtained in the tissues of *H. occipitalis* at Badagry. Fe concentration in water, sediment and tissue also varied significantly (P<0.05) between sampling sites. It was highest in sediments from Amuwo-Odofin and lowest at Yaba, while in the water samples, Fe was highest at Badagry and least at Ikorodu, with BCF of 19.38 at Yaba as the highest and 4.11 at Ikorodu as the lowest.

Zn levels in water did not vary significantly (P>0.05) between sampling sites and overall, it was highest in water samples at Amuwo-Odofin and lowest at Ikorodu, while in the sediment, it was highest at Yaba and least at Badagry. The sediment and tissue concentrations of Zn however, were significantly different (P<0.05) among the sampling sites. High BCF of 121.04 and 149.42 were recorded at Ojo and Yaba, respectively for this heavy metal. BASF with respect to Zn was highest at Badagry (171.49) and lowest at Ikorodu (0.55). Lead (Pb) was heavy metal with the lowest concentration recorded in water, sediment and muscles of *H. occipitalis* and values were not significantly different across sampling sites. It was not detected in all three components at Badagry while at Amuwo-Odofin it was only detected in the muscle tissues at a concentration of 0.27 mg/kg. Overall, Ni recorded the highest level of BCF as compared to the other metals with a value of 514 at Ikorodu. Also, its concentrations in sediments and the frog tissues was significantly different across sampling sites.

### Assessment of oxidative stress

*H. occipitalis* were found to express significantly different (P<0.05) anti-oxidative stress enzyme activities and lipid peroxidation and across sites (Table 3). Reduced glutathione was induced highest in *H. occipitalis* collected at Amuwo (145.60 ± 50.38 units), while it was lowest at the sub-urban/rural town of Ikorodu (27.43 ± 4.02 units). GSH levels interestingly exhibited strong positive correlation with concentrations of Cu, Fe and Zn in the *H.*

**Table 2.** Water (n=3), sediments (n=3) and *H. occipitalis* muscle tissue (n=5) heavy metal concentrations (mg/kg), biota to soil accumulation factor (BSAF) and bio-concentration factor (BCF) in sites of Lagos State.

| Sampling location | Heavy metals | | | | | |
|---|---|---|---|---|---|---|
| | Cd | Cu | Fe | Zn | Pb | Ni |
| **Amuwo-Odofin** | | | | | | |
| Water | ND | 0.03[a] | 5.88[a] | 6.67[a] | ND | 0.03[a] |
| Sediment | 0.61[a] | 0.98[a] | 42.03[a] | 15.21[a] | ND | 1.09[a] |
| Tissue | 0.61±0.01[a] | 7.10±0.11[a] | 109.10±3.68[a] | 120.20±1.49[a] | 0.27±0.03[a] | 3.26±0.09[a] |
| BSAF | 1.00 | 7.24 | 2.60 | 7.90 | * | 2.99 |
| BCF | * | 236.7 | 18.6 | 18.0 | * | 125.4 |
| **Ojo** | | | | | | |
| Water | 0.01[a] | 3.03[a] | 4.47[b] | 0.96[a] | 0.06[a] | 0.34[a] |
| Sediment | 0.60[b] | 1.06[b] | 31.40[b] | 12.68[b] | 0.08[a] | 1.22[b] |
| Tissue | 0.21±0.11[a] | 5.33±0.17[a] | 48.67±0.36[b] | 116.20±2.12[b] | 0.12±0.02[a] | 3.58±0.01[b] |
| BSAF | 0.35 | 5.03 | 1.55 | 9.16 | 1.5 | 2.93 |
| BCF | 21 | 1.76 | 10.9 | 121.0 | 2.0 | 10.5 |
| **Yaba** | | | | | | |
| Water | ND | 1.08[a] | 5.80[c] | 0.86[a] | 0.83[a] | 0.47[a] |
| Sediment | 0.14[c] | 1.19[c] | 7.33[c] | 20.46[c] | 8.35[a] | 0.98[c] |
| Tissue | ND | 13.40±0.19[a] | 112.40±2.03[c] | 128.50±1.69[c] | 18.24±0.89[a] | 7.28±0.37[c] |
| BSAF | * | 11.26 | 15.33 | 6.28 | 2.18 | 8.14 |
| BCF | * | 12.4 | 19.38 | 149.4 | 22.0 | 15.5 |
| **Badagry** | | | | | | |
| Water | 0.23[a] | 0.44[a] | 6.08[d] | 2.72[a] | ND | 0.94[a] |
| Sediment | 0.42[d] | 0.07[d] | 8.33[d] | 0.67[d] | ND | 0.01[d] |
| Tissue | 5.03±0.14[a] | 0.84±0.02[a] | 50.70±0.43[d] | 114.90±0.78[d] | ND | 3.20±0.15[d] |
| BSAF | 11.98 | 12 | 6.09 | 171.49 | * | 320 |
| BCF | 21.9 | 1.9 | 8.3 | 42.2 | * | 3.4 |
| **Ikorodu** | | | | | | |
| Water | ND | 0.08[a] | 0.26[e] | 0.22[a] | 0.20[a] | 0.01[a] |
| Sediment | 0.26[e] | 1.34[e] | 13.14[e] | 6.77[e] | ND | 0.79[e] |
| Tissue | ND | 0.74±0.02[a] | 3.19±0.11[e] | 3.70±0.07[e] | 4.90±0.17[a] | 5.14±0.16[e] |
| BSAF | * | 0.55 | 0.24 | 0.55 | * | 6.51 |
| BCF | * | 9.3 | 4.11 | 16.8 | 24.5 | 514.0 |

ND = Not detected; * = Data not available; dissimilar alphabets (a, b, c, d, e) implies significant differences per metal.

**Table 3.** Antioxidant enzyme activity in liver tissues of African tiger frogs *(H. occipitalis)* collected from five local government areas of Lagos State (mean ± SD; n= 5).

| Biomarker | Sampling location (LGAs) | | | | | |
|---|---|---|---|---|---|---|
| | Amwuo-Odofin | Ojo | Yaba | Badagry | Ikorodu | F Cal |
| MDA (units) | 3.31 ± 1.62 | 5.60 ± 3.65 | 4.21 ± 4.22 | 8.60 ± 2.69 | 5.87 ± 2.44 | [b]4.32 |
| GSH (Units) | 145.60 ± 50.38 | 126.80 ± 16.70 | 121.50 ± 44.93 | 68.38 ± 8.65 | 27.43 ± 4.02 | [c]24.11 |
| SOD (U/mg pro) | 1.09 ± 0.82 | 1.86 ± 2.21 | 1.18 ± 0.33 | 1.25 ± 0.71 | 2.59 ± 0.98 | [a]2.85 |
| Protein (mg) | 77.43 ± 7.21 | 68.68 ± 32.79 | 90.38 ± 14.45 | 113.30 ± 9.19 | 34.38 ± 7.42 | [c]28.64 |

The letters a, b, c represent how significantly different each parameter is across the different locations.

*occipitalis* muscle tissues. There was however a negative correlation (r = -0.5721) with tissue Ni levels and a weakly positive (r = 0.3458) with Cd. With respect to SOD induction, the reverse was the case because the lowest value (1.09 ± 0.82 µ/mg protein) was obtained at Amuwo-Odofin, while the highest (2.59 ± 0.98 µ/mg protein) was detected in those from Ikorodu, indicating that those obtained at Amuwo-Odofin were under a much more intense oxidative stress. The SOD levels showed strong negative correlation with Cu (r =-0.5477), Fe (r =-0.8809) and Zn (r =-0.6993) across sampling sites but Cd and Ni showed weak negative correlation. Lipid peroxidation as expressed by the malondialdehyde levels (MDA) was inconsistent among the frogs across all sampling locations. It also showed negative correlation with metals in tissues of frogs from the various sites except for Ni which was strongly positively correlated (r = 0.9155) with the lipid peroxiidation product.

## DISCUSSION

The findings in this study points to widespread pollution which varies significantly depending on the predominant activities in the area and hence unsustainable utilization of the environment. Amphibians are physiologically sensitive animals, inhabiting some of the harshest and unpredictable habitats (Hickman et al., 2008) and hence are already living under adaptation stress. In the present study, the physico-chemistry of waters, levels of heavy metals and certain biomarkers of oxidative stress as surrogate bioindicators of aquatic pollution in *H. occipitalis* were evaluated.

Measured levels of physical and chemical characteristics of water bodies show clearly a large disparity between sampling locations. Nitrate and TDS levels in all sites remained lower than the Nigerian National set limit of the Federal Environmental Protection Agency (FEPA, 1991). Whereas high BOD and COD levels were recorded particularly in areas associated with high anthropogenic activities, such Amuwo, Ojo and Yaba LGA/LCDA. These high readings of chemical and biological oxygen demand were corroborated by the generally high sulphate, phosphate, suspended solids and most of the heavy metals assessed. Saliu and Ekpo (2006) have earlier reported high level of phosphate and nitrate levels in Ogbe creek which receives high input of sewage and other organic wastes in Lagos. Population density is often associated with high level of waste generation and hence pollution (Ajao et al., 1996). Areas around Ikorodu Local Government which is characterized by relatively moderated population density and low level of industrial activities either recorded the lowest values or generally low values of pollution indicating parameters. Low pH values indicative of high acidity were recorded in all sites with levels below 5.0 at Amowu-Odofin and Ojo, which are associated with high level of commercial and industrial activities. According to Freda (1986), acidity of ponds has been linked with reproductive effects in amphibians by causing direct mortality of embryo and larvae which are the most sensitive stages of their development.

Domestic sewage, combustion, emissions, mining operations, metallurgical activities and industrial effluents, all sources of anthropogenic metal inputs into the environment are prevalent in the sampling areas particularly at Amuwo-Odofin, Ojo and Yaba, and according to Chinni and Yallapragda (2000) most of metallic inputs into the environment exhibit some form of toxicity. Badagry and Ikorodu are less inhabited and disturbed, although they are the new choice areas for urban sprawl and unplanned human settlements. The levels of Pb were significantly higher in Yaba than in other locations, probably due to the high daily automobile traffic density and the preponderance of road side mechanic workshops from where Pb leaches into the environment. High sediment Cd and Ni levels recorded at Ojo could be linked to leachates from electronic and battery waste dumps which are common in the area.

The non-biodegradability of these metals makes them persistent and increases their environmental health impacts. The recent Pb poisoning in Gold mining communities in Zamfara State, North-Western Nigeria which lead to the death of hundreds of children and domestic animals upon chronic exposure in soil and water (WHO, 2010) raises important concern regarding the extent of potential harm possible from unregulated commercial practices prevalent in the country. Cd accumulates in the liver and kidney, leading to massive proteinuria as a result of breakdown of kidney cells when the metal levels exceed critical concentrations (Walker et al., 2001). The toxicity of cadmium, like few other metals lies in its high bioaccumulative tendency (Hopkins, 1989).

Generally, sediments accumulated more heavy metals than the water and these confirms earlier observations by Don-Pedro et al. (2004) in the Lagos lagoon. Given the static nature of sediments, they tend to accumulate more toxicant than water which may flow away, drain off or even evaporate. Iron and zinc were higher in both water and sediments samples when compared with other heavy metals in most sampling areas.

The high content of Fe and Zn in the sediment may be due to clayey material that forms the soil structure in the area sampled. Don-Pedro et al. (2004) also reported high Fe and Zn concentrations in the sediments of the Lagos lagoon. The high concentration of metals in sediment may also be attributed to human activities such as wastes from automobiles and generator fumes, burning of fossil fuel, discharge of untreated sewage and industrial effluents containing metals into water bodies, as well as the natural ability of the sediment to act as sink (Kakulu and Osibanjo, 1988). This is in consonance with Odiete (1999), who concluded that sediment is the major depository of metals, in some cases, holding more than 99% of the total amount of a metal present in the aquatic system.

The muscle burdens of Fe and Zn in *H. occipitalis* were significantly higher than those of other metals in all sites except for Ikorodu. The reason for this may be traced to dietary intake since frogs feed on herbivorous insects that may have accumulated these metals from aquatic plants which constantly absorb these metals from the soil Nummelin et al. (2007), as well as through direct uptake from contaminated water and sediments. The concentration of Pb was generally low, but in Yaba, it was significantly higher in tissues than the environment and as indicated by BCF, this could be as a result of high level of bioaccumulation directly from the environment from atmospheric depositions given the high vehicular traffic in this area. This is in line with the findings of Charles et al. (1986) who reported low bioaccumulation of Pb in bullfrog (*Rana catesbeian*) and green frog (*Rana clamitans*) tadpoles inhabiting highway drainages. High accumulation of Zn in the tissue of frog could be based on specific adaptive mechanism to absorb Zn from the environment for onward transfer to the kidney where it is needed for metabolic process and co-enzyme catalyzed reactions (Jaffar and Pervaiz, 1989). Zinc also acts as a catalyst in metal biomolecules and sulphur ligands to form tetrahedral zinc metalloproteins.

Zinc (BSAF) was also highest in almost all sampling areas and this may also be linked with the natural tendencies of biota to take up Zn, for being an essential metal. However, it must be noted that the levels of metals detected in most sampling stations were significantly higher than the Nigerian national set limits (FEPA, 1991), thus threshold of tolerance may often be exceeded leading to oxidative stress and physiological imbalance, deformities and mortality. Wall (1999) had earlier published a thesis that confirmed the ability of heavy metals to induce abnormalities such as teratogenicity in the northern leopard frogs (*Rana pipens*) obtained from creeks and marsh lands in Vermont, USA.

MDA production did not follow a uniform pattern and was not consistent with metal levels in the different areas studied and this may be due to some other extraneous factors not captured within this study. Membrane damage and repair occur simultaneously in different cells leading to the formation of unsaturated fatty acids and the production of the lipid peroxidation product, MDA (Timbrell, 2000).

The simultaneous process of damage and repair could have accounted for the irregular levels of MDA detected in the sampled frogs irrespective of location. This contradicts the findings of King et al. (2012) who reported a consistent increase in the lipid pero-xidation product in catfishes, *Clarias gariepinus* exposed to sub lethal concentrations of petroleum products and crude oil. However, the definite trend of responses in the case of King et al. (2012) could be due to the stable conditions that a laboratory environment confers as compared to what is obtainable in field studies like this present one.

Hence, MDA did not appear to be suitable for use as biomarker of heavy metal pollution stress against *H. occipitalis* in non laboratory conditions. Frogs captured at Ikorodu area with the lowest levels of heavy metals, had the highest level of SOD activity. This may imply causal factors other than heavy metal pollution. SOD levels in this study appeared to be lower in frogs from areas with higher metal pollution, showing a somewhat inverse relationship. This was corroborated by the consistent negative correlation reported between the heavy metals accumulated in the frog tissues and SOD activities. This was however in contradiction with reduced glutathione (GSH) values estimated, because higher levels of GSH activity were detected in frogs from the most polluted areas, that is, Ojo, Yaba and Amuwo-Odofin. Interaction of toxic heavy metals with GSH metabolism is an essential part of the toxic response of many metals (Hultberg et al., 2001).

When GSH is depleted by metal, its synthesizing systems start generating more GSH form cysteine via r-glutamyl cycle. If GSH depletion continues because of chronic metal exposure, several enzymes in antioxidant defense systems may protect this imbalance (Hultberg et al., 2001; Stohs and Bagchi, 1995). This investigation revealed that the level of Pb in Yaba was highest and this corresponds with high level of GSH activity in frogs from this location. This is probably due to the fact that GSH received a boost by antioxidant enzymes and self re-synthesis after depletion as observed by King et al. (2012) and Hultberg et al. (2001). The apparent GSH activity in liver samples also suggests an adaptive and protective role of this biomolecule against oxidative stress induced by prevailing environmental stressors including heavy metals. The results are in agreement with the findings of Stohs and Bagchi, (1995) on fish from Painpat River in India.

## Conclusion

This study has revealed that there is widespread heavy metal pollution in Lagos State emanating from diverse sources. The bioaccumulative potentials of measured heavy metals in *H. occipitalis* obtained around Lagos metropolis raises salient pollution management questions. The fact that oxidative stress markers (GSH and SOD) correlated with heavy metal accumulation in some locations makes a case for their use in monitoring environmental pollution. The findings also raise concerns regarding the effectiveness of lipid peroxidation product MDA as an effective biomarker of oxidative stress resulting to environmental pollution in anurans in the wild.

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*Full Length Research Paper*

# Geophysical study of saline water intrusion in Lagos municipality

**OLADAPO, Michael Ilesanmi[1], ILORI, Olugbenga Bashiru[2] and ADEOYE-OLADAPO, Oluwakemi Olanike[3]**

[1]Department of Applied Geophysics, Federal University of Technology, Akure, Ondo State, Nigeria.
[2]Lagos State Water Corporation, Lagos, Lagos State, Nigeria.
[3]Department of Physics, Adeyemi College of Education, Ondo, Ondo State, Nigeria.

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**Saline water intrusion presently constitutes serious concerns in the Lagos municipality just like many other coastal cities, thus necessitating its intervallic study. The present study involving 52 borehole logs (consisting of natural gamma and electrical resistivity components) was aimed at delineating intruded and vulnerable zones. Saline water columns defined by low resistivity values in the range of 0.1 and 20 Ωm as compared to fresh water (≥ 100 Ωm) were delineated on 22 logs. Four of the geo-sections generated in this study indicate saline water intrusion at depths varying from surface in Satellite Town, Kirikiri, Ijora, Iganmu, Apapa, Lagos Island, Ikoyi, Victoria Island and Lekki to depths ranging from 40 m at Iganmu to 158 m at Lekki. Intrusions of 47 m (143 - 190 m) and 60 m (56 - 116 m) were delineated at Ajah; 50 m (265 - 315 and 258 - 308) at Lakowe; 57 and 112 m (51 - 108 m and 198 - 308) at Ibeju Lekki, Akodo and 122 m at (233 - 355m) at Awoyaya. The hydrogeologic importance of the Coastal Plain Sand aquifer unit in Lagos is under severe threat of continued sea water intrusion on its southern flank. This study illustrates the current extension of the sea water intrusion. It highlights the depreciation of the water resource due to over pumping at higher rate than the natural recharge and slow sea level rise.**

**Key words:** Borehole logs, saline water intrusion/incursion, natural gamma, resistivity, freshwater sand.

## INTRODUCTION

Seawater intrusion is an inevitable problem of coastal fresh water aquifer associated with urban area (Hwang et al., 2004). Coastal aquifers constitute a vital source of fresh water in these regions, and are increasingly used to meet the water supply needs (Pareek et al., 2006). There is vital need to monitor the feasible risk of saline water intrusion of the coastal aquifers because, once saline intrusion into coastal aquifer has occurred, it is extremely difficult to overcome and improve the management of the water resources based on long term strategy. Less than 2% of seawater intrusion in the fresh water can diminish the water's potability (Custodio, 1987). Frequently, bore-holes have to be abandoned and other water sources sought, often at high cost. The challenge of saline water contamination in coastal aquifers is driven by a violation of the delicate hydrogeological balance that exists between freshwater and seawater in coastal aquifers (Goldman and Kafri, 2004) due to large-scale ground-water abstraction occasioned by rapid urbanization (Pareek et al., 2006).

Due to the proximity of Lagos to the Atlantic Ocean (Figure 1), the general population is faced with problems of freshwater abstraction from the subsurface. It is becoming harder for groundwater developers to construct

*Corresponding author. E-mail: oladapom@yahoo.co.uk.

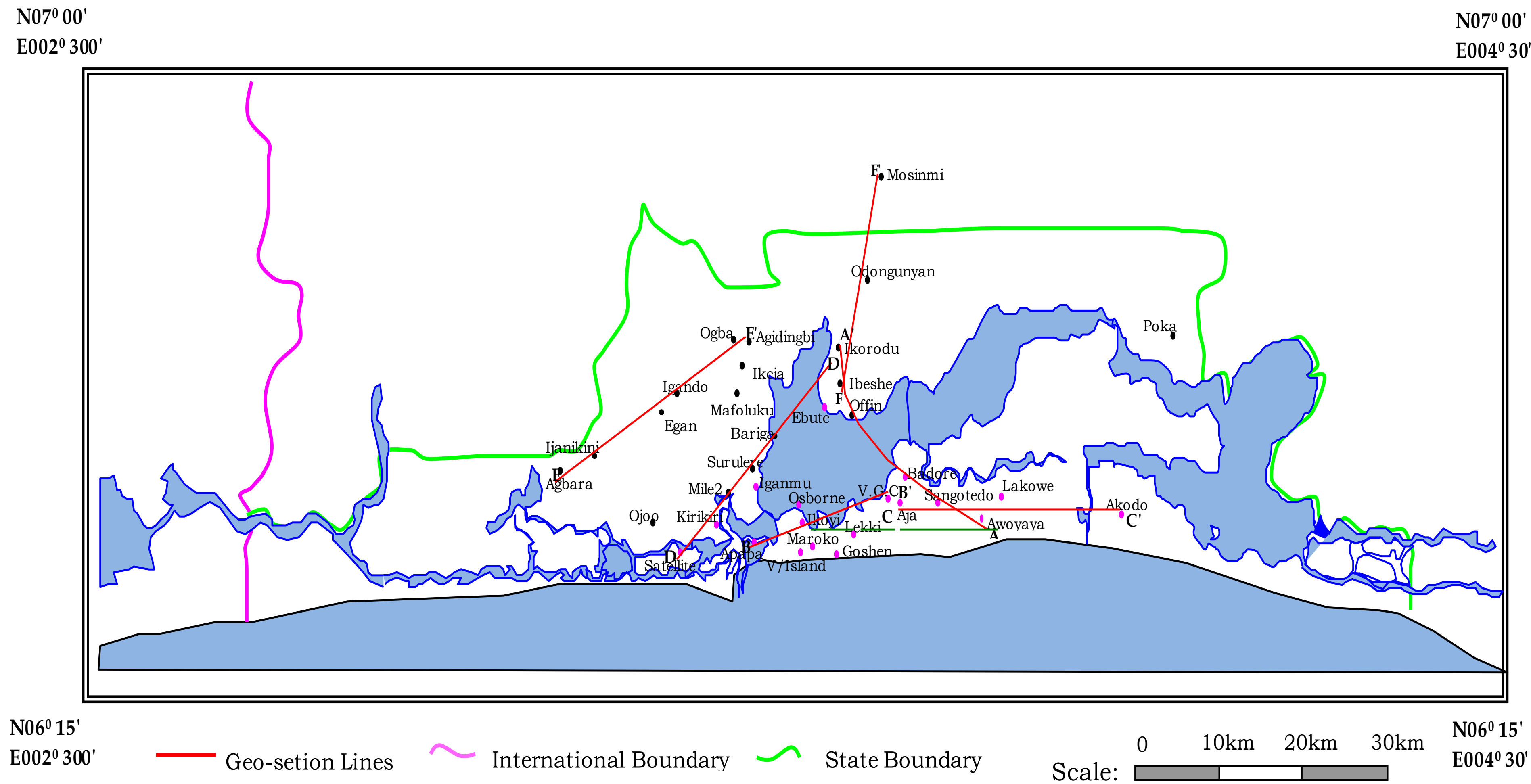


**Figure 1.** Map of Lagos State showing location of boreholes utilized for study and geo-section lines.

boreholes in areas adjoining the sea without encountering salt water. Some localities deemed to be very problematic within Lagos metropolis have been previously investigated using the electrical resistivity method (Ayolabi et al., 2003; Adepelumi et al., 2008).

Saline water intrusions vary in character and thickness. Accordingly, identification, distribution and nature of the intrusion can be used to identify areas where aquifer(s) may be more vulnerable to contamination to mitigate the degradation of the resources. The approximate thickness of the intrusion can be used to identify potentially sensitive areas.

The large resistivity contrast between salt water-saturated formation and the fresh water-saturated formation has been used for studying the salt water intrusion in coastal areas (Bates and Robinson, 2000; Hwang et al,, 2004). Fitterman et al. (1999), Nowroozi et al. (1999) and Paillet et al. (1999) have reported the applicability of geophysical well logging and surface geophysical surveys for the evaluation of the seawater intrusion characteristics. Numerous measurements and studies have established correlation between resistivity values and groundwater salinities (Zarroca et al., 2011). In overall majority of cases, the portions of aquifers saturated with seawater present resistivity values that are generally below 3 Ωm (Goldman and Kafri, 2004). Portions saturated with brackish water exhibit resistivity values between 3 and 10 Ωm (Yechieli et al., 2001; Repsold, 1989).

This study is aimed at identifying the lithological units, saline water and fresh water horizons of the aquifer and thus enabling the determination of the interface between the saline water and freshwater aquifer sands. The hydrogeological setting of the coastal areas of Lagos as may be observed from this study will reveal information on the geological stratigraphy and the fresh water extension so that fresh groundwater aquifer can be effectively protected for future use.

### Description of the geology, hydrogeology and geomorphology of Lagos

Lagos is underlain by the Benin Basin (Figure 2). The rocks of the Benin Basin are mainly sands and shales with some limestone which thicken towards the west and the coast as well as down dips to the coast (Oteri and Atolagbe, 2003). The stratigraphic description of sediments in the basin has been provided by various authors (Elueze and Nton, 2004; Nton, 2001; Okosun, 1990; Omatsola and Adegoke, 1981; Ako et al., 1980). Five lithostratigraphic formations covering the cretaceous to Tertiary ages have been described. The formations from the oldest to the youngest include: Abeokuta Group (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Late Paleocene - Early Eocene), Oshosun Formation (Eocene) and Ilaro Formation (Eocene). The Abeokuta Group present an unconformity with the basement complex.

The Abeokuta Formation constitutes a deep aquifer only in the northern parts of Lagos city (Ikeja area) where boreholes to the aquifer are about 750 m deep. The Ilaro and Ewekoro Formations are not key aquifers in Lagos as they are predominantly composed of shale/clay. The only source of hydraulic information on the Ilaro formation was obtained at Lakowe where no fresh water horizon was intercepted. It has not been possible to differentiate the Ewekoro as a target aquifer in any boreholes or existing wells in the metropolis. The formation apparently represents a minor groundwater resource in Lagos.

The Coastal Plains Sands is the main aquifer in Lagos that is exploited through hand-dug wells and boreholes. It forms a multi-aquifer system consisting of three aquifer horizons separated by silty or clayey layers (Longe et al., 1987; Kampsax and Sshwed, 1977). The aquifer thickens from its outcrop area in the north of the city to the coast in the south and the sand percentage in the formation also changes from north to south (Longe et al., 1987).

### MATERIALS AND METHODS

Fifty-two (52) borehole logs were used for the study. The logs consist of natural gamma ray, single point resistance, short and long normal resistivity (Figure 3). The log analysis involved the identification of lithology, fluid content, saline water zones, establishing of saline water horizon thickness and delineating of freshwater aquifer.

Resistivity is measured by means of the introduction of a known voltage through a probe consisting of R16, R32 and R64 units in a water filled hole. The natural gamma radiation of the logged rock encountered in the hole is also measured with the same sonde but with a different probe. The natural gamma content and the resistivity values are measured with ELGG™ sonde. The logging tool utilized is the RG PC Logger II™ (Plate 1) with PCL II™ software. The natural gamma ray log component is interpreted qualitatively to describe the lithological sequence of the borehole formation while the resistivity component is interpreted to describe the water quality (Figure 4).

Coode et al. (1996) has correlated the natural gamma ray log obtained from different borehole locations in Lagos and their work forms the basis on which different sand aquifers were identified and classified. The resistivity data presented on the logs were interpreted qualitatively in terms of resistivity values of formation at various zones. Interpretations of the logs were based on the classifications of Zohdy and Martin (1993) and modified by Ibrahim (2008) (Table 1).

## RESULTS AND DISCUSSION

The results of the study are presented as geo-sections and maps. The geo-sections enabled the identification of the various lithological units within the study area. The maps were utilized to illustrate the fresh/saline water lateral interface boundaries. Six sections were generated from the study for the following axes:

A-A’ Ikorodu - Badore - Sangotedo - Awoyaya; B-B’ Apapa - Ikoyi - Victoria Island - Lekki - Ajah; C-C’ Victoria Garden City - Sangotedo - Awoyaya - Lakowe - Akodo; D-D’ Satellite Town - Kirikiri - Iganmu - Bariga - Ikorodu; E-E’ Agbara - Egan - Idimu - Agidingbi; F-F’ Mosinmi - Odongunyan - Ikorodu - Ibeshe.

Twenty-two (22) of the 52 logs interpreted intercepted saline water at various depths. The shallowest saline water interface was obtained at Victoria Island area (southern flank of the metropolis) while the deepest interface was delineated at depth of 308 m in Lakowe area (southeast of the metropolis).

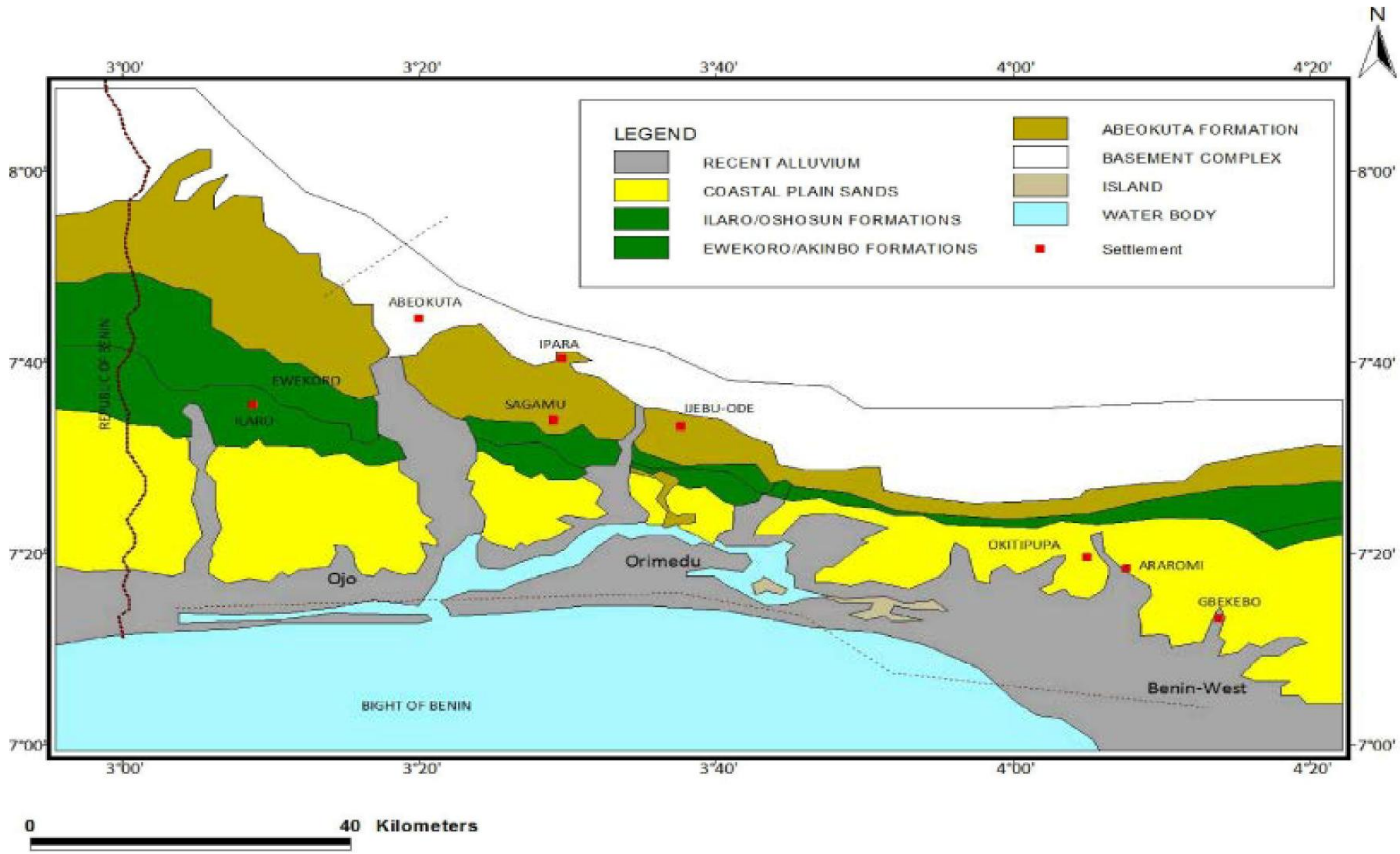


**Figure 2.** Geological map of Lagos.

**Geo-section A-A': (Ikorodu - Badore - Sangotedo - Awoyaya)**

The geo-section for profile A-A' is presented in Figure 5 while the interpretation summary is presented in Table 2. The section shows a general lithological dip in the south laterally in the NW-SE direction. Seven borehole logs covering four areas - Ikorodu, Badore, Sangotedo and Awoyaya were utilized for generating the section. The section shows a significantly thick clay/shale column from depth of 111 to 454 m (thickness of

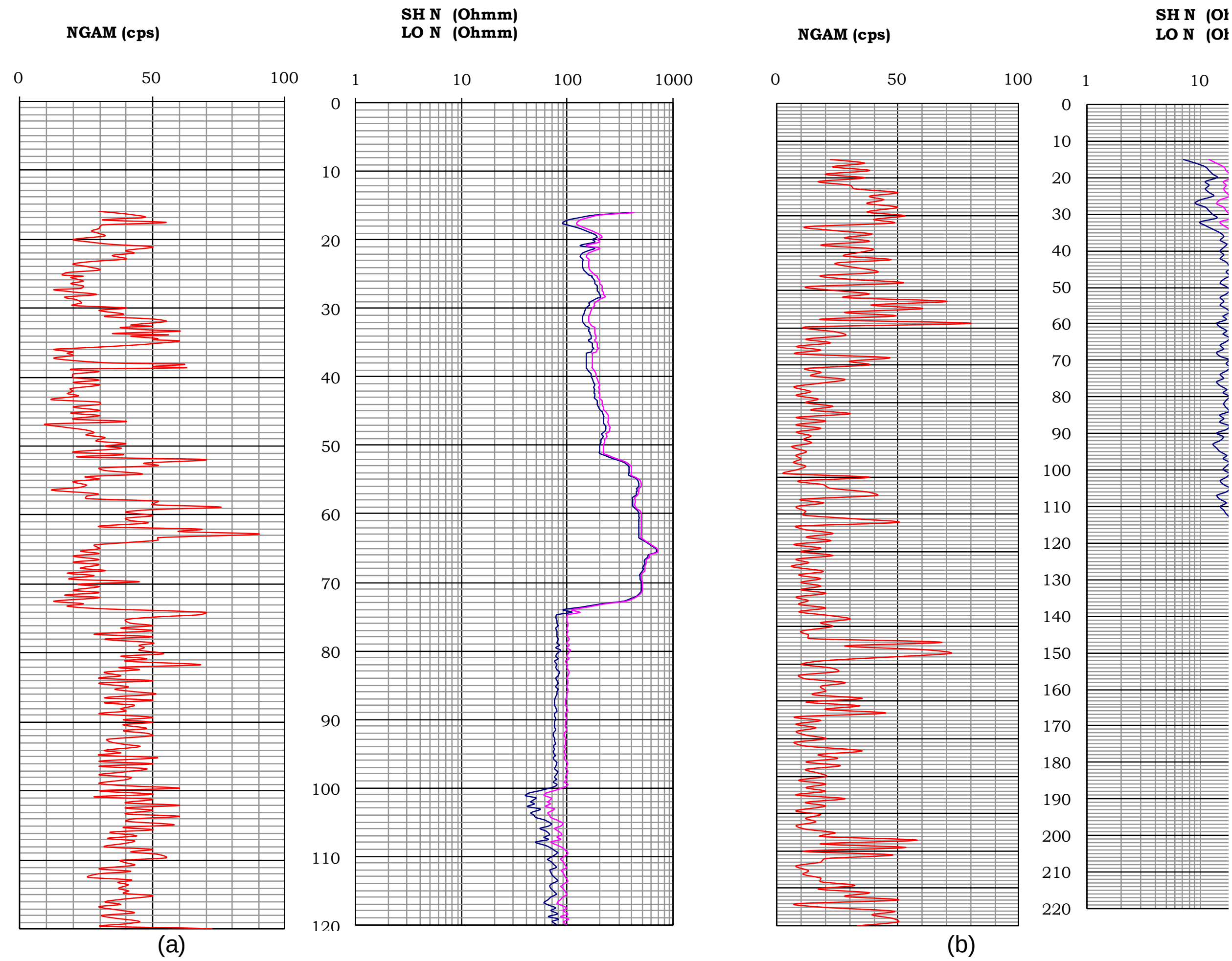


**Figure 3.** Typical borehole logs with (a) Odogunyan and (b) Osborne Estate Ikoyi logs (as examples) utilized for study.

**Plate 1.** The RG PC Logger II™ Unit mounted on sports utility vehicle used for borehole loggings utilized for the study.

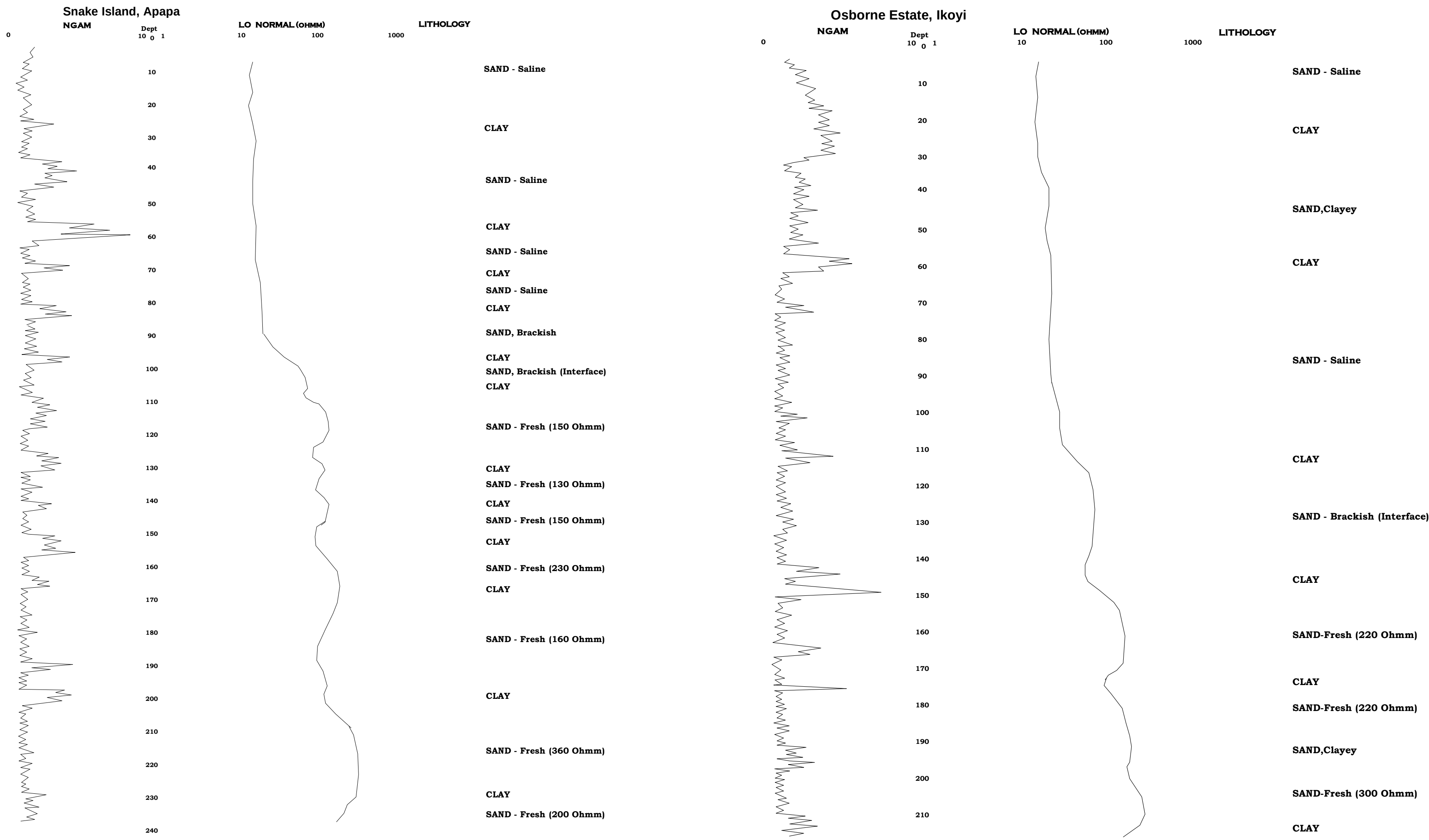


**Figure 4.** Typical logs and the lithology-water quality interpretation from the study area.

of 343 m) at Ikorodu. Thus, domestic boreholes may be terminated at limited depth of 110m within Ikorodu and environ while industrial boreholes should be drilled to depths in excess of 455 m.

**Geo-section B-B’: (Apapa - Ikoyi - Victoria Island - Lekki - Ajah)**

This axis constitutes the western half of west-east flank of the State and it is proximal to the Atlantic Ocean shore line. The axis connects the south-west edge of the metropolis to the south edge. Fourteen (14) borehole logs studied within the axis

**Table 1.** Resistivity values for water and sediment rock.

| Resistivity (Ω-m) | Sediment rock | Interpretation |
|---|---|---|
| 0.5 - 2.0 | Very porous sand, or saturated clay | Seawater, very saline water TDS = 20.000 mg/l |
| 2.0 - 4.5 | Porous sand, or saturated clay | Saline water, TDS= 10.000 mg/l |
| 4.5 - 10.0 | Sandy saturated or Sandy clay | Salty Brackish water, TDS = 10.000-1500 mg/l |
| 10.0 -15.0 | Sandy clay, sandy gravel | Brackish water, TDS = 5000-1500 mg/l |
| 15.0 -30.0 | Sand, gravel. Some clay | Poor quality fresh water, TDS = 1500 - 700 mg/l |
| 30.0 - 70.0 | Sand, gravel, minor clay | Intermediate quality fresh water, TDS ~ 100 mg/l |
| 70.0 - 100.0 | Sand, gravel, no clay | Good quality fresh water, TDS small |
| More than 100.0 | Coarse sand, gravel, no clay | Very good quality fresh water, TDS very small |

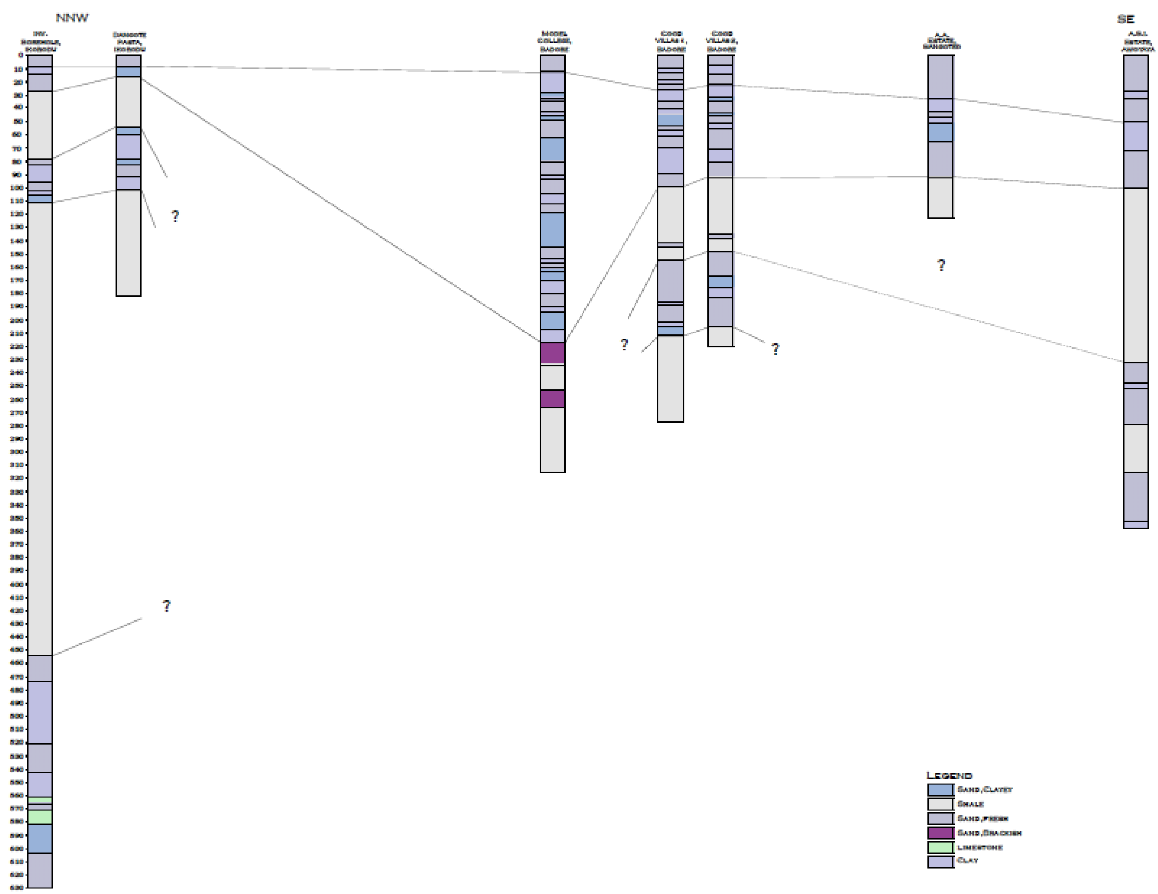


**Figure 5.** Geo-section A-A' showing lithology correlation across Ikorodu - Badore - Sangotedo - Awoyaya axis.

**Table 2.** Interpretation summary of borehole logs within profile A-A'.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| Lagos Road waterworks, Ikorodu | 114 | 15-27, 78-83, 96-102,105- 111,455-474, 520-544, 566-571, 605-627 | None |
| Dangote Spata, Ebute | 18 | 80-90 | None |
| Model College, Badore | 31 | 40-48,54-64,76-112,118-124,144-154, 180-196 | None |
| Coop Villa Bh1, Badore | 28 | 12-17, 20-24.8, 155-166, 173-186, 188-202, | None |
| Coop Villa Bh2, Badore | 27 | 13-20, 62-70, 150-164, 176-188, 196-202, | None |
| Ajayi Apata, Sangotedo | 22 | 16-33, 43-46 | None |
| Eko-Akete, Awoyaya | 20 | 18-24, 30-44 | 233 - 355 |

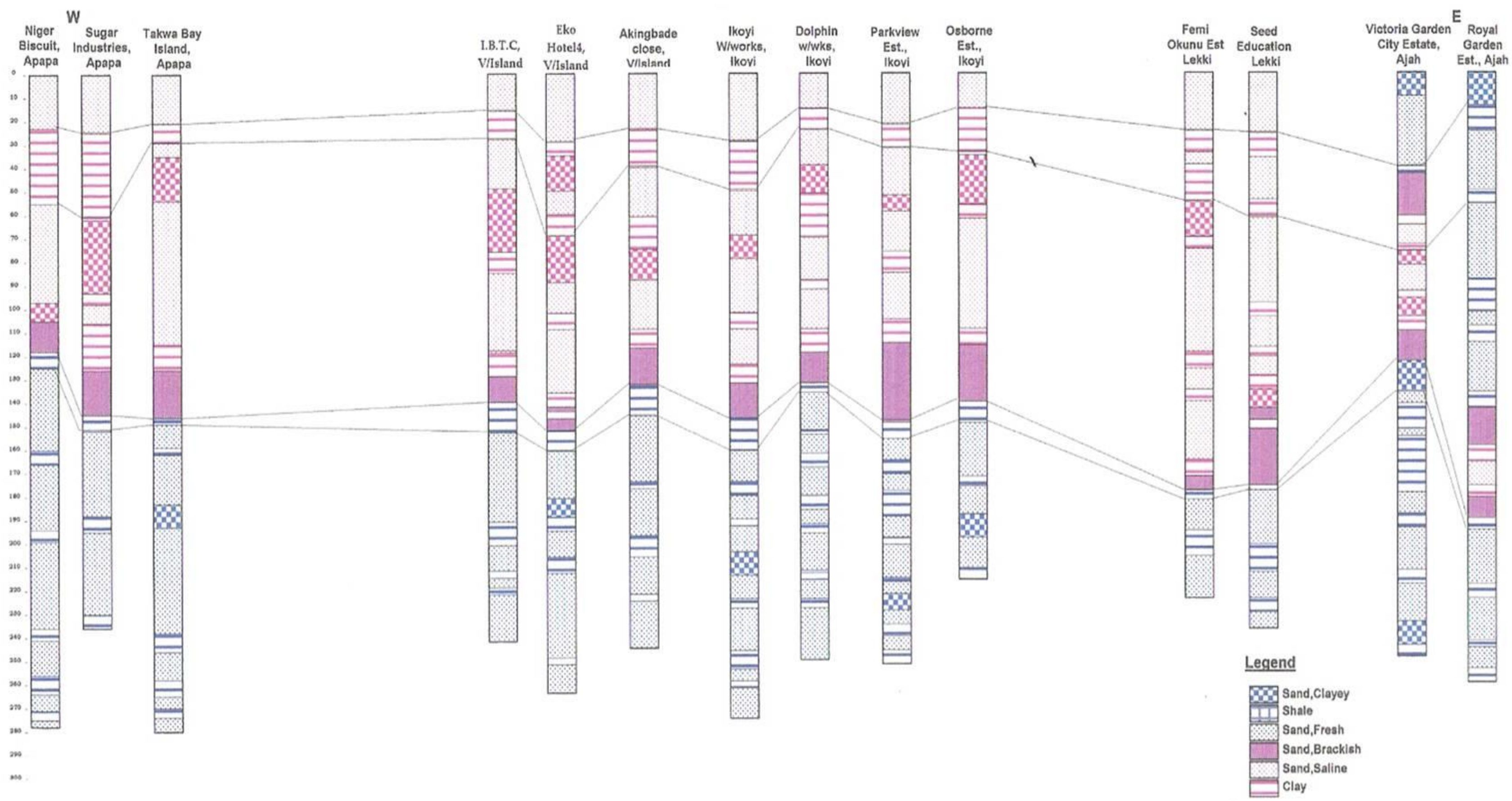


**Figure 6.** Geo-section B-B' showing lithology correlation across Apapa - Ikoyi - Victoria Island - Lekki - Ajah axis.

were obtained at Ikoyi, Dolphin, Victoria Island and Lekki. The geo-section generated for the axis is presented in Figure 6 while the interpretation summary is presented in Table 3. Within the axis, the delineated sand units are saline water saturated to depths varying between 118 and 196 m in Apapa and Ajah, respectively. At Ajah however, lenses of fresh water were delineated within the thick saline water sand. Net thickness of saline water sand units varies between 21 and 48 m in Ajah.

**Geo-section C-C': VGC (Ajah) - Sangotedo - Awoyaya - Lakowe - Akodo Axis**

This is the eastern half of the west-east axis of the study area which connects the southern limit to the south-eastern edge. Eight borehole logs were obtained for this study in the axis. The section generated from the logs is presented in Figure 7 while the interpretation summary is presented in Table 4. The net thickness of saline water sand increases eastwards (from Sangotedo) within the axis thus making freshwater abstraction more difficult on the eastern flank. However, at Akodo two lenses of freshwater were delineated.

**Table 3.** Interpretation summary of borehole logs within profile B-B'.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| Niger Biscuit, Apapa | 4 | 148-159, 162-183, 192-238, 246-258, 264-270, 274-280 | 0 - 125 |
| Sugar Industries 1, Apapa | 6 | 149-159, 162-184, 208-226, 232-236, 239-248 | 0 - 136 |
| Tarkwa Bay Island, Apapa | 10 | 148-155, 158-168, 171-179, 182-186, 188-193, 206-226 | 0 - 130 |
| Ikoyi Bh1 W/works, Ikoyi | 15 | 161-174, 179-190, 193-204, 215-224, 228-246, 253-259, 261-276 | 0 - 138 |
| Dolphin W/wks, Ikoyi | 5 | 137-152,154-162,169-180,187-192,195-214, 218-224, 229-250 | 0 - 131 |
| Parkview Estate, Ikoyi | 8 | 156-165, 171-178, 189-198, 201-215, 217-222, 230-235, 240-245 | 0 - 138 |
| Osborne Estate, Ikoyi | 5 | 164-172,176-193,202-208 | 0 - 148 |
| IBTC, V/Island | 20 | 154-191, 203-213, 215-219, 222-242 | 0 - 144 |
| Eko Hotel Bh4, V/Island | 19 | 153-193,194-208, 214-237 | 0 - 144 |
| Akingbade Close, V/Island | 18 | 148-174, 176-198, 208-220, 224-242 | 0 - 140 |
| Femi Okunnu Estate, Lekki | 27 | 182-196, 206-224 | 0 - 140 |
| Seed Education, Lekki | 15 | 166-188,192-196,198-232 | 0 - 158 |
| Victoria Garden City Estate., Ajah | 17 | 30-40, 136-141,152-155, 179-188, 193-212, 217-234 | 56 - 116 |
| Royal Garden Estate, Ajah | 17 | 46-50, 57-88, 102-108, 114-136, 190-218, 223-242, 245-252 | None |

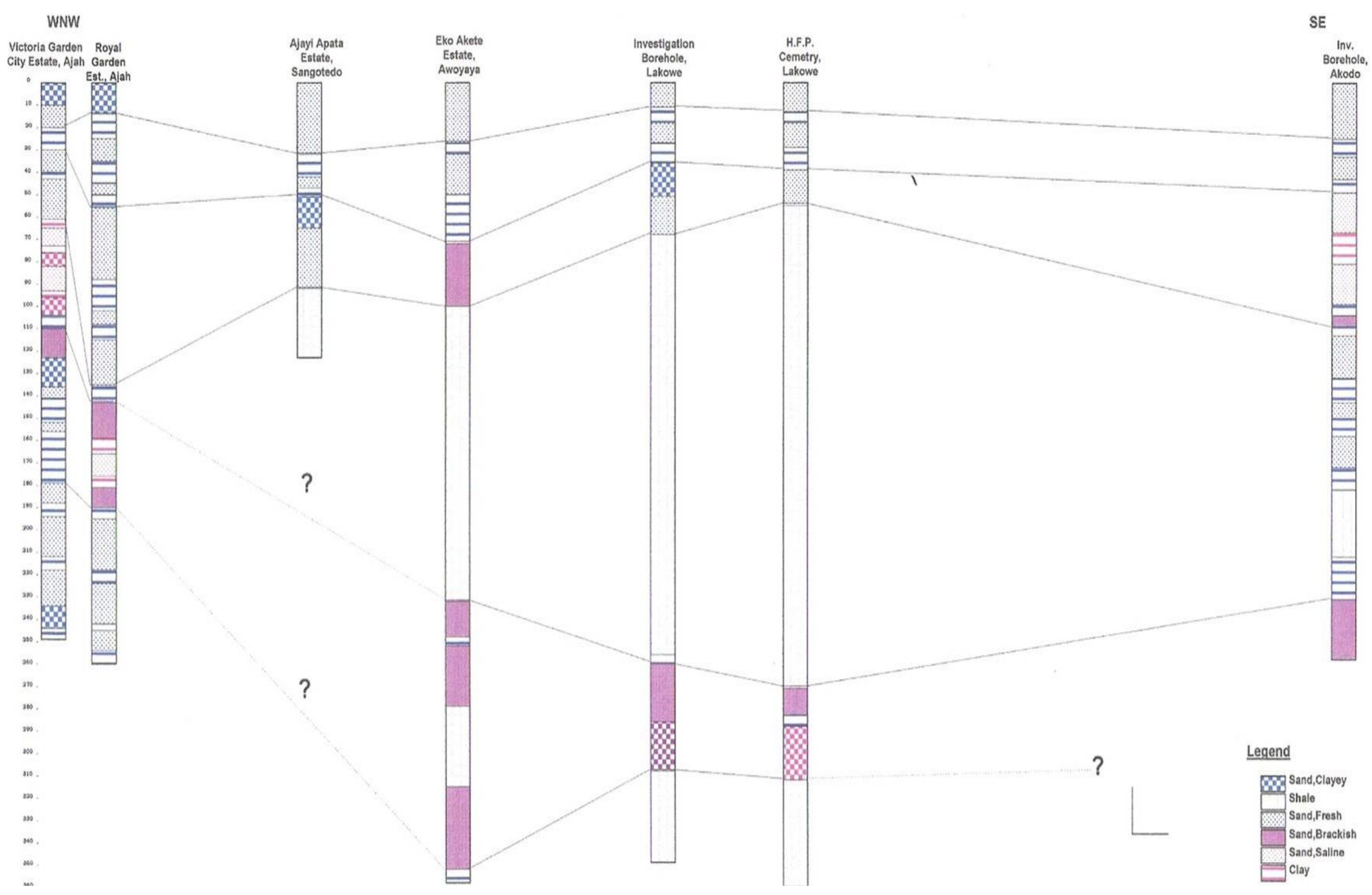


**Figure 7.** Geo-section C-C' showing lithology correlation across Victoria Garden City (Ajah) - Sangotedo - Awoyaya - Lakowe - Akodo axis.

**Table 4.** Interpretation summary of borehole logs within profile C-C'.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| Victoria Garden City Est., Ajah | 17 | 30-40,136-141,152-155, 179-188, 193-212,217-234 | 56 - 116 |
| Royal Garden Est., Ajah | 17 | 26-35, 46-50, 57-88, 102-108, 114-136, 190-218, 223-242, 245-252 | 143 - 190 |
| Golden Park Est., Sangotedo | 22 | 20-36, 44-57, 60-68, 82-100, 112-124 | None |
| Ajayi Apata, Sangotedo | 22 | 16-33, 43-56 | None |
| Eko-Akete, Awoyaya | 20 | 18-24, 30-50 | 233 - 355 |
| HFP Cemetry, Lakowe | 29 | 15-54 | 265 - 315 |
| Lakowe Gram.Sch. Lakowe | 26 | 21-27 | 258 - 308 |
| Ibeju-Lekki Secretariat, Akodo | 10 | 12-18, 36-46,108-132, 144-150, 159-168 | 51 - 108, 196 - 308 |

The hydrogeological setting on the axis is fairly complex. Saline water intrusion within the coastal plain sand within the axis is interspersed with lenses of freshwater sand units on the western flank around Ajah. At Victoria Garden City, the saline water sand is dominant from 62 to 124 m. At Sangotedo, Awoyaya and Lakowe, a significantly thick clay/shale column predominates with thickness varying from 133 m to 214 m at Awoyaya and HFP Cemetry in Lakowe, respectively, thus truncating the coastal plain sands (Figure 7). At Akodo, the coastal plain sand is again intercepted with a sequence of consisting of alternation of fresh and saline sand units.

### Geo-section D-D': Satellite Town - Kirikiri - Iganmu - Bariga - Ikorodu Axis

The geo-section (Figure 8) which transverses southwest to northeast of the metropolis, was generated using seven logs obtained from Satellite town, Amuwo-Odofin, Iganmu, Bariga and Ikorodu. Summary of the interpretation is presented in Table 5. Saline water intrusion is prevalent at shallow levels on the South-western and central areas of the section around Satellite Town, Kirikiri, Ijora Badia and Iganmu.

### Geo-section E-E': E-E' Agbara - Egan - Idimu - Agidingbi axis:

The geo-section (Figure 9) transverses the north-western flank of the metropolis utilizing seven geophysical borehole logs. The geo-section covers Agbara, Igando and Ogba and spans about 39 km. According to the summary (Table 6), there is no saline water sand unit incursion within the flank. Thus, the area is generally underlain by the vital fresh water sand units. A significantly thick shale unit was penetrated at Agbara.

### Geo-section F-F': Mosinmi - Odongunyan - Ikorodu - Ibeshe axis

Geo-section of profile F-F' is presented in Figure 10. The profile transverses the northern flank of the metropolis in SSW-NNE direction and crosses into nearby Ogun State in the north. Just like the Geo-section of profile E-E', there is no observable incursion of saline water in the northern flank of the metropolis from Ibeshe in the south to Mosinmi in the north at the time of study (see Table 7).

Saline water intrusion map of Figure 11 was generated from the twenty two geophysical borehole logs showing penetration into saline water incursion zones (Figure 11). The map highlights the lateral extent of saline water incursion within the city. We can observe that the saline water intrusion is severe on the southern coastal areas of the city. The areas mostly affected are Apapa, Kirikiri, Ijora, Satellite Town, Iganmu, Bariga, Lagos Island, Victoria Island, Lekki, Ajah, Badore, Sangotedo, Awoyaya, Lakowe and Akodo areas.

## Conclusions

Four of the geo-sections generated in this study (profiles A-A', B-B', C-C' and D-D') indicate saline water incursion at depths varying between 0 m (surface) in Satellite Town, Kirikiri, Ijora, Iganmu, Apapa, Lagos Island, Ikoyi, Victoria Island and Lekki to depths ranging from 40 m at Iganmu to 158 m at Lekki. Intrusions of 47 (143 - 190 m) and 60 m (56 - 116 m) were delineated at Ajah; 50 m (265 - 315 and 258 - 308) at Lakowe; 57 and 112 m (51 - 108 and 198 - 308 m) at Ibeju Lekki, Akodo and 122 m (233 - 355 m) at Awoyaya. The hydrogeologic importance of the Coastal Plain Sand aquifer unit in Lagos is under severe threat of continued sea water incursion and intrusion on its southern coastal flank. Results presented in this paper show that the process of salt water intrusion is active on southern flank of Lagos metropolis and geophysical wireline logs have proved to be precious

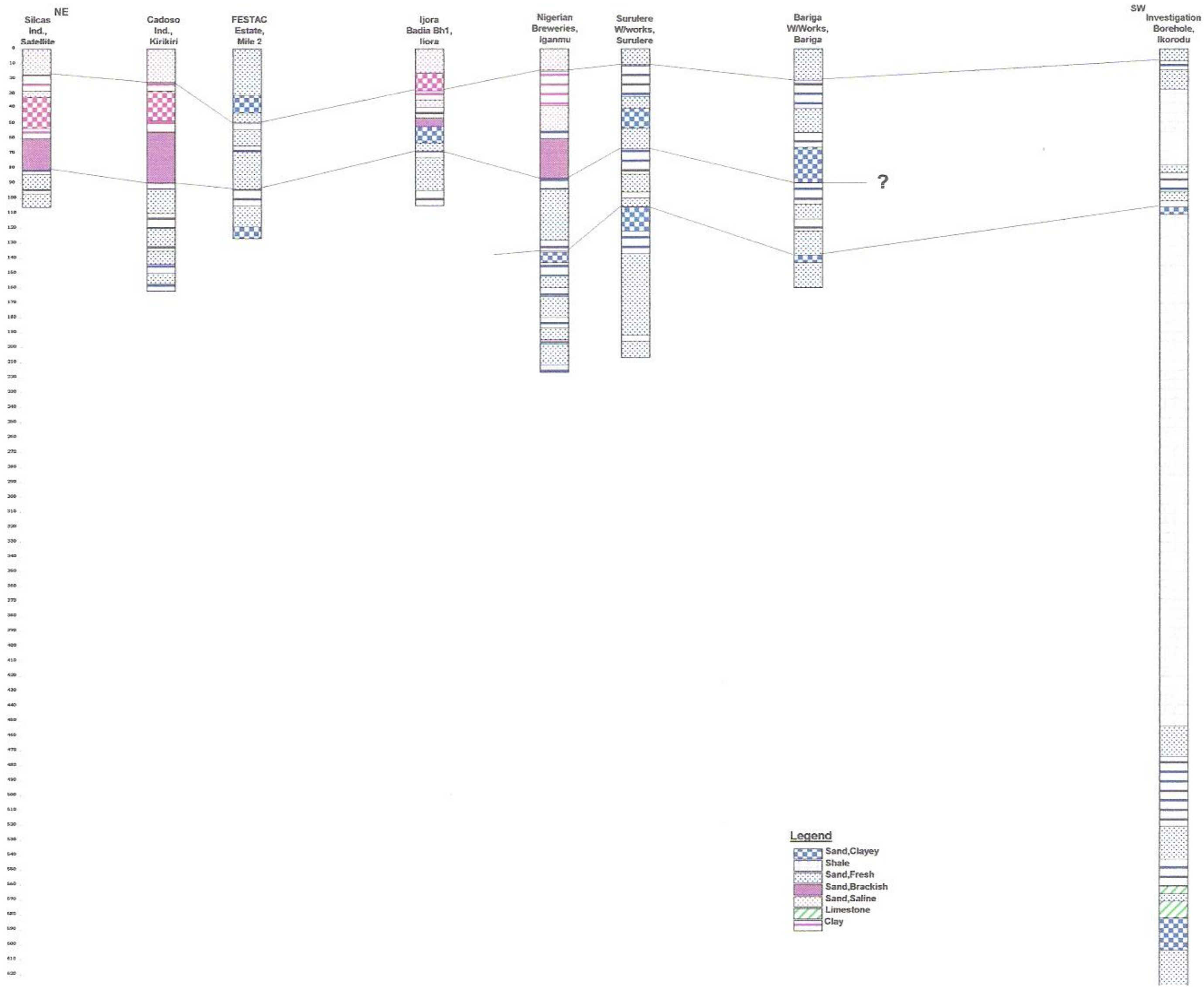


**Figure 8.** Geo-section D-D’ showing lithology correlation across Satellite Town - Kirikiri - Iganmu - Bariga - Ikorodu axis.

**Table 5.** Interpretation summary of borehole logs within profile D-D’.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| Silcas Ind., Satellite Town | 23 | 82-94, 96-104 | 0 - 80 |
| FESTAC Estate, Mile 2 | 31 | 18-32, 40-50, 56-64, 66-94, 106-118 | None |
| Cadoso Ind., Kirikiri | 27 | 100-110, 120-132, 134-144, 149-156 | 0 - 92 |
| Ijora Badia Bh1, Ijora | 17 | 62-68, 72-92 | 0 - 54 |
| Nigerian Breweries, Iganmu | 23 | 58-88, 96-128, 152-160, 166-180, 188-194, 198-212 | 0 - 40 |
| Surulere W/works, Surulere | 49 | 32-40, 54-66, 84-95, 100-106, 138-198, 194-206 | None |
| Bariga W/works, Bariga | 37 | 14-20, 40-56,106-114,122-138, 144-160 | None |
| Lagos Road waterworks, Ikorodu | 115 | 15-27, 78-83, 96-102,105- 111, 455-474, 520-544, 566-571, 605-627 | None |

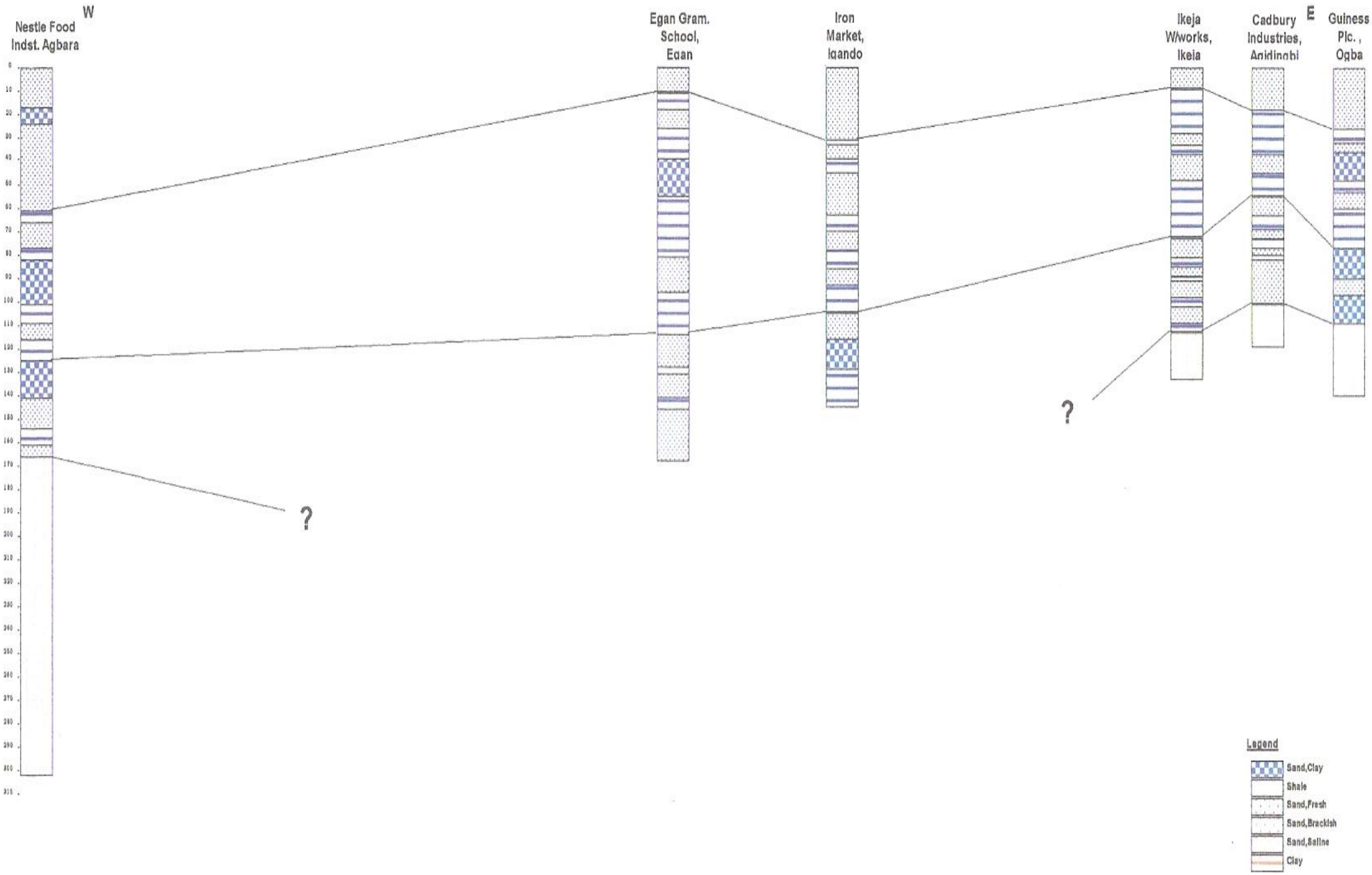


**Figure 9.** Geo-section E-E’ showing lithology correlation across Agbara - Egan - Idimu - Ikeja - Ikorodu axis.

**Table 6.** Interpretation summary of borehole logs within profile E-E'.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| Nestle, Agbara | 29 | 24-54, 56-61, 82-101, 110-114, 142-155, | None |
| Egan Gram. Sch. Egan | 19 | 81-96,114-129,132-141, 146-164 | None |
| Iron Market, Igando | 66 | 14-32, 34-39, 46-62, 70-76, 88-93, 106-116 | None |
| Ikeja W/works, Ikeja | 64 | 29-32, 40-48, 74-80, 86-88, 90-96, 104-108 | None |
| Cadbury, Ogba | 44 | 57-62, 65-72, 77-80, 82-100 | None |
| Guiness, Agidingbi | 65 | 14-25, 30-36, 52-60, 82-108 | None |

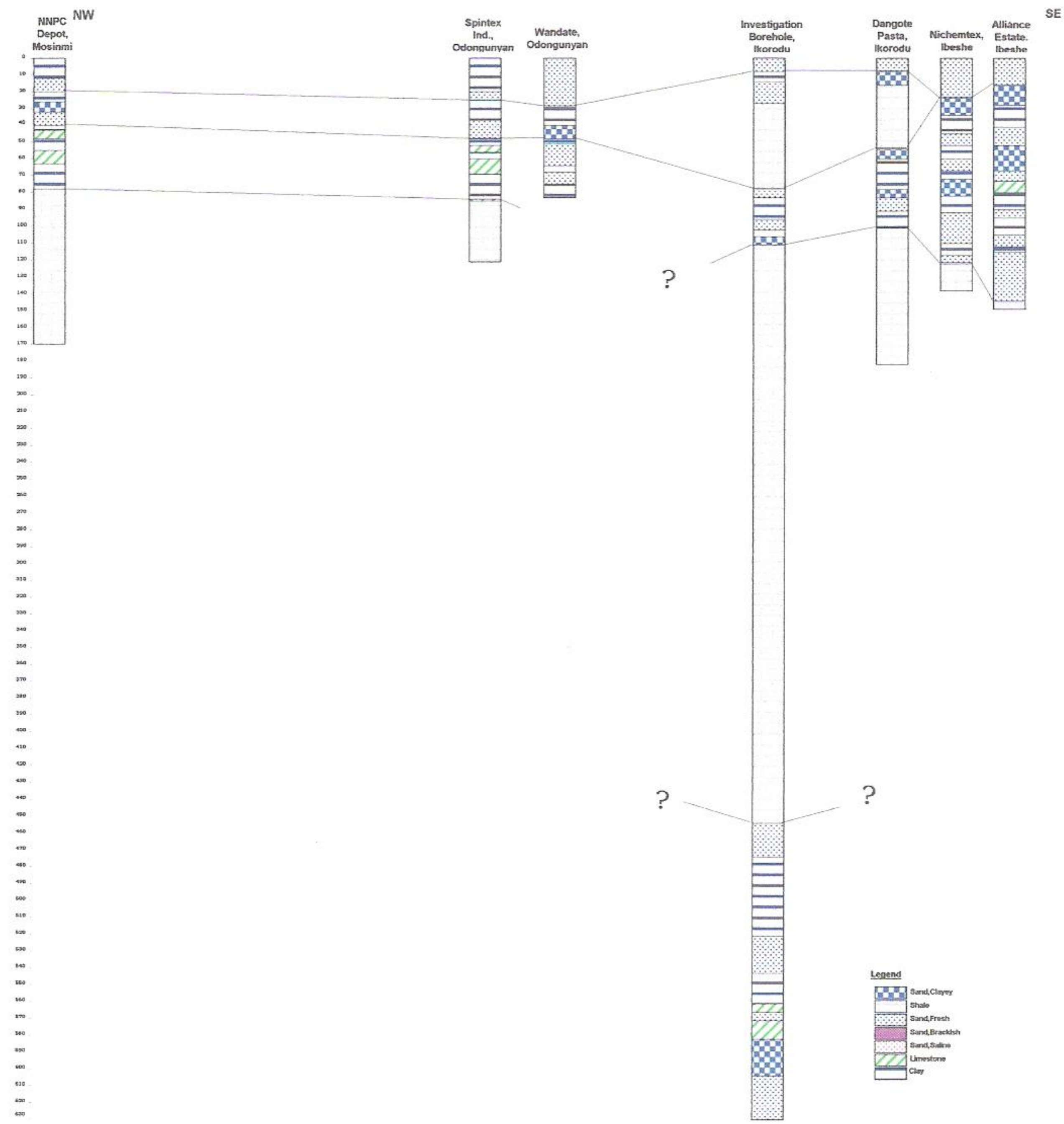


**Figure 10.** Geo-section F-F' showing lithology correlation across Mosinmi - Odongunyan - Ikorodu - Ibeshe axis.

**Table 7.** Interpretation summary of borehole logs within profile F-F'.

| Location | Elevation (m) | Fresh water zone depth (m) | Saline water zone depth (m) |
|---|---|---|---|
| NNPC Depot, Mosinmi | 94 | 13-20, 34-40, 44-47, 56-63 | None |
| Spintex, Odongunyan | 46 | 22-24, 42-48, 58-69 | None |
| Wandate, Odongunyan | 91 | 12-30, 50-64, 67-78 | None |
| Lagos Road waterworks, Ikorodu | 115 | 15-27, 78-83, 96-102,105- 111, 455-474, 520-544, 566-571, 605-627 | None |
| Dangote Spata, Ebute | 18 | 80-90 | None |
| Nichemtex, Ibeshe | 15 | 46-52, 60-68, 91-110, 115-122 | None |
| Alliance Est. Ibeshe | 18 | 42-52, 104-111, 114-144 | None |

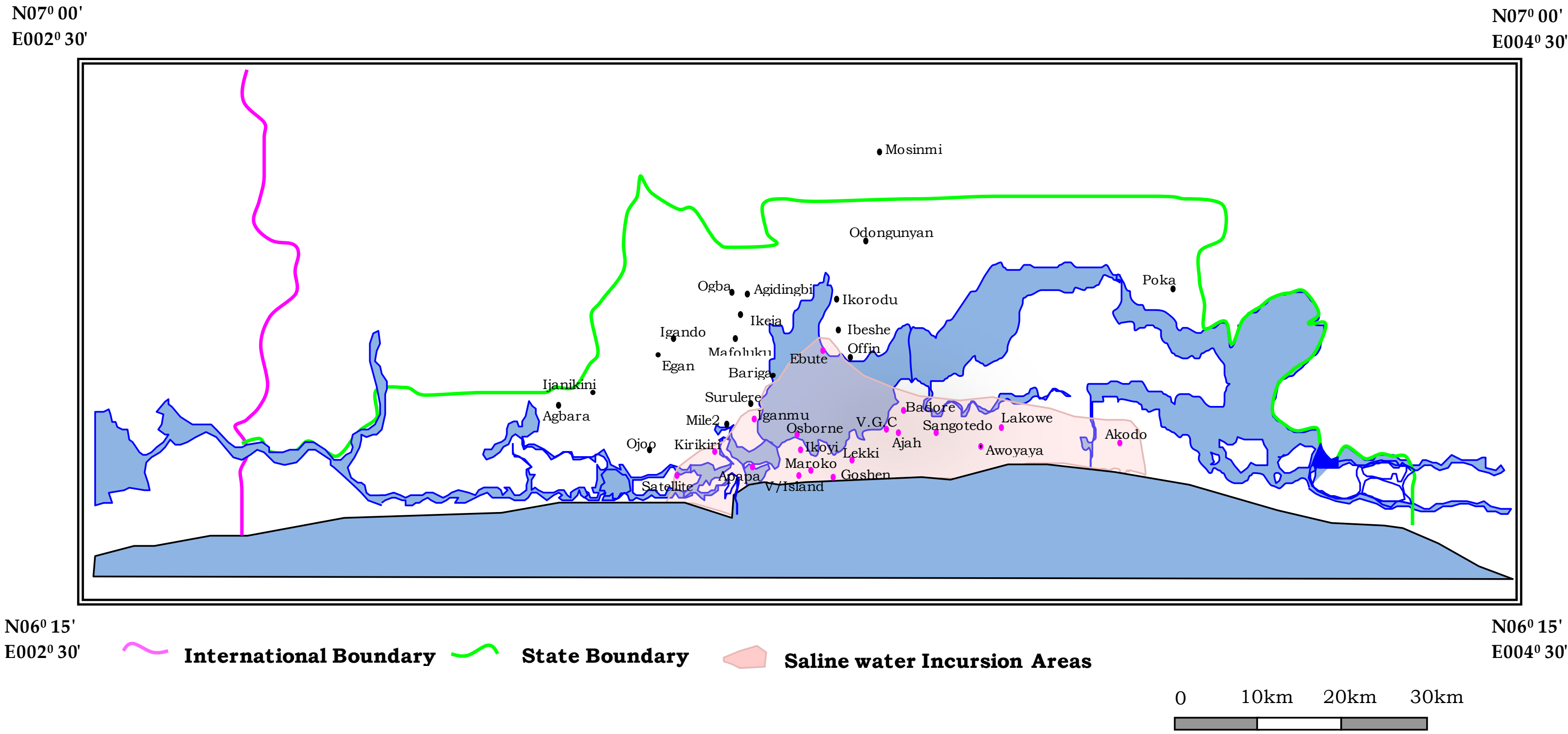


**Figure 11.** Map of Lagos showing the lateral extent of saline water intrusion within the metropolis.

tools for periodically monitoring the intrusion.

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*Review*

# Geographic information system planning and monitoring best practices for West Africa

**Akajiaku C. Chukwuocha[1]* and Ngozi AC-Chukwuocha[2]**

[1]Department of Surveying and Geoinformatics, Federal University of Technology, Owerri, Nigeria.
[2]Department of Environmental Technology, Federal University of Technology, Owerri, Nigeria.

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**Phenomenal increases in the number and sizes of urban settlements across the West African coastal region are leading to massive reclamation of swamps and destruction of natural ecosystems. Poor urbanization policies, inefficient planning and monitoring technologies are evident. The consequences include some of the worst types of environmental hazards. Best urbanization practices require integrated planning approaches that result in environmental conservation. Geographic Information systems (GIS) provide the platform for integration and processing of multi-sector Geosciences data in order to accurately predict results of different planning options. This paper presents the West African urban environmental problems. Using some concluded studies, it illustrates the functionality of integrating data in GIS for efficient planning and monitoring while calling on the governments of West Africa to adopt GIS based planning for best results.**

**Key words:** GIS, Urban Planning, Urban Monitoring, West Africa, Best Practices, Pollution, flooding.

## INTRODUCTION

As the cities of West Africa are growing in sizes and numbers, the attendant urban problems are increasing. For years now, West African urban areas have recorded devastating environmental problems including such phenomena as flooding, erosion, pollution.

Many researchers have done quite some work on the West African environment and seem to all point to the same environmental planning as a major issue in handling the environmental problems of urban West Africa. Aderogba (2012) studying recent floods and sustainable growth and development of cities and towns in Nigeria concluded, “More attention has to be paid to urban physical planning”.

Koenig (2009) writing on the challenges of urban growth in West Africa with case study of Dakar, Senegal writes, “Dakar has made substantive efforts to create forward looking plans that take into account the needs and desires of all major groups. However attempts at participatory planning are not always easy to reconcile with grand strategies proposed by important economic and political actors.”

Odufuwa et al. (2012) studying floods in Nigerian Cities concludes, “Impact of floods is more pronounced in low-lying areas due to rapid growth in population, poor governance, decaying infrastructure and lack of proper environmental planning and management.”

Karley (2009) writes, “... for the city (Accra Ghana), there is no evidence that unusual rainfall has been occurring recently that could explain the increased occurrences of flooding being experienced. Rather, the cause of the problem is the lack of, drainage facilities to collect the storm water for safe disposal. These could in turn be attributed to the ineffective planning ...”

This paper proposes that planning of the West African urban environments be made more efficient by integrating geographic information systems (GIS). This

*Corresponding author. E-mail: achukwuocha@yahoo.com.

will enable Urban Planners and policy makers to consider best practices options for the conservation of the urban environment.

The aim of this paper is to propose to West Arican urban planners and policy makers to adopt the best practices methods and technologies offered by the Geographic Information Systems for the sustainable development of the West African environment. The objectives of the paper include: i) to highlight the growing environmental hazards in West Africa due to poor planning of the environment using other research papers; ii) to reference concluded research works in demonstrating that more efficient urban areas result from integrating geosciences data on a GIS platform in different areas of designs and planning for the urban environment; iii) to highlight immediate identifiable areas where GIS may be used in environmental planning and monitoring and iv) to call on policy makers, planners and governments of West Africa to adopt these best practices for the conservation of the West African Urban environment.

## URBANIZATION PRACTICES AND PROBLEMS IN URBAN WEST AFRICA

A United Nations report on population growth in the urban centers across the world in the 21st century (Ginkel, 2008), projects that it is expected that by 2030, half of all of Africa's population will live in urban centers. However, the implication of this growth includes the increased pressure on natural resources, and the environment, in order to provide more infrastructures such as housing, water, transport, electricity, schools, etc. The consequences include unprecedented and varied impacts on the environment.

"Since 2007, the flood situation in West Africa is becoming more and more recurrent and the impact on the population and infrastructures is becoming more severe" reports Dieye (2010), for the United Nations Office for the Coordination of Humanitarian Affairs, Regional Office for West and Central Africa (UNOCHA/ROWCA).

The major cities of West Africa lie along the coastal shores of the Atlantic Ocean. Nine of all the 11 countriesthat line up the shore of the West African coast have their capital cities in the delta swamps by the Atlantic Ocean. It is true that the capital cities of Nigeria and Cote D'Ivoire were later moved away from the coast line to Abuja and Yamoussoukro respectively, the former seats of government and the present business capitals, Lagos, and Abidjan also sit on the coast line. These massive urban settlements are expanding fast. Demand for more land for construction of facilities coupled with citizen poverty across the region is leading to more degrading environmental practices. Ecosystems are being destroyed by efforts that convert the little spaces that can be found anywhere to farm crops for sustenance. Forests are foraged both for fuel wood, and logging to provide timber for new constructions.

Much more seriously is the impact of reclamation of land by both the government and citizens to construct new facilities. A study of the satellite images of the cities will show that the many estuaries, channels, tributaries and mangrove forests that mark the immediate shoreline of the sea are disappearing very fast or have already completely disappeared in these cities. Reclamations are happening in Port Harcourt, Warri, Benin and Lagos Nigeria, Cotonou Benin Republic, Lome Togo, Accra Ghana, Abidjan Cote d'Ivoire, Monrovia Liberia, Freetown Sierra Leone, Conakry Guinea, Bissau Guinea Bissau, Banjul the Gambia, and Dakar Senegal and many other urban centers across the region (Figure 1). The flooding of the urban cities of the West African Coast has now become perennial with its attendant loss of properties and lives.

Several papers such as Atedhor et al. (2010), in "Changing rainfall and anthropogenic-induced flooding: Impacts and adaptation strategies in Benin City, Nigeria", Karley (2009), in "Flooding and physical planning in urban areas in West Africa: situational analysis of Accra Ghana", Integrated Regional Information Networks, IRIN (2009) in "Burkina Faso: Coping with urban flood-displaced", Koenig (2009), in "The Challenges of Urban Growth in West Africa- The Case of Dakar, Senegal", and Aderogba (2012) in "Qualitative Studies of Recent Floods and Sustainable Growth and Development of Cities and Towns in Nigeria" have reported a vast array of the typical urban environmental problems in West African cities. They mostly point to the deficiencies in planning of the urban cities as key in the environmental problems that are about to overwhelm the region.

Federal Ministry of Water Resources and Rural Development Nigeria (undated), writes on a number of urban environmental problems in Nigeria, listing several devastating urban flooding events that have taken place in Nigeria over the years.

On urban resources, the Nigerian Ministry notes: "There is excessive pressure on available urban resources, infrastructure and space, evident in cities such as Lagos, Kano, Port-Harcourt, Aba, Onitsha, Ibadan, Kaduna and of recent Abuja, especially its satellite towns."

The Nigerian Ministry writes further: "Pollution from many industries is a growing problem. In commercial centres like Lagos, Port-Harcourt, Kano, Kaduna, Warri, Aba and Onitsha, coloured hot and heavy metal-laden effluent, especially that from textile, tannery, petrochemicals and paint industries, constitute severe danger to water users downstream."

Federal Ministry of Water Resources and Rural Development [Nigeria] (undated) notes further that, "The following characterise the urban and semi urban centres:

1) The various non biodegradable household petroche-


**Figure 1.** Map of West Africa.

mical products such as polythene bags, plastic containers, foam packages and tyres; and 2) Million litres of crankcase oil disposed from mechanic workshops, industries, power stations and commercial houses are ischarged carelessly into drains and ground surfaces at various locations within the watersheds.

The Soil Erosion and Flood Control Department further writes, “In many cities, plants are no longer used for home landscaping. Example, in Abuja many areas earmarked as green belts are being taken over by corner shops, roads and paved concrete surfaces."

Traditional urban plans rely only on the analogue topographic maps which are laid out on drawing boards. When the Computer Aided Design (CAD) is employed, the approach of the planners is fixed on providing the required facilities. Even when they know the need for conserving the environment they are not equipped to generate the information they require for efficient urban planning decisions. The plan calculations and considerations in these cases focus only on what is visible on the drawing board.

Topographic calculations for drainage installations for instance, follow on the general slope aspect. With today’s digital geospatial analysis tools, this is quite inappropriate. Decisions in urban-planning cannot be based only on what is desired to be provided in the city without looking at the effect on the environment. The Geoscientists should come up with plans that will enhance the natural landscape while compromising only what is inevitable in a sustainable way.

The urban practices already noted in the cited paper were observed with visits to the cities and studied high resolution satellite images across West Africa. Some of such practices include bulldozing of large areas of land, sometimes unnecessarily, to site possibly smaller structures.

There are general increases in industrial waste not disposed adequately. Hydrocarbon pollution and other unhealthy activities are the order of the day in these cities. There may be some exception where the government may have shown some interest in preserving the environment, like in Calabar, Nigeria. But the environmental preservation efforts are actually limited.

Governments across West Africa involve in massive constructions to provide needed infrastructure without taking into account in a scientific way the long term implications on the environment. If the environment does not survive, the humans that depend on the environment will not also survive.

## NEED FOR EFFECTIVE URBAN PLANNING

Effective urban planning is a very complex issue and cannot be carried out merely to provide only the facilities humans desire to have in place in their settlements and not consider the full implications of the constructions and the altering of the natural habitat. There is an urgent need to adopt a method for regional planning which provides for integration of data from a wide span of Geosciences, Sociology and Economics to monitor and manage the existing cities and plan the next urban cities, predict the future of the cities and hence consciously channel the growth of the urban areas in a sustainable way. Data required here will be in digital form and would include but not exclusive to those from: i) Up to date topographic maps or surveys, ii) current and archived satellite images over the region of interest, iii) Direct field survey captures such as 3-dimensional coordinates of points, iv) aerial photographs, v) Up to date demographic surveys and maps, vi) Soil surveys and maps, vii) Ecosystem surveys and maps, viii) Land use maps of existing urban areas, ix) Data on the major business occupations especially those that have direct impact on the urban environment, x) Up to date data on the natural and artificial drainage and xi) Storm water precipitation data over the years.

The aims here are to: i) integrate planning at regional levels to take care of, for instance, drainage by sub-sheds of major watersheds using topographic data, land use and storm water data etc; ii) plan the urban areas to sustain the ecosystems and avoid such phenomena as desertification, gully erosion, and flash floods; iii) predict the growth pattern of the cities and provide for the growthin sustainable ways and iv) monitor the growth to ensure that the plan is adhered to strictly and particularly that people do not encroach into reserved areas to use as refuse dump sites or for construction of illegal structures.

Williams (2000) writes on ecosystem planning, "It is clear that a new way of addressing urban problems is needed and that it will have to be more efficiently integrated, more sensitive to ecology and community, more respectful of uncertainties, and more open to citizen involvement than what now prevails. This has led to an ecosystem approach to planning: 'an approach that begins with an ecologically-bounded area, stresses the integration of social, economic, and environmental factors, and seeks to involve all the relevant interests and power-holders in identifying desirable futures, evaluating alternative pathways and implementing preferred solutions'". The article further outlines basic principles that reflect the characteristics of ecosystem planning as follows:

1) Base planning units on natural boundaries, reflecting ecological functions while replacing a politically-oriented hierarchy of units.
2) Design with nature, and respect human activity and its effect on the environment as well as the limits of resource availability and ecosystem resilience.
3) Consider global and cumulative effects, because a much broader and longer perspective must be considered, like attention to off-site, cross-boundary, intergenerational, and cumulative effects.
4) Encourage inter-jurisdictional decision making, and overcome the present fragmentation and isolation with integrated planning and implementation.
5) Ensure consultation and facilitate cooperation and partnering, involving the widest range of stakeholders effectively and openly in the planning process.
6) Institute long term monitoring, feedback, and adaptation of plans, to assess what happens to communities and ecosystems as plan implementation unfolds.
7) Adopt an interdisciplinary approach to information, by greater information gathering (e.g. ecological capacity and functions), more integration of information, and greater cooperation among information providers.
8) Adopt a precautionary but positive approach to development that aims not just to avoid further damage but also to reduce stresses and enhance the integrity of ecosystems and communities.
9) Ensure that land-use planning integrates environmental, social, and economic objectives, but this depends on the planning body having a firm base of established institutional power to foster multi-interest cooperation and implementation.
10) Link ecosystem planning with other aspects of democratic change, social learning, community building, and environmental enlightenment.

The geographic information system (GIS) is a complex data storage, processing and display tool with inestimable capacities to integrate multi-sectored data in a scientific way. It is GIS that is needed to effectively respond to these many urbanization problems in order to generate the information needed for accurate decision making in urban planning and monitoring.

## USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN URBAN PLANNING AND MONITORING

### *GIS and integration of geoscience data*

The geographic information system (GIS) is a computer storage, computing and display system that links inter-related geospatial data through appropriate algorithms, to derive needed information on environmental phenomena and display same in a clearly understandable way. A number of features make the GIS most desirable in handling geospatial matters. The GIS employs the impressive capacities of the computer in storing volumes upon volumes of data, its unrivalled speed in sorting stored data and processing them for needed information. Today, there are in place seamless interfaces for data exchange between the data capture units in the field and the processing computers in the office. The miniaturization of computers with increased computing powers and storage capacities as is in the laptops and palmtops, and the unlimited link between computer systems across the globe through the World Wide Web or locally within the local network, make the system a compulsory necessity if the professional must meet with the demands of high efficiency in today's world. In the field of Environmental Studies, Urban Planning, Engineering, Surveying and Geodesy, the GIS provides the rare opportunity of combining the perceptibility of graphics with the accuracy of digital computations at great speed. Different formats of data storage and exchange, data processing and information display, are combined in achieving and demonstrating results. For example, in considering the hydraulics of storm- water flow in a watershed, the topography of the land spread, the soil types, the land use and the land cover, infiltration rates and the precipitation rates, are all factors that need to be considered. It is obviously difficult if not impossible to independently derive information on each of the factors over a unit of space considered and to integrate these step-wise over the whole land in an analogue manner, in order to decide for example, how to place drainage to mitigate flooding and erosion.

The GIS displays graphical digital elevation models (DEM's) and Digital Terrain Models (DTM's) using elevation and topographic data. The needed land cover or soil type factor in infiltration, and precipitation rate over the land are held in GIS, in form of satellite image data, or map data. The factors influencing storm water runoff flow are integrated by powerful software that drive these complex computations which yield accurate predictions of future possibilities that prove extremely valuable in taking measures to mitigate potential disasters. Additionally, the GIS can handle data over very vast regions beyond what can be laid out on a table at any scale at all. The largest regions can be handled even to the minutest details by the capacity of the computer to organize geospatial data in recognizable spreadsheets and to view information as graphics, coupled with the capacity to zoom in and out on the areas of interest and beyond.

### *Application of GIS in urban planning*

The West African urban centers can no longer be planned just in the traditional form that seeks only to provide facilities needed by humans without accurately determining the consequences of those choices on the environment and allowing alternative options. The use of GIS in urban planning is necessary to provide needed information about the environment of the proposed or existing urban area from a very complex mesh of environmental data. Ginkel (2008), writes "using earth observation and GIS, it will be possible to prepare on time, at much lower cost the optimal direction of urban growth, taking into account the local topography and many other characteristics, to guarantee a sound development of the cities and timely reduction of environmental risks."

Much of the information needed for modern urban planning are products of geospatial data integration and mathematical processing. They are such information that could not be handled independently or purely mathematically without expression in graphical space. For instance in planning a city in a way to preserve habitats, we would most likely be seeking to know what locations and what size of the space hosts a habitat of interest. We may want to know the criteria for choosing the habitat that may be altered for urban use and how the habitat may be altered. All these information are not only displayable on a GIS platform, GIS software are capable to show areas that match prescribed criteria in colour codes. If also it is needed to isolate areas that are up to certain degree of slope, and which are in areas of certain soil types from choice of sites for some facilities, the GIS is instructed by the query tools or scripting instructions. Provided that the background data on the issues in question are integrated by algorithms in the GIS over the area of the proposed or existing urban center, the result of this isolation is displayed on the GIS platform by colour coding. Data required for the slope query is the topographical data. Data required for habitats query is the land cover data. The soil data will provide for the soil type information. Some other very useful data types will include demographic data, rainfall data, land use data. Urban Planners should also be interested in utilities needed to sustain the city. For example what road types are needed for the different areas of the city? Again where will be the most suitable to locate an airport, or university etc considering ecological issues. The GIS also can enable preliminary studies that determine what type of surfacing will be most suitable given for roads given the soil type and rain data.

### Availability of GIS data needed for urban planning and monitoring

The GIS data requirements are becoming increasingly available globally. Imagery coverage of the earth at 5 m resolution or higher stands now at nearly 100%. The topography of the earth is fully covered by the Shuttle Radar Terrain Model (SRTM) at 90 m, 30 m and 1 km resolution levels. Other accurate sources of digital elevation data would include all stereo-capable imaging satellites such as SPOT 5. Even though weather conditions change abruptly, GIS has made it possible for weather to be monitored in real time. Weather data have been so monitored that global weather prediction has become a near-totally-accurate science. Satellite weather data are accessible online globally and precipitation rates or volumes are accurately predicted. The Satellite images provide detailed land cover and land use data which are useful in all urban planning exercises all over the world.

The websites for these Satellite data are easily accessible through internet search engines such as Google, Yahoo search, etc. However International Water Management Institute (IWMI) website is an example of sites that warehouse diverse Remote Sensing Satellite data useful for urban planning and monitoring. It also lists a number of web links to important satellite data websites. These include among others:

i) http://www.iwmidsp.org which is a satellite warehouse of sorts.
ii) www.iwmidsp.org for advanced High resolution Radiometric AVHRR satellite data. Cost: Free download. Format: ERMapper.ers
iii) http://free.vgt.vito.bel for SPOT vegetation free download, Format: data binary.
iv) Http://edcimswww.cr.usfs.gov/pub/imswecome/ for MODIS, Terra and Aqua Satellite data, Cost: free. Format: .hdf
v) http://glcf.umiacs.umd.edu/index.shtml for Landsat data of 1970's, 1990's, and 2000's. Cost: Free. Format: GEOTIF or MrSid
vi) http://landsat.org/ for Landsat data. Cost: $50 to $600 per scene. Format GEOTIF
vii) http://glovis.usgs.gov/imgviewer/ or http://edcimswww.cr.usgs.gov/pub/imswelcome for Landsat data of recent and historical times from United States Geological Surveys (USGS). Cost: $450 to $600 per scene. Format: GEOTIF
viii) http://www.spaceimaging.com/ for Landsat (recent and historical) data for commercial sources of Space Imaging: Format:GEOTIF. Costs Approx. $1,000
ix) http://www.spotimage.fr/html/167.php for SPOT HRV data:(Historical and recent) Format:GEOTIF , costs: $2000 for 60km x 60km
x) http://http://glovis.usgs.gov/imgviewer/ or http://edcimswww.cr.usgs.gov/pub/imswelcome/ or http://asterweb.ipl.nasa.gov/ for ASTER data, Format: GEOTIF, cots: approx $50 to $150 for 60km x 60km.
xi) http://eol.usgs.gov/ or http://edcimswww.cr.usgs.gov/pub/imswelcome/ for ALI (next generation landsat data) Format: GEOTIF, Costs: approx $.500 for 100km by 100km.
xii) http://www.nrsa.gov/in/ for IRS LISS data (Historical and recent), Format GEOTIF, Costs: approx. $1,000 for 100 by 100 km.
xiii) http://www.spaceimaging.com/ for IKONOS from Space Imaging, Format: GEOTIF, Cost: 10 by 10km approx. $1500 or more
xiv) http://www.digitalglobe.com/ for quickbird from Space Imaging, Format: GEOTIF, Cost 10 by 10km approx. $1500 or more.
xv) http://www.orbimage.com/index.html Format: GEOTIF, Cost: 10 by 10km approx. $1500 or more.
There are also many other independent sites through which these data can be acquired.

## PROPOSALS FOR OPTIMIZING ENVIRONMENTAL CONSERVATION USING THE GIS

Gironas et al. (2007), has proposed a morphological approach in planning urban areas. They note that up to this point, the quantification of changes to the structure of the drainage patterns caused by urbanization has not been developed in detail, and no formal methodologies are used to characterize urban catchments from a morphological and topological point of view. Finally, no special measures in storm water management are being taken in order to imitate natural conditions of the drainage pattern.

In this case, the morphological and topological features of the area of interest should be considered. For instance in planning the storm water drainage, storm water flow from the farthest distances that drain into that area should be considered and taken care of in as natural a way as possible. The urban area planning should not concentrate on the areas of developmental interest only. Every factor that contributes to the functioning of that environment should be considered

The central issues in regional planning are to effectively take care of runoff that may increase as a result of urbanization without causing damage to other habitats and to preserve as much as possible the natural ecosystems.

## SOME REPORTED EFFORTS AT GIS BASED FACILITY PLANNING FOR THE WEST AFRICAN URBAN ENVIRONMENT

### GIS based urban drainage network design

Chukwuocha (2012) reports on the "GIS based urban drainage network design for Owerri, South East Nigeria". This Ph.D dissertation, reports on drainage design that positioned drainages on the natural flow routes which would effectively drain the watershed subcatchments. Using the GIS, the discrete topographic data of the area was converted into a Digital Elevation Model (DEM). The DEM was then automatically analyzed on the GIS platform to determine the natural drainage routes and the corresponding subcatchments which drained into the determined routes. Needed engineering drainage details such as elevations of the nodes, sizes of conduits that would effectively drain the subcatchments were determined. Simulations were run to ascertain that these drainages would effectively drain the sub catchments.

One big advantage of this GIS based natural drainage route drainage network design ensures efficiency at several levels including the fact that these drainages were located in the best positions that drained the entire sub catchments in a an accountable manner. The method provides needed information in a number of other areas such as the velocity of runoff in each sub catchment which is useful in water-borne diseases studies; the run-off coefficient map of the studied area and so on.

### Land use allocation by run - off calculation

When a region is in consideration for urbanization, systematic and scientific approaches should be used in choosing land allocations to the urban facilities. Tang et al. (2005), presents the Runoff MINinimization (ROMIN) model that may be used in sorting between sites for land use allocations. This model compares the soil type of the site in combination with the proposed land use and calculates the resultant runoff.

Comparing different land use options and their runoffs, the minimal runoff land use combination option is adopted. The ROMIN model is quite adaptable for use in a GIS platform. Data and computation of Runoff and decision of the optimal option are automated and in GIS, this can be handled over large regions impossible to be laid out fast in graphical drawing table.

## ADDITIONAL POINTS ON GIS BASED URBAN PLANNING

### Land use allocation by consideration of existing natural ecosystems

AmphibiaWeb (2010), reports that when amphibian habitat is drained, filled or cut and then converted into parking lots, housing developments or agricultural developments, the natural amphibian habitats are completely destroyed. Habitat alteration occurs when changes made to the environment adversely affect ecosystem function, even if not completely or permanently. An example is when heavy livestock graze in the amphibian environment. These livestock trample on the amphi-bians and other organisms that occur in the aquatic region.

Habitat fragmentation occurs when interlinked habitats are cut apart by land uses introduced between them. Hanski (1999) developed a model for the threshold for metapopulation persistence which predicts that isolated populations are more likely to go extinct in the long run than populations that are slightly connected. With the GIS as a tool we can map the entire region of interest in broad ecosystem groupings. We then consider what optimal areas of each ecosystem grouping must be preserved. The ecosystems must be allowed to link up to more natural unaltered habitats. If habitat destruction must occur, we must employ a gradual process that allows the population to migrate into safer habitats, since the amphibians and of course all other species will have links to other natural habitats.

We should determine what minimum limits of the different habitats that we must not allow urbanization to affect. In GIS, buffering is a toll that enables one to set limits of minimum or maximum distances from a known point or line. Polygonization helps us mark out areas automatically when we have defined the criteria. These tools will be useful in marking out limiting factors of every habitat that we are concerned with. The habitats are also identifiable in satellite images, using certain criteria such as, the predominant plant type, marshiness of environment or otherwise, the topography of the area etc.

### Mitigation against urbanization - induced flash floods and gully erosion

GIS-based hydrologic studies and predictions lend so well to the mitigation of flash floods and gully erosions in urban areas.

Lansigan (2007) notes that effective response to these hydrological problems may include:

i) Effective comprehensive land use plan (CLUP) which include the critical areas prone to flooding, landslides and soil erosion.
ii) Regulated land use conversion of lands for urban uses with appropriate provision for adequate drainage system.
iii) Protective management of watershed areas, and clearing of watershed areas and clearing of waterways, rivers and creeks by regular removal of debris that may obstruct smooth flow of water.
iv) Information, education and communication program on flood protection, and response measures at the village-level.

In a paper, Junior et al. (2009) notes the usefulness of the GIS using multi-temporal digital elevation data analysis in studying urbanization-induced gully erosions. These studies are then used in predicting other areas prone to future gullying so that mitigation will be provided. Flood studies must be carried out at regional levels. All areas that drain into the desired urban center or hydrologically connected with it should be considered together. These areas may be vast and can only be handled digitally in a GIS platform.

### Integration of vegetative cover in urbanization

The increasing level of urban air pollution has been highlighted. Also, the risk of bare soils due to the scraping of top soil by earth moving machines in urban areas is known to increase the chances of desertification and soil erosion as the soil particles become loose and cake as direct sun heat bakes the particles. Paving of much of the urban areas looks beautiful, but it leads to increase in storm water runoff and runoff velocity and force, hence increasing the potentials for flood disasters and erosions.

It is useful to make policies that encourage the sustenance of green areas in urban areas. One or two average-height trees may be required to be planted in all premises depending on the parcel size. This may mean that the sizes of the parcels allotted for instance for residences will have to be increased, but this should only require policy shift.

Grass lawns and trees planted by the side of paved walkways to increase vegetation life in the cities also help to hold together soil particles and shade them from baking under the sun, while acting as filtering agent of the air pollutants.

Furthermore, the urban planners should incorporate in each layout vegetation areas that must be preserved. The choice of where to locate green areas can also be made in watersheds by setting a given buffer from natural running waters, and marking them out both in the layout plans and on the ground.

## GIS BASED URBAN DEVELOPMENT MONITORING

Monitoring urban development is as important as the planning. It is not just enough to plan urban areas, it must be seen that the plans are carefully followed. GIS employing state of the art earth observation and geospatial data capture technology, without doubt are today the most robust and effective environmental monitoring systems in the world. The capacity to detect change in the environment even long before on-site inspectors can see them is particularly very useful in urban development monitoring. The GIS has become an inevitable tool to effectively monitor and accurately predict environmental activities.

In the West African cities, environmental policies are often flouted by desperate developers. The governments obviously do not have the capacity to check every new building sprouting up in every corner. Even when local officials find illegal developments they sometimes get compromised by the developers because the authorities up the line have no means of seeing what is going on at those sites. Building houses across the natural drainage channels or constructions within reserved areas of watersheds are regular occurrences that the governments appear incapable to handle.

Various archived satellite data hold records of the state of a region as the urban area was conceived, the pre-urbanization data. The GIS platform also holds the urban concept in its designed form. As developments continue, more satellite data are captured which record the alterations that are beginning to occur due to the new urban development. These new satellite data records can be matched with the urban plan on a GIS platform to determine compliance with the plan and possibly detect deviations in land use from the plan.

It is also important to monitor the effects of even complying with the new plan. For instance high resolution satellite imagery like IKONOS and Quick bird can reveal flooding where the design had not anticipated it. Unauthorized timbre lumbering can be noticed in forest reserves, or solid waste dumping can be discovered when it has only grown a few meters, and stopped.

Land use/land cover change detection is a key feature of the geographic information system (GIS). When a satellite image or digital area photograph is superimposed over an earlier image, GIS can reveal spots where changes have occurred. The capacity of detecting very small changes is fully dependent on the resolution of the satellite images in use. Every day the resolution of satellite images available in the market are improving. Satellite Imaging systems such as Quickbird, Ikonos Geoeye, WorldView and many others are offering improvements in the already high spatial and temporal f resolution images . For instance new constructions in a reserved area can be discovered in 2 days of the project taking off if the area is monitored by GIS using constantly uploaded WorldView images. Consider the following facts on worldview taken from Mapmart web site:

WorldView-1 Imagery features a high capacity, panchromatic imaging system at half-meter resolution imagery. Operating at an altitude of 496 kilometers WorldView1 has an average revisit time of 1.7 days and is capable of collecting up to 290,000 square miles per day of half-meter imagery. Launched September 18, 2007, WorldView-I has amassed an amazing library of highly-accurate and detailed black and white imagery.

This satellite is also equipped with state-of-the-art geolocation accuracy capabilities and exhibits stunning agility with rapid targeting and efficient in-track stereo collection. This makes for a quick collection of highly-detailed imagery suitable for mapping, feature extraction and orthorectification ground control.

WorldView-1 - 0.5 meter Panchromatic Imagery, Resolution: 0.5 meter Band: Panchromatic only Projection: UTM, Lat/Long, State Plane, Datum: NAD 27, 83, WG 84

Format: Geo TIFF, JPEG, NTIF, Dates: 2007 - presentLAND INFO Worldwide Mapping, LLC (2010) published the following on the WorldView-2 satellite imaging system: WorldView-2, the world's newest high-resolution commercial color imaging satellite, was launched on October 8, 2009 from Vandenburg Air Force Base in California. WorldView-2 is the first high-resolution satellite with 8-Multispectral imaging bands. WorldView-2

**Table 1.** Technical features of Geoeye and Ikonos.

| Satellite feature | Geoeye-1 | Ikonos |
|---|---|---|
| Resolution | 0.50 m | 1 m |
| Blue | 450-510 nm | 445-516 nm |
| Green | 510-580 nm | 505-595 nm |
| Red | 655-690 nm | 632-698 nm |
| Near IR | 780-920 nm | 757-853 nm |
| Launch date | 06-Sep-08 | 24-Sep-99 |
| Revisit time | 3 days at 40° latitude with elevation > 60° | 3 days at 40° latitude with elevation > 60° |

will simultaneously collect panchromatic imagery at 0.46m and Multispectral imagery at 1.84m. Due to U.S. Government Licensing, the imagery will be made available commercially as 0.5m imagery. WorldView-2 is capable of collecting up to 975,000 square kilometers of imagery per day (376,000 square miles). The technical features of Geoeye and Ikonos satellite images presented in Table 1 are adapted from Geoeye Inc (2011).

The implication of this is that the West African environment can be monitored to stop illegal reclamations, ecosystem destructions, illegal constructions, and scraping of land surfaces, and illegal lumbering etc. Beyond detecting infrastructural changes, it is possible to detect flooding threats by observing the colour of the water bodies on the satellite images. These colours change with depth of the water body. Integrating the water depth data with weather forecasts is inestimable in predicting flooding.

With 0.5 to 1 m spatial resolution it is possible to detect heaps of refuse being dumped in river banks or other illegal places shortly after they start accumulating. Several other harmful practices to the environment can be monitored using GIS. The long 1m lines of seismic cuttings in the mangrove are visible as grid wire lines. Logging is discovered using the change detection tool of GIS over a time. It is obvious that in the modern West African cities monitoring by GIS is inevitable.

## FUTURE WEST AFRICAN URBAN CITIES

Given the improving understanding of the complex problems of urbanization, different approaches are being adopted across the globe to deal with these problems. Debates are also on going on best practices. For instance which is better: to grow a city horizontally or vertically? In horizontal expansion the argument is that lower human population density leads to less human impact on the environment. However some like Ginkel (2008), argue that vertical city growth, where housing in skyscrapers encourage high population density, limit humans from accessing and impacting more environmental space.

The future West African urban cities should be planned with an eye on responding positively to the already noted many urban environmental problems. Training of more personnel on the development and use of the Geographic Information System will be critical in handling the urban planning challenges effectively.

Some of the general points that need to be considered are briefly discussed below:

i) encourage urban cities to be more upland: Given the fact of global warming which is resulting in the overflow of the seas, it is common sense to consider that future cities should be sited on higher grounds than the level of the immediate sea shore where the present West African cities are located. This way the surge of the sea into urban habitations will be mitigated.

ii) Ecosystem planning: Planning of future cities in West Africa should take the factors of ecosystem planning seriously. Such practices such as reclamations, scraping of surfaces, bearing of earth surfaces, paving of entire premises, and disregard for the ecosystems should be discouraged.

iii) Provision of adequate infrastructure: Inadequate infrastructure for the use of the urban community quickly gets worn out and over used due to the pressure of the high population. There is the need to provide adequate infrastructure such as roads, water, sanitation, public transport, housing and electricity and domestic energy in a sustainable way. For the future urban centers of West African urban centers will need to be provided and lack of provision of necessary facilities to serve the urban cities.

iv) Effective drainage systems: The importance of effective drainage systems cannot be overemphasized given the tendencies of the urban cities to flood. Adequate and effective drainage systems should be provided to ensure that storm water runoffs are handled without inducing erosion or flooding. The effective drainage systems design should be carried out taking full consideration of the geomorphology of the area involved and the runoff potentials. For the urban area, the 100- year storm event should be used in calculating runoff.

v) Guided city growth: Urban centre managers must admit from start that the city however planned will outgrow what is provided for initially. Adequate arrangements must be made to manage the growth of the city in such a way that future growths are provided for. It is also to be considered to grow other urban centers so that no one urban area will be under too much growth pressure at any time.

vi) Collaboration among West African governments: West African Urban Planners should group land masses in regions. Normally, regions are quite large, and may incorporate multiple urban settlements, suburbs, rural areas and reserves. For ecosystem planning there is need to integrate some level of general planning by the governments of West Africa. This can be achieved through the Economic Community of West Africa (ECOWAS) or her agency. At this level the aim is to provide policies to ensure that naturally linked up ecosystems are still linked up in the resulting urban plans and that decisions on what should be preserved are taken with the entire region in view.

For optimal use and conservation of the urban environment, planners of urban areas should consider the morphology of the different areas and employ the criteria of environmental homogeneity in grouping areas under regions across a country. This will ensure that measures taken in a region to preserve the environment will have the same positive effect across. It will also provide units for gauging the effect of planning options and decisions. In the developing world, many urban areas are planned in layouts in a strip-wise manner. The detailed planning efforts of providing infrastructures, placing roads, gutters and storm water catchment basins concentrate on the strip of land in consideration. A regional level planning often called master- plan only locates the major roads and railways that will run across the entire region and major features that may serve the region such as military barracks, tertiary healthcare facilities, government centers and airports. Generally, the only scientific criteria considered in choosing the region to locate an urban area, is the extent of land required.

## CONCLUSION

Urbanization is the way forward and it will continue as people clog together to offer services to earn their living. Humans cannot however continue to destroy the environment. That should be in the past now. The
Geographic Information System offers the 21st century urban areas of West Africa the opportunity to optimize the use and preserve the environment.

Policy makers and urban area monitoring bodies should no longer feel helpless in the face of the rapid growth of urban centers. With GIS, hundreds of squares of kilometers can employ globally attested best practices for satisfactorily planning and monitoring the West African urban environment.

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# Assessment of some heavy metals and physicochemical properties in surface soils of municipal open waste dumpsite in Yenagoa, Nigeria

**AMOS-TAUTUA, Bamidele Martin W.[1]*, ONIGBINDE, Adebayo O.[2] and ERE, Diepreye[1]**

[1]Department of Chemical Sciences, Faculty of Science, Niger Delta University, Wilberforce, P.M.B 071, Yenagoa, Bayelsa State, Nigeria.

[2]Chemistry Unit, Basic Sciences Department, Babcock University, Ilishan, Remo, Ogun State, Nigeria.

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**The current study was designed for the assessment of lead, cadmium and chromium and some physicochemical properties of soils collected from an open dumpsite in Yenagoa, Nigeria. Surface soil samples at two depths (0-10 and 10-20 cm) were randomly collected at the dump field and control site, and were analyzed for physicochemical parameters and contamination by lead, chromium and cadmium using standard analytical methods. The results show that the main dumpsite had higher sand (>80.0%) and lower clay and silt contents than the control site. Soil mean pH varied between 4.89±0.05 in the control and 7.60±0.02 in the dump. Total nitrogen (N) content of the dump soils ranged from 0.06±0.07 to 0.24±0.09% and is slightly higher than that of the control soil. This is reflected in the high value of organic matter (4.71±0.85%) in dump soils. Available P was quite high ranging from 35.00±1.01 to 84.20±1.02 mg/kg. Cation exchange capacity (CEC) varied between 12.98±0.31 and 91.07±0.11 cmol kg$^{-1}$. ECEC levels were moderate to high ranging from 14.10±0.10 to 91.47±0.11 cmol/kg. All the soil samples had very high base saturation (>90.0%) and exchangeable Ca, Mg, K and Na, far above the critical levels set by FAO for agricultural soil. Average levels of Pb ranged from 14.75±0.05 to 16.14±0.04 mg/kg in the dump and 8.35±0.05 to 8.78±0.07 mg/kg in the control. Mean concentration of Cr in the dump soil varied between 0.05±0.01 and 0.06±0.01 mg/kg, and is slightly higher than the control (0.005±0.01 mg/kg), while Cd was found in trace amounts (<0.0001±0.01 mg/kg). These values are all far below the maximum tolerable levels set by FAO and WHO for agricultural soil. It is suggested that the dumpsite and the control area with their adequate soil nutrients and low levels of metals should eventually be converted to agricultural farmland. No remediation is needed at this time.**

**Keywords:** Dump waste soil, heavy metal, soil fertility.

## INTRODUCTION

Landfills have long been used as repositories for industries, municipal and commercial wastes. Nigeria, a developing country with non adequate waste disposal or recycling processes is at a risk of metal and organo-metallic contamination of its soil and surface water bodies, which poses health hazard and soil deterioration for agricultural purposes. Yenagoa Township, the capital city of Bayelsa State is located in a humid tropical, wetland area where high rainfall and temperatures favour rapid degradation of organic materials (Ayolagha, 2001).

In Bayelsa State, solid wastes are handled by the Bayelsa State Ministry of Environment. The Ministry has

*Corresponding author. E-mail: bweinpere@yahoo.com.

allocated an extent of land along Yenagoa-Tombia road for disposal of solid wastes collected from Yenagoa town and its environs. As Yenagoa is a non-industrialized city, the refuse generated within the city comprise largely of degradable materials from markets, offices, hospitals and households such as garbage, plastics, textiles, stationeries, sludge from sewage, dead animals, ashes, wood, food and farm waste products. However, metallic materials from damaged vehicle parts, electronics, computers, cans, etc, are also disposed in the same way as the other non-metallic materials, thereby constituting a source of metal contamination.

Open dumps are generally unsanitary and constitute malodorous places in which disease-carrying vermin such as rats and flies proliferate (Bellebaum, 2005). Methane and other gases are released into the surrounding air as microorganisms decompose the solid wastes and fires pollute the air with acrid smoke and other numerous volatiles. Liquids that ooze and seep through the solid waste heap ultimately reach the soil, surface water and ground water. Hazardous materials such as heavy metals, pesticides and hydrocarbons that are dissolved in this liquid often contaminate soil and water (Adelekan and Alawode, 2011). Anikwe and Nwobodo (2001) suggested that continuous disposal of municipal waste on soil may lead to increase in heavy metals in the soil and surface water that would be inimical to deep feeding plants. Heavy metals such as arsenic, cadmium, lead, chromium, nickel, cobalt and mercury are of concern primarily because of their ability to harm soil organisms, plants, animals and human beings (Adelekan and Abegunde, 2011). More emphatic are the untreated dumplings that rapidly increase soil toxicity making such large area dumpsites potentially hazardous for agricultural purposes. Yet these workers (Anikwe and Nwobodo, 2001; Adelekan and Alawode, 2011; Adelekan and Abegunde, 2011) also indicate that municipal waste dumpsites bear soils that are sufficiently rich in organic matter that would be acceptable for surface feeder plants. Consequently, Brady (1996) and Helmore and Ratta (1995) reported that open dump fields perform a dual purpose of safe disposal of wastes and simultaneously create improved physical and chemical properties of soils that constitute productive agricultural fields. Other studies have also revealed that dumpsites around two major cities in Nigeria could be effectively utilized for residential and agricultural purposes without risk of heavy metal toxicity (Urunmatsoma and Ikhouria, 2005; Asalawalam and Eke, 2006). Old dump fields therefore can be seen to provide farmers with fertile plots for cultivation of vegetables and other surface feeder crops.

Public concern about environmental pollution has focused attention on the disposal of urban and industrial waste hence this study intends to determine the contents of lead, chromium and cadmium and the fertility status of the soil of the dump field in Yenagoa area in view of interpreting the suitability of its soil for crop production.

## MATERIALS AND METHODS

### Study area

Yenagoa, the capital city of Bayelsa State, Nigeria lies between latitude 4° 50' to 5° 00' North and longitude 6° 11' to 6° 25' East. The town is located in a humid tropical wetland area with mean annual rainfall of about 2539 mm and an average mean temperature of 26.2°C. The dump field investigated is located opposite HPEB 119 Company along the Yenagoa-Tombia road lying between latitude 4° 58' 59.20"North and longitude 6° 19' 18.20"East (Ayolagha, 2001).

### Waste soil sampling

Surface soil samples, after removing the overlying wastes, were collected randomly from the dump field at two depths; 0-10 and 10-20 cm using a Dutch soil auger and a spatula. Another set of soil samples were also collected at the same depths, from uncultivated land, at 100 m away from the dump site, to serve as control. The soils were air dried for three days, ground and sieved through a 2 mm sieve. These were stored in labelled polythene bags and were taken to the laboratory for analysis.

### Analyses of some physico-chemical parameters of soil samples

Particle size distribution otherwise known as mechanical analysis was determined by hydrometer method (Bouyoucos, 1962) using sodium hexametaphosphate as dispersant. The texture class was also determined using the 'textured triangular diagram' (Loganathan, 1984).

Soil pH was measured in water suspension (1:2.5) using the glass electrode coupled pH meter. The potential acidity was measured in a 1:10 (w/v) ration of soil to solution of 1 M KCl.

The cation exchange capacity (CEC) was determined by extracting the cations with 1 M ammonium acetate buffered at pH 7. 30 ml of 1 M $CH_3COONH_4$ was added to 5 g of soil. The suspension was shaken for 2 h and then centrifuged (15 min, 6000 rpm). After centrifugation and filtration, the filtrate was transferred into a 100 ml flask and two other volumes of 30 ml ammonium acetate were added successively after 30 min of agitation and centrifugation. The final filtrates were completed to 100 ml with ammonium acetate solution.

Calcium (Ca) and magnesium (Mg) were determined by EDTA titration while potassium (K) and sodium (Na) were determined by flame photometry. Exchangeable acidity (EA) was determined by titration method (Juo, 1979). The effective cation exchange capacity (ECEC) was calculated as the total exchangeable bases plus exchangeable acidity.

Percentage base saturation (BS%) was calculated as the percentage of the sum of exchangeable bases divided by ECEC. Available phosphorous (Av. P) was extracted with Bray solution 11 and the phosphorous determined by the molybdenum method described by Udo and Ogunwale (1978). The percent organic matter (%OM) was calculated from the percent organic carbon (OC%) measured using Walker-Black (1934) wet oxidation method. Total nitrogen (TN) was determined using the modified Kjeldahl distillation methods (Juo, 1979).

### Sample preparation and analyses of heavy metals

One gram of each of the sieved soil samples was digested using the nitric/perchloric acid digestion procedure, as described by Odu et al. (1986). The concentrations of heavy metals, Pb, Cr and Cd

**Table 1.** Physical properties/particle size distribution and metal concentrations of soil samples

| Sample Code | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture | pH $H_2O$ | Pb (mg/kg) | Cr (mg/kg) | Cd (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| DS | 0-10 | 87.40 ±0.03 | 6.12 ±0.02 | 6.48 ±0.03 | Loamy sand | 7.09 ±0.02 | 14.75±0.04 | 0.05 ±0.01 | <0.0001±0.01 |
| | 10-20 | 91.42 ±0.02 | 3.14 ±0.02 | 5.46 ±0.02 | Sandy | 7.60 ±0.01 | 16.14±0.05 | 0.06 ±0.01 | <0.0001±0.01 |
| CS | 0-10 | 39.41 ±0.01 | 16.13±0.01 | 46.47 ±0.04 | Clay | 5.01 ±0.03 | 8.78 ±0.07 | 0.005±0.01 | <0.0001±0.01 |
| | 10-20 | 37.40 ±0.03 | 14.15±0.01 | 48.45 ±0.03 | | 4.89 ±0.05 | 8.35 ±0.05 | 0.005±0.01 | <0.0001±0.01 |

DS = Dumpsite; CS = control site. Data represent mean ± SD of two replicates.

**Table 2.** Chemical properties of soil samples.

| Sample Code | Depth (cm) | pH KCl | pH $H_2O$ | ΔpH | Av. P (mg/kg | OC | OM | TN | C/N | Exchangeable cation Ca | Mg | K | Na | CEC | EA | ECEC | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ← % → | | | | ← (cmol/kg) → | | | | | | | |
| DS | 0-10 | 5.90 ±0.02 | 7.09 ±0.02 | -2.81 ± 0.01 | 84.20 ±1.02 | 2.73 ±1.25 | 4.71 ±0.85 | 0.24 ±0.09 | 11.38 ±0.67 | 72.80 ±0.05 | 14.00 ±0.12 | 2.36 ±0.06 | 1.91 ±0.23 | 91.07 ±0.11 | 0.40 ±0.04 | 91.47 ±0.11 | 99.56 ±0.03 |
| | 10-20 | 5.86 ±0.01 | 7.60 ±0.01 | -2.26 ± 0.01 | 68.22 ±0.89 | 0.60 ±1.07 | 1.03 ±0.64 | 0.06 ±0.07 | 10.00 ±0.57 | 45.60 ±0.10 | 12.40 ±0.07 | 1.13 ±0.10 | 1.95 ±0.08 | 61.08 ±0.09 | 0.96 ±0.06 | 62.04 ±0.10 | 98.45 ±0.05 |
| CS | 0-10 | 4.32 ±0.03 | 5.01 ±0.03 | -1.21 ± 0.03 | 37.12 ±0.85 | 1.98 ±1.03 | 3.38 ±0.56 | 0.15 ±0.86 | 13.20 ±0.94 | 10.35 ±0.09 | 5.72 ±0.11 | 0.26 ±0.11 | 0.48 ±0.17 | 16.81 ±0.12 | 1.66 ±0.87 | 18.47 ±0.09 | 91.01 ±0.02 |
| | 10-20 | 4.26 ±0.02 | 4.89 ±0.05 | -1.37 ±0.04 | 35.00 ±1.01 | 1.87 ±1.06 | 3.22 ±0.55 | 0.14 ±0.43 | 13.36 ±0.74 | 8.00 ±0.08 | 4.40 ±0.65 | 0.17 ±0.20 | 0.41 ±0.09 | 12.98 ±0.31 | 1.12 ±0.66 | 14.10 ±0.10 | 92.06 ±0.04 |

DS, Dumpsite; CS, control site; Av. P, available phosphorous; OC, organic carbon; OM, organic matter; TN, total nitrogen; C/N, carbon/nitrogen ratio; CEC, cation exchangeable capacity; EA, exchangeable acid; ECEC, effective cation exchangeable capacity; BS, base saturation. Data represent mean ± SD of two replicates.

were determined using atomic absorption spectrophotometer (UnicamSolaar32 model) following the standard procedures as given in APHA (1995). All analyses were done in duplicates.

## RESULTS AND DISCUSSION

### Characteristics of the soil samples

The results expressed as mean ± standard deviation of physico-chemical properties of the soils are presented in Tables 1 and 2.

### Textural properties

Texture is related to certain physical properties of soil such as plasticity, permeability, ease of tillage, fertility, water holding capacity and overall soil productivity. For instance, for irrigation purposes, loamy and clay textures are classed as soils of high moisture holding capacity while loamy sands and sands have low moisture holding capacity (Brady, 1996).

In this study, the main dumpsite had higher sand and lower clay and silt contents than the control site. This was corroborated by Ideriah et al. (2006) who determined the soil quality around a solid waste dumpsite in Port-Harcourt, Nigeria, which is in the same humid tropical wetland area as Yenagoa.

According to Nyles and Ray (1999), soils with separate high sand and low clay content have high pollutant leaching potentials. Though the soils of the dumpsites predominantly contain high sand fractions (>80.0%) that allows high permeability of water and leacheates, the textural class (loamy sand) may be suitable for sanitary landfills (Loughry, 1973). The soils from the control sites consisted of moderately high clay fractions thus they exhibit plasticity and encourage surface water flooding and pollution. This clayey texture of the control soils also favours low permeability of water and leacheates (Ahn, 1993).

### pH measurement

pH affects the mobility of heavy metals in soil. It has been found that soil pH is correlated with the availability of nutrients to the plant (Gray et al., 1998). Consequently, as pH decreases, the solubility of metallic elements in the soil increases and they become more readily available to plants (Oliver et al., 1998; Salam and Helmke, 1998).

Lower pH would favours availability, mobility and redistribution of the metals Pb and Cd in the various fractions due to increased solubility of the ions in acidic environment (Oviasogie and Ndiokwere, 2008). In the present study, soil pH (in $H_2O$) ranged from 4.89±0.05 in the control to 7.60±0.02 in the dump indicating a moderate acidic to a neutral reaction. The moderately acidic soil from the control site may tend to have an increased micronutrient solubility and mobility as well as increased heavy metal concentration in the soil (Odu et al., 1985). The value of KCl pH bears a strong correlation with aluminium saturation. Aluminium displaced by $K^+$ on the exchange complex consumes $OH^-$ ions and increases $[H^+]$. The KCl pH values in the soils from the control are less than 5.2 which showed that exchangeable aluminium is present in the soils while the values in the dump soils were greater than 5.2 which are indicative of the presence of non-exchangeable aluminium. This could be attributed to hydrolysis, polymerization and precipitation (USDANRCS, 2004)

ΔpH is the numerical difference between the values of pH measured in KCl and $H_2O$, which results from the displacement of $OH^-$ ions by $Cl^-$ ions. It also highlights the displacement of the ions $H^+$ adsorbed on the exchange sites of the adsorbing complex from soil towards the soil solution (Yobouet et al., 2010). Since the ΔpH values for all the soil samples were negative, it means that the colloids have net negative charge which reflects the cation-exchange capacity as seen here which is very high (USDANRCS, 2004).

### Organic carbon and soil organic matter

The presence of organic carbon increases the cation exchange capacity of the soil which retains nutrients assimilated by plants. Total organic carbon in the soils under investigation in this study was low to moderate ranging from 0.6±1.07 to 2.73±1.25% as indicated in Table 2. The moderately high amount of organic carbon of the refuse dump soils is suggestive of degradation or presence of degradable and compostable wastes (Munoz et al., 1994).

Soil organic matter (SOM) enhances the usefulness of soils for agricultural purposes. It supplies essential nutrients and has unexcelled capacity to hold water and absorb cations. It also functions as a source of food for soil microbes and thereby helps enhance and control their activities (Brady, 1996). The organic matter in the soil samples varied from 1.03±0.64 to 4.71±0.85%. The dump soils contain high amount of organic matter, about 4.71±0.85% which may be responsible for increase in the soil pH as compared to that of the control soil. This observation was supported by Oyedele et al. (2008) who reported that dump sites had significantly higher pH regime and soil organic matter as compared to the control soil. Ayolagha and Onwugbuta (2001) also demonstrated that high OM (>2.0%) in soils is conducive for heavy metal chelation formation.

### The total nitrogen content

The total N content of dump soils ranged between 0.06±0.07 and 0.24±0.09% which is slightly higher than those of the control site which varied between 0.14±0.43 and 0.15±0.86%. The C/N calculated ranged from 10.00±0.57 in dump soil to 13.36±0.74 in control soil. Our result was supported by Brady (1996) who reported that C/N ratio in the topsoil is commonly between 10 and 12 in humid regions. Onwurah (2000) stated that C/N ratio is an index of biomass and they are responsible for the general restoration of microbial flora. Generally, if the ratio is below 20, this is often adequate to satisfy the N requirements of micro flora that decompose the residues (Eja et al., 2003). According to Ideriah et al. (2006), the low values of C/N ratios showed high decomposition and efficient mineralization process of the dump area. The waste dump C/N ratio is between 10.00±0.57 and 11.38±0.67 and it is lower than that of the control soil which is between 13.20±0.94 and 13.36±0.74. Therefore, the waste dump most likely contributed significantly to the very high levels of these soil properties.

### Available phosphorous

The dumpsite had higher levels of P ranging from 68.22±0.89 to 84.20±1.02 mg/kg as compared to the control which varied between 35.00±1.01 and 37.12± 0.85 mg/kg; this could be attributed to the presence of high amount of organic matter and plants decomposition

(Ideriah et al., 2006). The high concentration of phosphorous contributes to good growth of plants as was observed. All the soil samples had available P values more than 10 mg/kg considered suitable for crop production (FAO, 1976).

**Cation exchange capacity**

The cation exchange capacity is the amount of exchangeable cation per unit weight of dry soil that plays an important role in soil fertility. It depends especially on the pH, clay and on the soil organic matter content. Results of this study revealed that soils from the dump had higher values of CEC ranging from 61.08±0.09 to 91.07±0.11 cmol $kg^{-1}$ as compared to that of the control site which varied between 12.98±0.12 and 16.81±0.31 cmol $kg^{-1}$, although the clay content at the dumpsite was much smaller than that at the control site. So it is possible that a large part of exchangeable bases at the dumpsite must have been existing as a water-soluble form rather than an exchangeable form adsorbed at cation exchange sites. The increase in the TEB and organic matter in the dump field may result in plants taking up nutrients more easily (Aydinalp and Marinova, 2003).

ECEC levels were moderate to high varying from 14.10±0.10 to 91.47±0.11 cmol/kg. However, the ECEC status of dump soils was higher than those of the control and far above 20 cmol/kg regarded as being suitable for crop production (FAO, 1976). All the soil samples analyzed had very high base saturation (>90.0%) and were higher than 60%, the critical limit established for ecological zone (Holland et al., 1989). This also followed the pattern reported by Isirimah et al. (2003) for productive agricultural soil. The exchangeable acidity (EA) was generally low varying between 0.40±0.04 and 1.66±0.87 cmol/kg.

All the soil samples had high Ca values above 4.0 cmol/kg regarded as lower limit for fertile soils (FAO 1976). Exchangeable K varied from 1.13±0.10 to 2.31±0.06 cmol/kg in dump soils; these are higher than the levels in control soils and above 0.2 cmol/kg which is regarded as the critical limit of exchangeable K in soils (Unamba-Opara, 1985). The implication of these is that the soils are rich in nutrients and therefore an indication of good yield potential without any input of fertilizers.

**Heavy metal concentrations**

The evaluation of dumpsite soils for the concentration levels of toxic elements is essential for healthy crop production, thus this study has endeavoured to determine the levels of Pb, Cr and Cd in the various soil samples.

The distribution of mean concentration± standard deviation of the metals present in the soils is shown in Table 1. The result shows that the metal loads from the refuse dump soils were found to be slightly higher than the control area (100 m from the dumpsite) with the exception of Cd which was found in traces in all the soils. Our results are collaborated by Al-Turki and Helal (2004) and Ren et al. (2005) who reported that lead and cadmium are anthropogenic metals, and without external interference, are normally not abundant in upper layer soils.

**Lead**

The mean levels of Pb ranged from 14.75±0.04 to16.14±0.05 mg/kg in the soil samples from the dumpsite and 8.35±0.05 to 8.78±0.07 mg/kg in the control. These values were lower than EC (1986) upper limit of 300 mg/kg and the maximum tolerable levels proposed for agricultural soil, 90-400 mg/kg set by WHO (1993) and NEPCA (2010). This is in agreement with the results obtained from similar study by Umoh and Etim (2013) for soils from dumpsites within Ikot-Ekpene in Akwa-Ibom State, Nigeria.

Concentration of lead in the soils from both areas could be as a result of its sources from automobile exhaust fumes as well as dry cell batteries, sewage effluents, runoff of wastes and atmospheric depositions owing to the close proximity of the sites to high vehicular traffic along Yenagoa-Tombia road.

**Chromium**

The mean concentrations of Cr in the dump soil varied between 0.005±0.01 and 0.200±0.01 mg/kg, which was slightly higher, as compared to the control (0.005±0.01 mg/kg), but are still lower than the critical permissible level which is 50 mg/kg for soil recommended for agriculture by MAFF (1992) and EC (1986). Sources of Cr in the soils could be due to waste consisting of lead-chromium batteries, coloured polythene bags, discarded plastic materials and empty paint containers (Jung et al., 2006).

**Cadmium**

Cadmium levels in all the soil samples were found in trace amounts (0.0001 ± 0.01 mg/kg) and these values are far lower than the natural limits of 0.01-3.0 mg/kg in soil as given by MAFF (1992) and EC (1986).

The values of the metal concentrations obtained for both sites are all far below the maximum tolerable levels proposed for agricultural soil. This is in agreement with the findings of Asawalam and Eke (2006) and Njoku and Ayoka (2007) who investigated the trace metal concentrations and heavy metal pollutants from dump soils in Owerri, Nigeria.

Even though these heavy metal concentrations fell below the critical permissible concentration level, it seems that their persistence in the soils of the dump site may lead to increased uptake of these heavy metals by plants.

## Conclusion

The concentration of the metals, Pb, Cr and Cd are all far below the maximum tolerable levels set by FAO and WHO for agricultural soil. The results of this study have clearly demonstrated that the low levels of heavy metals in the studied soil samples are consistent with the composition of the municipal wastes generated in Yenagoa and its environs. The results also show that the soil is not polluted by various pollutants and not harmful for recreational and agricultural purposes. It is therefore suggested that the dumpsite and the control area with their adequate soil nutrients and low levels of metals should eventually be converted to an agricultural farmland. No remediation is needed at this time.

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*Full Length Research Paper*

# Evaluation of the performance of improved sweet potato (*Ipomoea batatas* L. LAM) varieties in Bayelsa State, Nigeria

**C. Wariboko* and I. A. Ogidi**

Department of Crop Production Technology, Niger Delta University, Bayelsa State, Nigeria.

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**This study was conducted using randomized complete block design with three replications each in two locations (Amassoma Wilberforce Island and Yenagoa, Bayelsa State) to evaluate the performance of improved sweet potato varieties (Ex-Igbariam, TIS 8164, 199004-2 and TIS 87/0087 including Kukunduku local) from March to June 2010. There were significant differences among varieties at both locations and across locations but locations and location x variety interaction were non-significant for sweet potato root yields. Ex-Igbariam and TIS 87/0087 had higher fresh root yields of 7.39 and 4.17 t ha$^{-1}$, respectively, than others across locations. Regarding trailing characteristic (soil surface cover), too, varieties were significantly different at both locations and across locations but location and location x variety interaction were non-significant with Ex-Igbariam and TIS 87/0087 having best soil surface cover, and consequently, best weed suppressants. There was incidence of diseases but that of insects was low. For fresh root phenotypic characteristics, Ex-Igbariam and 199004-2 had yellow flesh, indicative of the presence of vitamin A precursor. Since Ex-Igbariam, TIS 87/0087 and a few others showed real promise in yield and carotene content, carrying out a multi-locational trial would, hopefully, enable selection of high - yielding varieties for commercial production to improve farmers' yields and income in the different agro-ecological zones of Bayelsa State.**

**Key words:** *Ipomoea batatas* L. Lam, improved variety, yield, Nigeria.

## INTRODUCTION

Sweet potato (*Ipomoea batatas L. Lam*), the only member of the genus Ipomoea whose roots are edible, is one of the world's most important food crops because of its high yield, nutritive value and capacity to tolerate marginal environmental conditions (Hahn, 1977; Date and Eronico, 1987). It contains about 70, 1.5, 0.5, 25 and 1 water, fat, carbohydrate, fibre and ash, respectively (Martins and Leonard, 1955). Of the carbohydrates, 3-4.5% is sugar and the remainder mostly starch while 0.2 and 0.5% of the ash are calcium and phosphorus, respectively. Also, it contains carotene and fair quantities of ascorbic acid and B vitamins.

Regarding utilization, sweet potato cultivation is for human consumption (Hahn, 1977; Horton, 1988; Nwokocha and Okwowulu 1996; Tewe et al., 2000; Odebode, 2004: Odebode et al., 2008), livestock feed (Tewe and Ologhobo, 1983; Scott and Wall, 1992; Woolfe, 1992; Asuquo et al 1992; Asuquo and Anuebunwa, 1993; Okoroji et al., 1996; Onwubuemeli et al., 1996; Okposen et al., 1996; Ojeniyi and Tewe, 2003), industrial processing to make alcohol and starch (Martins and Leonard, 1955; Prain et al., 1997) including confectioneries (Obieri et al., 2004; Igbokwe et al., 2005; Uzoka et al., 2005; Odebode, 2004; Odebode et al., 2008). The green leaves

*Corresponding author: clintonwariboko@gmail.com

could be consumed by humans and animals (Okposen et al., 1996) including fish (Madugba et al., 2005) while the whole plant is a natural weed suppressant (Udealor et al., 1993; Nnawuchi et al., 2001; Melifonwu and Ikeorgu, 2003; Ajagu et al., 2005). Also, potato root intake is medicinal in combating blindness and diabetes in humans (Low et al., 1996; Carey et al., 1999).

Its large starchy sweet-tasting roots are an important root vegetable (Purseglove, 1992; Woolfe, 1992) and, sometimes, the young leaves and shoots are eaten fresh. Although the leaves and shoots are edible, the starchy tuberous roots are by far the most important product. In some tropical areas, they are a staple food crop.

In West African countries (Guinea, Sierra Leone and Liberia) as well as in Northeastern Uganda and East Africa, the consumption of young leaves and vine tips of sweet potato as a vegetable is common. In 1990, FAO reported sweet potato leaves and shoots as good source of vitamins A, C and B2 (riboflavin) (FAO, 1990). However, sweet potato varieties with dark orange flesh have more beta carotene than those with light coloured flesh and their increased cultivation is being encouraged in Africa where vitamin A deficiency is a serious health problem (Hagenimana et al., 1999b).

Right now, sweet potatoes are useful in Africa to combat a widespread vitamin A deficiency that results in blindness and even death for 250,000 - 500,000 African children yearly. About two - thirds of the children developing xerophthatmia, the blindness - inducing disease resulting from lack of vitamin A, die within a year of losing their sight (Low et al., 1996; Carey et al., 1999; Bourke and Vlassak, 2004). Though for long it has been a staple food of the continent's diet, the African sweet potato contains white flesh which has no beta carotene (a precursor to vitamin A) unlike its sweeter, yellow-orange fleshed relative.

Although researchers long believed that African states would reject the coloured variety, an International Potato Centre (CIP) project conducted in Eastern and Southern Africa over the past ten years has identified a yellow-orange variety palatable to Africans (Woolfe, 1992). The researchers complemented their findings with the development of a nutritional education programme that has been successful in motivating African mothers to accept new varieties of sweet potato. Now researchers intend to focus their efforts on developing a more productive crop and expanding the reach of their education programme (Wardle et al., 1991).

Globally, sweet potato is a very important food crop and ranked fourth in terms of consumption as the world's most important. FAO (2004) reported that approximately 129,536,275 million tons were produced in more than 100 countries and Asia as the world's largest sweet potato - producing region with 114 million tons annually as the leading supplier of sweet potatoes. However, nearly half of the sweet potatoes in Asia are for animal feed with the remainder primarily for human consumption either as fresh or processed products. In contrast, African farmers produce only about 12 million tons of sweet potatoes annually but most of the crop is for human consumption. Also, they indicated the world potato hectarage in 2004 as 9074459 ha comprising 4874180, 945000, 602000 and 500,000 ha from China, Nigeria, Uganda and Tanzania, respectively. However, the major obstacles to sweet potato growth in the tropics are insects and diseases such as the sweet potato weevils and viral diseases.

In China, recent research by CIP personnel has shown that sweet potato yield could increase by as much as 30 - 40% without additional fertilizer, pesticide or genetic improvement (Prain et al., 1997). In a five year project in the province of Anhui and Shandong, using a procedure that eliminates viral diseases from planting materials, scientists had virus-free cuttings that developed into healthy plants. Extending this to all of China's sweet potato-growing regions, benefits exceeding USD$1.5 billion could be realized and would considerably reduce the country's reliance on cereal imports for livestock feed.
In Kwara State, sweet potato enjoys the high cultural status of yams (*Dioscorea* sp.) in Southern Nigeria celebrating with feasts and cultural dances. Although Nigeria produces only 0.2% (about 0.26 million tons per year on 20 - 25 thousand ha) of the world total (Horton, 1988), there are indications of the crop turning into a life saver and foreign exchange earner for Nigeria. It has a 4-month growth cycle and its cultivation could be two to three times with supplementary irrigation.

On-shelf technology from National Root Crops Research Institute, Umudike, Nwokocha and Okwowulu (1996) reported mean total yields of 8.41, 15.18 and 11.16 t $ha^{-1}$ in 1993 including 9.15, 14.32 and 19.85 t $ha^{-1}$ in 1995 for improved varieties TIS 8441, 87/0087 and 8164, respectively. Later, Ojeniyi and Tewe (2003) indicated that the International Institute of Tropical Agriculture (IITA), Ibadan and the National Root Crops Research Institute (NRCRI), Umudike had reported high agronomic yield potential of sweet potato as a food security crop in Nigeria but the high potential was yet to be converted into increased output under the present cropping system.

However, one of the reasons identified for the failure to achieve increased sweet potato production in Nigeria was the bad agronomic system of cultivation. Also, the devastating pests notably *Cylas* sp. (sweet potato weevil), viruses and rots need control. After harvest, up to 80-100% of the roots could be lost within one to two weeks and so effective storage methods are necessary. The dark/brown discoloration of the sweet potato flour on or after reconstitution needs elimination.

*Cylas* sp., the most economically important field pest which devastates the root tubers of sweet potato has been a major constraint in production. *Acraea acerata* is a pest reported for the first time at Umudike in 1985 and population dynamics of *A. acerata* showed it as mainly a dry season pest occurring mainly from mid-November to mid-December (Anioke et al., 1987). However, the incidence of pests is, generally, low due to prolonged rainy season which is inimical to the development of insect pests (Anioke et al., 1990). Also, they reported TIS 81/647 as having the highest percentage of *Cylas* sp. damage on its tuber but TIS 2498 and TIS 87/0087 were found to be tolerant to the weevil *A. acerata* Hew damage on foliage. In addition, they reported the incidence of young instars of *Zonocerus variegatus* which caused serious damage to leaves. In 1991, NRCRI reported TIS 87/0087 as having good growth habit and tolerance to virus and *Cylas* sp. when harvested at four months. Based on the fact that sweet potato creeps, it is a natural weed suppressant, and given the right plant density and appropriate varieties, can develop a thick cover fast (Nwokocha, 1992). However, it has been observed that a mixture of Alachlor (Lasso) and Cloramben mixed at the rates of 1.92 and 2.88 kg ai/ha, respectively, has served in NRCRI, Umudike as an effective pre-emergence herbicide (Nwokocha, 1992).

Since sweet potato is important in Bayelsa State, it features in the farming system with growing interest. Usually, farmers cultivate local varieties which are not only low-yielding and less nutritive but, also, susceptible to diseases including insects and, some late-maturing, making evaluation of improved varieties for cultivation necessary.

The objective of this study, therefore, was to evaluate the performance of improved sweet potato varieties that would enable selection of high-yielding ones for commercial production to improve farmers' yields and income in Bayelsa State, Nigeria.

## MATERIALS AND METHODS

A field experiment was conducted from March to June 2010 at two locations (Amassoma and Yenagoa, Bayelsa State) both in the Niger Delta humid tropics with bimodal rainfall pattern. The experiment was conducted on a two-year fallow land previously cultivated with maize (*Zea mays*). Four improved varieties (Ex-Igbariam, TIS 8164, 199004-2 and TIS 87/0087) from National Root Crops Research Institute (NRCRI) Umudike and a locally grown variety Kukunduku (control from Amassoma) in a randomized complete block design with three replications. After taking pre-cropping soil samples for analysis and land preparation without liming since smallholder farmers usually do not apply lime, planting of sweet potato was with four node vines plots at 100 x 30 cm spacing giving a population density of 33,333 plants per hectare. Weeding was at 4 and 8 weeks after planting (W.A.P) and basal application of 100 kg/ha NPK 20:10:10 fertilizer after the first weeding. A total of 5 treatments were used and these were replicated thrice. Plot size was 5 x 4 m. The treatments are: $T_1$- Ex-Igbariam; $T_2$- TIS 8164; $T_3$- 199004-2; $T_4$- TIS 87/0087; $T_5$- Kukunduku local (control).

All these potato varieties are, however, phenotypically viny and trailing varieties. Sweet potato fresh root yield was determined in tonnes per hectare including soil surface cover (trailing characteristic) on a scale of 1-5 with 1 as very good, 2 good, 3 average, 4 bad and 5 very bad.

Insect and disease incidence was on a scale of 0-5 with 0 as absent and 5 high as well as fresh root phenotypic characteristics (skin and flesh colour).

### Statistical analysis obtained

The data obtained were subjected to analysis of variance (ANOVA) according to procedures of Statistical Analysis System (SAS 1999) and split plot arrangement (combined analysis) by Gomez and Gomez (1984). Differences between means were determined using least significant difference (LSD) statistic ($p \leq 0.05$).

## RESULTS

### Chemical and physical properties of soil at the experimental sites

The soil was clay, acidic (low pH) as well as low in organic matter and total nitrogen including essential nutrients (Table 1).

### Sweet potato fresh root yields

The results obtained show that the treatments (varieties) were significantly different at Amassoma and Yenagoa locations. In Amassoma location, TIS 8164, 199004-2, TIS 87/0087 and Kukunduku local were not significantly different but were significantly different from Ex-Igbariam which had the highest fresh root yield (12.81 t $ha^{-1}$) followed by TIS 87/0087, TIS 8164, 199004-2 and Kukunduku local which had 7.48, 7.01, 5.99 and 5.67 t $ha^{-1}$, respectively (Table 2). Although the trend was the same at Yenagoa, mean fresh root yields were higher at Amassoma.

In a combined analysis using split plot arrangement with locations as main plot and treatment sub plot, the results obtained (Table 3) show means for fresh root yields of the sweet potato varieties across locations as 7.39, 4.19, 3.93, 3.28 and 3.09 t $ha^{-1}$ for Ex-Igbariam, TIS 87/0087, TIS 8164, 199004-2 and Kukunduku local, respectively, still, with the same trend.

### Soil surface cover (trailing characteristics)

In Table 4, there are means for the soil surface cover (trailing characteristic) and the results obtained at Amassoma and Yenagoa locations showed that treatments (varieties) were significantly different. In Amassoma, TIS 87/0087 had the highest (best soil surface cover) followed by Kukunduku local, TIS 8164, Ex-Igbariam and 199004-2 with 4.3, 3.8, 3.3 and 2.7, respectively, whereas at Yenagoa, TIS 87/0087 and Kukunduku local were highest and non-significantly different but significantly different from TIS 8164, Ex-Igbariam and 199004-2 which had 3.8, 3.3 and 2.6, respectively. In a combined analysis using split plot

**Table 1.** Soil characteristics of Amassoma, Wilberforce Island and Yenagoa locations.

| Parameter | | Amassoma, W. Island | Yenagoa |
|---|---|---|---|
| Organic matter (%) | | 1.81 | 1.9 |
| pH* | | 4.8 | 4.32 |
| Mechanical | Sand | 23 | 25 |
| Analysis (%) | Silt | 31 | 34 |
| | Clay | 46 | 41 |
| Soil texture | | Clay soil | Clay soil |
| Total N (%) | | 0.07 | 0.09 |
| Available P (mg/kg) | | 78.1 | 86.6 |
| CEC (cmo1/kg) | | 2.0 | 2.02 |
| | Ca | 1.16 | 1.41 |
| Exchangeable | Mg | 10.0 | 12.0 |
| Bases (cmo1/kg) | K | 47.0 | 48.0 |
| Base saturation | | 42 | 51 |

*pH in 1:10 distiled water.

**Table 2.** Mean fresh root yields (t $ha^{-1}$) of sweet potato varieties at Amassoma, Wilberforce Island and Yenagoa.

| Treatment | Amassoma, W. Island | Yenagoa |
|---|---|---|
| Ex-Igbariam | 12.81 | 11.81 |
| TIS 8164 | 7.01 | 6.08 |
| 199004 - Z | 5.99 | 4.96 |
| TIS 87/0087 | 7.48 | 6.44 |
| Kukunduku local | 5.67 | 4.64 |
| LSD .05 | 2.31 | 2.44 |

**Table 3.** Mean fresh root yields (t $ha^{-1}$) of sweet potato varieties across locations.

| Treatment | Fresh root yields |
|---|---|
| Ex-Igbariam | 7.39 |
| TIS 8164 | 3.93 |
| 199004 - Z | 3.28 |
| TIS 87/0087 | 4.19 |
| Kukunduku local | 3.09 |
| LSD .05 | 1.61 |

**Table 4.** Mean soil surface cover* of sweet potato varieties at Amassoma, Wilberforce Island and Yenagoa locations.

| Treatments | Amassoma | Yenagoa |
|---|---|---|
| Ex-Igbariam | 3.5 | 3.1 |
| TIS 8164 | 3.8 | 3.8 |
| 199004 - Z | 2.7 | 2.6 |
| TIS 87/0087 | 4.9 | 4.3 |
| Kukunduku local | 4.3 | 4.3 |
| LSD 0.05 | 0.42 | 0.42 |

*Indicates soil surface cover (1-5) 1 as very good, 2 as good, 3 average, 4 bad and 5 very bad.

**Table 5.** Mean soil surface cover* of sweet potato varieties across locations (Amassoma, Wilberforce Island and Yenagoa) in Bayelsa State.

| Treatments | Soil surface cover |
|---|---|
| Ex-Igbariam | 1.92 |
| TIS 8164 | 2.28 |
| 199004 - Z | 1.58 |
| TIS 87/0087 | 2.58 |
| Kukunduku local | 2.58 |
| LSD .05 | 0.27 |

arrangement, locations and location x varieties interaction were non-significant while there were significant differences among varieties for this characteristic across locations (Table 5).

## Insect and disease incidence

The results obtained (Table 6) showed no incidence of diseases but that of insects was low.

## Fresh root phenotypic characteristics (skin and flesh colours)

Among the sweet potato varieties involved (Table 7), visual observation of fresh root cuttings showed that Ex-Igbariam and 199004-2 had yellow flesh indicative of the presence of vitamin A precursor (carotene).

**Table 6.** Incidence of diseases and insects* on sweet potato varieties at Amassoma, Wilberforce Island and Yenagoa locations.

| Treatment | Amassoma | | Yenagoa | |
|---|---|---|---|---|
| | Disease | Insect | Disease | Insect |
| Ex-Igbariam | 0 | 1 | 0 | 1 |
| TIS 8164 | 0 | 1 | 0 | 1 |
| 199004 - Z | 0 | 1 | 0 | 1 |
| TIS 87/0087 | 0 | 1 | 0 | 1 |
| Kukunduku local | 0 | 1 | 0 | 1 |

*Incidence of diseases and insects with 0 as absent and 5 high.

**Table 7.** Fresh root phenotypic characteristics of sweet potato varieties at Amassoma, Wilberforce Island and Yenagoa locations.

| Treatment | Amassoma, W. Island | | Yenagoa | |
|---|---|---|---|---|
| | Skin colour | Flesh colour | Skin colour | Flesh colour |
| Ex-Igbariam | Orange | Yellow | Orange | Yellow |
| TIS 8164 | Light pink | White | Light pink | White |
| 199004 - Z | Pink | Yellow | Pink | Yellow |
| TIS 87/0087 | Light orange | Cream | Light orange | Cream |
| Kukunduku local | Pink | White | Pink | White |

## DISCUSSION

Considering that the tolerable pH level for sweet potato growth and performance is 6.7 - 8, the pH level of 4.8 appeared low. This was expected because most soils in the state are acid and, traditionally, farmers do not apply lime. The basis for using these varieties is because they are early maturing and high yielding.

Except for slightly lower fresh root yields, the trend was the same in Yenagoa. In a combined analysis using split plot arrangement, locations and location x variety interaction were non-significant but varieties were significantly different with the same trend when compared with the results of Nwokocha and Okwowulu (1996) who reported mean total yields of 8.41, 15.18 and 11.16 t $ha^{-1}$ in 1993 including 9.15, 14.32 and 19.85 t $ha^{-1}$ in 1995 for improved varieties TIS 8441, 87/0087 and 8164, respectively, the results obtained with Ex-Igbariam having fresh root yield (12.81 and 11.81 t $ha^{-1}$ at Amassoma and Yenagoa, respectively) would be regarded acceptable under our experimental conditions of low pH. Therefore, selection of an improved variety for increased yield and commercial production appears feasible.

The observations obtained for soil surface cover (trailing characteristic) showed, therefore, that TIS 87/0087 and Kukunduku local provided better soil surface cover and suppressed weeds best indicating that selection of a good weed suppressant is feasible.

Since there was no incidence of diseases and that of insect was low because only a few grasshoppers and dragon flies were observed, the results were similar to those of Anioke et al. (1990) who reported, generally, low incidence of pests because of rainy season which is inimical to the development of insects.

Due to the fact that visual observation of fresh root cuttings showed that Ex-Igbariam and 199004-2 had yellow flesh, the results were similar to the reports of other scientists (Wolfe, 1992; Hegenimana et al., 1999) who indicated that sweet potato varieties with dark orange flesh have more beta carotene than those with light coloured flesh and their increased cultivation is being encouraged in Africa where vitamin A deficiency is a serious health problem.

## Conclusion

Generally, the study shows that the improved varieties are higher in root yields with Ex-Igbariam, TIS 87/0087 and few others showing real promise in yield and carotene content. It is, therefore, recommended that carrying out a multi-locational trial would, hopefully, enable selection of high-yielding varieties for commercial production to improve farmers' yields and income in the different agro-ecological zones of Bayelsa State.

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*Full Length Research Paper*

# Rainfall variability and rubber production in Nigeria

**Mesike C. S.* and Esekhade T. U.**

Rubber Research Institute of Nigeria, P.M.B. 1049, Benin City, Edo State, Nigeria.

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**The role of rainfall in plant could not be overemphasized because rainfall determines the amount of moisture present in the soil which is ultimately made available to plants. The aim of this paper was to determine the variability of rainfall and its effect on rubber production in Nigeria. Towards achieving this aim, time series data from 1971 to 2009 were collected on mean annual rainfall and total annual rubber production. The data was analyzed using descriptive statistics as well as correlation analysis. The results showed that high rubber production was recorded in 1991 while production was low in 1980 and 1983. Results also show that there is an inverse relationship between rubber production and rainfall. The study recommended that protective water proof containers should be used for collection of latex during raining season so as to prevent washing away of latex by rain.**

**Key words:** Rainfall, variability, trend, correlation, rubber production.

## INTRODUCTION

Climate plays a dominant role in agriculture having a direct impact on the productivity of physical production factors, for example the soil's moisture and fertility. Adverse climate effects can influence farming outputs at any stage from cultivation through the final harvest. Even if there is sufficient rain, its irregularity can affect yields adversely if rains fail to arrive during the crucial growing stage of the crops (Smith and Skinner, 2002; Molua and Lambi, 2007; Rudolf and Hermann, 2009).

Generally, there are many factors influencing crop production and these include soil, climate and diseases among others. In relation to climate, rainfall is the dominant controlling variable in tropical agriculture since it supplies soil moisture for crops and grasses for animals. According to Ayoade (1983), agriculture largely depends on climate to function. Hence, precipitation, solar radiation, wind, temperature, relative humidity and other climatic parameters affect and solely determine the global distribution of crops and livestock as well as their productivity.

Rainfall, among other factors, has always dictated how land is used in one way or another and it also affects the humidity condition of the atmosphere. Rainfall determines the vegetation cover of a particular geological zone and crop distribution. Heavy rainfall facilitates the growing of tree crops like cocoa, rubber, oil palm possible in the rainforest. Some of the attributes of rainfall that are important to crop production are the time of onset of the raining season, total amount of rainfall, distribution, number of rainy days and duration of rainfall as well as the time of its cessation (Akintola, 1995). Furthermore, rainfall determines the amount of moisture present in the soil which is ultimately made available to plants. Water plays a vital role in the growth of plant and it provides the medium through which nutrients are carried through the plant. According to Olaoye (1999), regular occurrence of drought as a result of erratic rainfall distribution and/or cessation of rain during the growing season reduce Nigeria's capability for increased crop production. Sdoodee and Rongsawat (2012) concluded that high rainfall tended to decrease tapping days per year. From the results, it was suggested that climate change and climate variability in Songkhla province tends to reduce latex yield because of an increase of rainfall leading to a reduction of tapping days.

Rain-fed crop production is a dominant mode of

*Corresponding author. E-mail: sammesike@gmail.com.

**Table 1.** Analysis of rainfall data from 1971 - 2009.

| Variable | Coefficient | Std. error | t-statistic | Prob. |
|---|---|---|---|---|
| Constant | 318.89 | 37.41685 | 8.522643 | 0.0000 |
| DR(-1) | - 0.376412 | 0.159985 | - 2.352793 | 0.0242 |
| Mean (mm) | | | 231.41 | |
| Standard deviation (mm) | | | 27.31 | |
| Maximum rainfall (mm) | | | 283.05 | |
| Minimum rainfall (mm) | | | 189.02 | |
| Trend coefficient (mm/ year) | | | - 0.38 | |
| Coefficient of variability (CV) | | | 11.80 | |

**Table 2.** Analysis of rubber production from 1971-2009.

| Variable | Coefficient | Std. error | t-statistic | Prob. |
|---|---|---|---|---|
| Constant | 8369.54 | 6469.65 | 1.293662 | 0.2040 |
| Q(-1) | 0.935243 | 0.062823 | 14.88697 | 0.0000 |
| Mean (tonnes) | | 97315.36 | | |
| Standard deviation (tonnes) | | 37765.84 | | |
| Maximum rubber production (tonnes) | | 155000.00 | | |
| Minimum rubber production (tonnes) | | 45000.00 | | |
| Coefficient of variability (%) | | 38.81 | | |
| Sum | | 3795299 | | |

agricultural production in the majority of rural sub-Saharan Africa (Cooper et al., 2008). The reliance of the agricultural sector on natural rainfall places it at a serious risk of shrinkage due to the inter-annual rainfall variations. Climate change impact assessments done by the Intergovernmental Panel on Climate Change (IPCC) (2007) and Buddenhagen et al. (1992) concluded that rain fed agriculture in Africa risks negative impacts due to climate change. Rain fed agricultural production in Africa in general is projected to be reduced by up to 50% by 2020 (IPCC, 2007). With the declining rainfall trends in most of the sub-Saharan Africa, agricultural production is most likely to decline (Droogers et al., 2001; Nnyaladzi, 2009).

Rubber is very important in the economy of Nigeria and contributes significantly to Nigeria export trade. Natural rubber thrives well in humid climate with well-distributed rainfall of 1800 to 2000 mm on a well-drained soil. The rain must be evenly distributed through the year and with not more than one dry month. Ideally, the number of rainy day should range from 100-150 days (Watson, 1989). Production statistics indicated that Nigeria has a total of 247,100 hectares of land under natural rubber cultivation where over 70% are owned by small scale farmers (Delabarre and Series, 2000). Rubber cultivation in Nigeria is mainly rainfed. The rain being generally seasonal, regulate the production of planting materials and tapping activities. For this reason we studied the rainfall variability in line with rubber production in Nigeria.

## MATERIALS AND METHODS

The empirical analysis covers the period between 1971 and 2009. Secondary data used for the analysis were obtained from Nigeria Meteorological Agency (NIMET), Central Bank of Nigeria (CBN) publications, such as Annual Reports and Statements of Accounts, and the Statistical Bulletin. Rainfall data used for this study were obtained from NIMET and the data related specifically to Delta state where over 70% of Nigeria rubber is produced was used. Data on quantity of rubber produced in Nigeria were obtained from CBN publications.

The data collected were analyzed with the use of descriptive statistics to analyze the trend of rainfall and rubber production in Nigeria. Correlation analysis was used to analyze the relationship between rainfall and rubber production.

## RESULTS AND DISCUSSION

### Trend analysis of rainfall

Rainfall shows a decreasing trend with the minimum value for the period (189.02 mm) recorded in 1977 and maximum value for the period (283.05 mm) recorded in 1999 (Figure 1). The mean and standard deviation values of rainfall are 231.41 and 27.31 mm, respectively (Table 1). This indicates that rainfall has a large variability of 11.8% with time. The rainfall trend coefficient of -0.38 mm per year is significant at 5%. This indicates a decreasing trend of rainfall in the region. The coefficient of the graph is DR = 318.89 - 0.38 t. Where: DR is the annual mean rainfall (mm) and t is the time (years). The trend equation had a negative slope of 0.38 indicating that over the time period of 1971 to 2009, the annual mean rainfall decreased by 0.38 mm per unit change in time.

### Trend of rubber production in Nigeria

Figure 2 shows the trend of rubber production in Nigeria. It could be observed that the highest rubber production of 155,000 metric tonnes was recorded in 1991 and the lowest productions of 45,000 tonnes were recorded in 1980 and 1983. This however, represents 4.1% of the total production during the period. There were steady increases in rubber production in 1987-1991. This period however fall within the first decade of economic deregulation. Table 2 shows that the mean and standard deviation value of rubber production are 97315.36 tonnes and 37765.84, respectively and this indicated that rubber production has a large variability of 38.81% over time.

### Correlation analysis

The result of the correlation analysis showed that rainfall

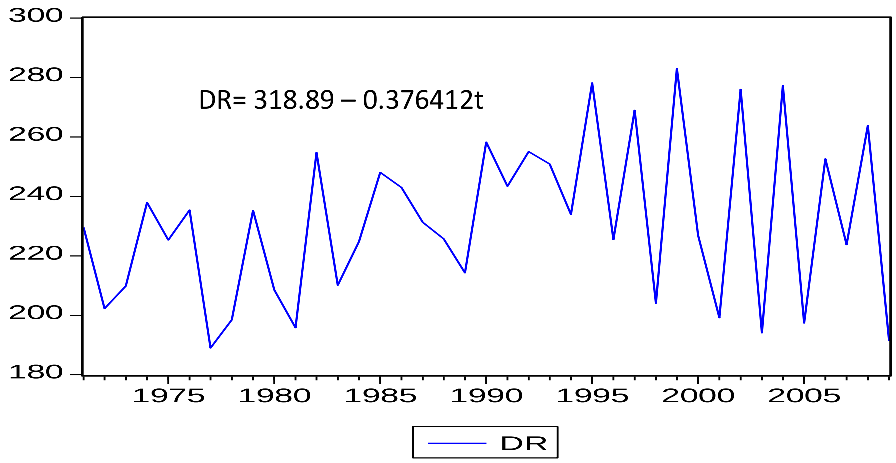


**Figure 1.** Trend of rainfall (1971 – 2009).

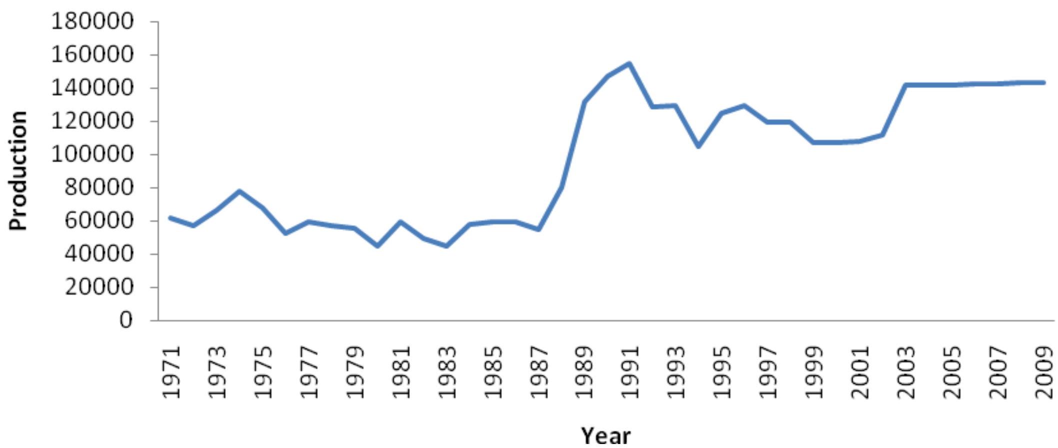


**Figure 2.** Trend of rubber production in Nigeria.

is inversely correlated with rubber production (-0.132). This result is line with Perera and Ranasinghe (2013) that recorded an inverse relationship between rainfall and rubber yield in Sri Lanka. The negative relationship between rubber and rainfall might be due to the fact that excess rainfall may affect tapping operation thus reducing latex yield.

## Conclusion and recommendation

The study has revealed that there was high variability and decreasing trend of rainfall during the period (1971-2009). High rubber production of 155,000 tonnes was recorded in 1991 while the lowest production of 45,000 tonnes was recorded in 1980 and 1983. Rubber production is inversely correlated with rainfall. The study therefore recommend that protective water proof containers should be used for collection of latex during raining season so as to prevent washing away of latex by rain.

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*Full Length Research Paper*

# Climate change and decline in water resources in Kikuletwa Catchment, Pangani, Northern Tanzania

**Linus K. Munishi[1]* and Pudensiana C. Sawere[2]**

[1]School of Life Sciences and Bio-Engineering, Nelson Mandela African Institute of Science and Technology, P O Box 447, Arusha, Tanzania.
[2]Pangani Basin Water Office, P O Box 3020, Arusha, Tanzania.

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**The sensitivity of hydrology and water resources to climate variation in Kikuletwa Catchment, Pangani Basin, northern Tanzania was assessed using 30 years of river level and climate data as well as questionnaire, focused group discussion (FGD) and participant observation. The results show a significant association between mean annual river level for Kikuletwa River and mean annual rainfall in the past thirty years. The results further indicate an inverse relationship between river level and temperature in the catchment suggesting the effects of climate change on water resources at Kikuletwa Catchment area. Although the results of our study indicate an upward trend in precipitation (from the two rain stations) over the past three decades, there was a consistent decline in river level in the main rivers. The eight villages covered by this study face a variety of water shortage and environmental challenges that are intertwined with the causes and consequences of a changing climate. Access to water is the primary natural resource concern in Pangani Basin and Kikuletwa catchment villages and a lack of infrastructure for storing and directing water during rainy periods limits opportunities for harvesting water for irrigation and other household uses. More than seventy percent of heads of household are farmers whose crop production depends mainly on rainfall. While water deficit remains a major concern, its severity is not immune to the challenges of shifting climate and environmental destruction resulting from livelihood activities in the study area.**

**Key words:** Climate change, water resources, agriculture.

## INTRODUCTION

Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates et al., 2008). The first decade of the 21st century was the warmest decade recorded since modern measurements began around 1850, which was also marked by dramatic climate and weather extremes such as long-term droughts in various regions of the world which includes Australia and East Africa (Oxfam, 2012; WMO, 2013). Climate change has become a source of uncertainty for planners and decision-makers in climate-sensitive economic sectors. For ample quantities of water available in all seasons has been declining (in most places) due to reduced stream flow especially in dry season because of evapotranspiration and increase in water demand for various uses (Neff et al., 2000). Additionally, observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced

*Corresponding author. E-mail: lmkasian@gmail.com. Tel: +255 272 970001. Fax: +255 272 970016.

snow cover and widespread melting of ice; and changes in soil moisture and runoff (Neff et al., 2000; Bates et al., 2008).

The perennial water of Kikuletwa catchment is a source of life to millions of people living in the area. The catchment is renowned for its agricultural values, centre of biodiversity, as well as an important source of water supply for various uses (Munishi et al., 2009). Water resource management (including northeast Tanzania in which the Kikuletwa catchment is found) clearly impacts on many policy areas, for example, energy (towards generation of hydroelectric power at the Nyumba ya Mungu dam, Hale, New Pangani Falls and Old Pangani). It also affects agriculture sector (especially on part of the country's major staples such as maize, rice and wheat) which employs 80% of the workforce and accounts for 45% of the country's GDP and 55% of foreign exchange earnings (Noel, undated). Other policy areas that are affected by water resource management include health and nature (biodiversity) conservation.

The montane forests (including East African mountains e.g., Meru and Kilimanjaro) are heavily threatened by global climate change impacts (Neff et al., 2000; Hemp, 2009). Many studies from around the world have considered the impacts of future climate changes on water resources to exhibit several significant trends. While decline in sream flow and catchment areas (which consequently affect water resources) in other regions of the world have been associated with observed changes in temperature and rainfall (Neff et al., 2000; de Wit and Stankiewicz, 2006; Bates et al., 2008), the effects of these past climate changes on river level (the depth of water at a monitoring station) in Kikuletwa Catchment remain unclear.

Also, the gradual increase in drought and human population has made water become a scarce resource not only in arid and drought-prone areas but also in humid or sub-humid zones, leaving its sustainability to be threatened by various human activities (Noel, undated; WWF, 2006; de Wit and Stankiewicz, 2006). While creating awareness among different stakeholders dealing with water use and management in these areas becomes important, further detailed study is necessary to provide quantitative information that would support and provide a framework upon which water could be used and managed. Considering the inadequate of this information and understanding of the effect of climate change on water resources, this study therefore aimed to assess the relationship between climate change and water resources at Kikuletwa catchment, Pangani Basin in Tanzania.

Assessing the consequences of climate change on water resources is therefore an important step in generating the information that will be used to provide solution to the water resource management challenges. Specific objectives were; (i) to assess rainfall and river level patterns of Kikuletwa catchment at Pangani over the past thirty years. (ii) To determine the relationship between river level and rainfall patterns in the selected rivers over the past thirty years, and (iii) to assess the extent of water scarcity in the villages around Kikuletwa Catchment in Pangani Basin.

## METHODS

### The study area

The research study was conducted in Kikuletwa catchment at Pangani basin northern Tanzania. The Pangani basin has two main river catchments with different tributaries, originating from the slopes of Mount Kilimanjaro and Meru. Both rivers rise in the basin's northernmost portions (Figure 1). The Pangani River Basin covers an area of 43,650 $km^2$ of which 3,914 $km^2$ lies in Kenya. In Tanzania, the basin is distributed through Kilimanjaro, Arusha, Manyara and Tanga administrative regions (PBWB, 2009).

### Climate

Mt Kilimanjaro and Meru areas are characterized by a typical equatorial climate. The distribution of precipitation over the year follows the Intertropical Convergence Zone and is affected by elevations. Due to its equatorial location, two distinct rainy seasons occur in the study area: the long rains from March to May, and the short rains around November. The driest period is from August to October, while April and May are the wettest months. The average rainfall ranges from 1000 to 1700 mm varying with elevation and aspect. And precipitation decreases from the lower forest boundary down to the plains, where it is less than 700 mm annually (Munishi et al., 2009). The annual precipitation reaches its maximum in the mid montane zone, and at higher elevation, precipitation declines, mainly starting near the upper forest border at higher altitudes (Hemp, 2009). The mean annual temperature decreases linearly upslope with a lapse rate of 0.56°C per 100 m starting at the foothills (Hemp, 2009) and the maximum and minimum temperature on the lower slopes (settlement areas) ranges are 15 - 30°C and 12 - l7°C, respectively (Munishi et al., 2009).

### Data collection and analysis

This study used questionnaire, focused group discussion (FGD) and participant observation to assess changes in water resources as well as identifying challenges that communities are facing as a result of climate change. We conducted separate focus groups of men, women and village leaders to provide context to the information gathered in household surveys. Participants were asked to identify the three most acute problems faced by villagers. Communities were selected based on their type of livelihood and degree of experiences on the changes in the climate that have been observed in the area for the past years. Assessments took place in three villages within Kikuletwa Catchment and five villages in Pangani main basin area. For villages around Kikuletwa Catchment were: Manyata, Mbuguni, and Olbil and for Pangani Mainstream Catchment area, the selected villages were; Sange, Ruvu Mferejini, Longoni, Ruvu Jiungeni and Makanya. Participant observation took place in the protected (catchment) areas, destroyed area and also some places along the rivers were used as study area for the purpose of confirming the real situation and type of environmental destruction in the area.

The climate data (temperature and rainfall) as well as river level for the past 30 years were obtained from the Department of Hydrology in Pangani Office and Arusha AirPort Meteorology Centre. River levels and rainfall data were collected from records on

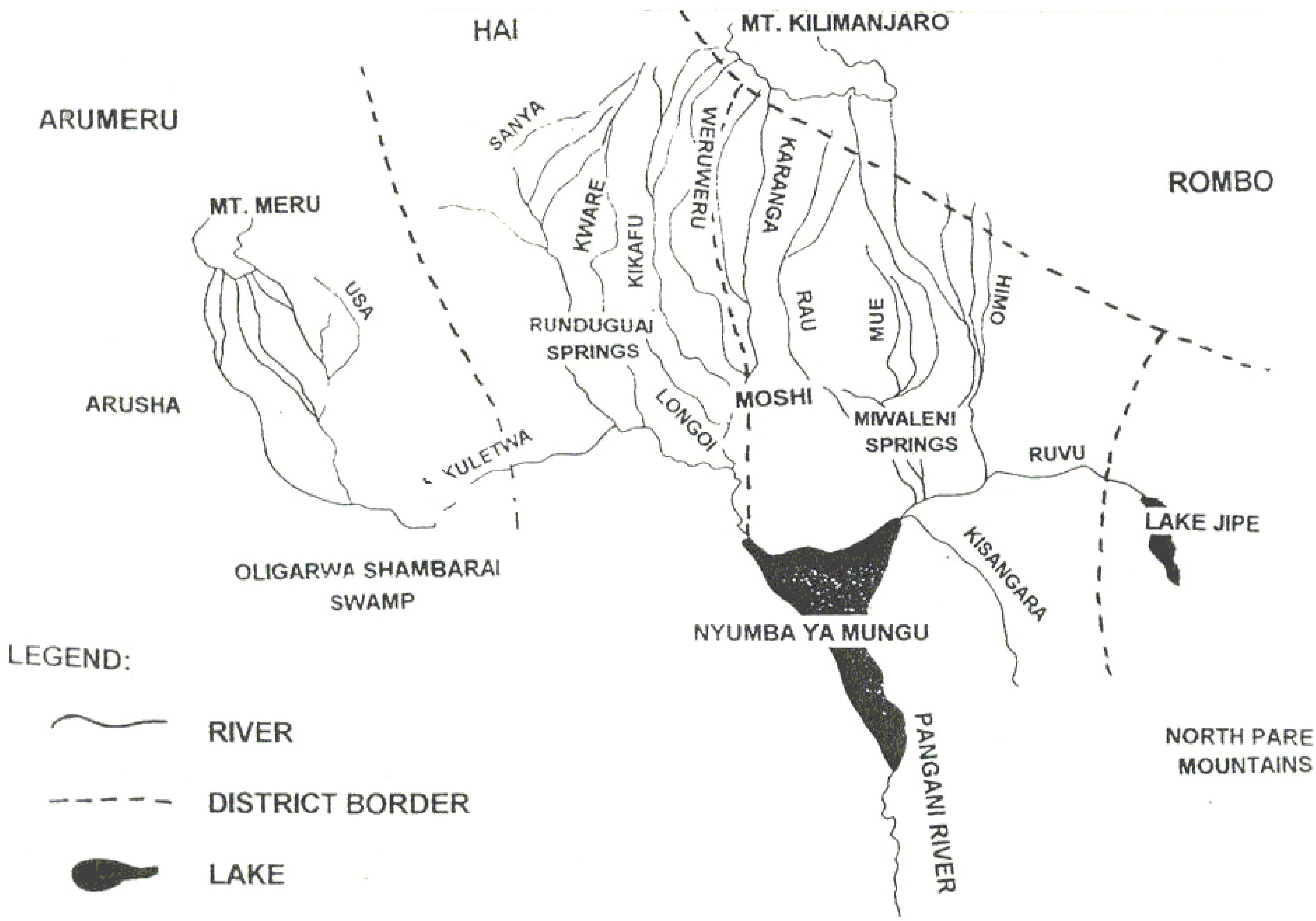


**Figure 1.** Pangani Basin and the Kikuletwa Catchment area.

**Table 1.** Mean annual rainfall data (mm) for ten-year interval from the two rain stations in Kikuletwa Catchment area.

| Rain gauge station (with rain amount in mm)/year | 1980-1990 | 1991-2000 | 2001-2010 |
|---|---|---|---|
| Tengeru | 905 | 887 | 954 |
| Themi | 855 | 876 | 1012 |

water levels from five major rivers (Malala, Maji ya Chai, Magadrisho, Karangai and Kikuletwa) and two (Tengeru and Themi) rainfall stations located within the study area. Thus, Pangani Water Office and Arusha Airport Meteorology Centres facilitate the gathering of data from these field stations for monitoring and research purposes.

The long term river level and rainfall data collected were subjected to statistical analysis for significance levels using correlation analyses in R 2.13.0 (R Development Core Team, 2011). The relationships between climate change (rainfall and temperature) and water resources (river level) for the Kikuletwa River were compared in correlation analysis. Qualitative data from FGD were summarized in key statements and presented in a table for interpretation and discussion.

## RESULTS

### Evaluation of long-term rainfall and river level data for the past thirty years

The mean annual rain-fall from the two (Themi and Tengeru) rain stations located on the study area was summarized on a ten year interval and is presented in the Table 1. The rainfall pattern seemed to have variation with no directional pattern on Tengeru rain gauge station. The mean annual rainfall reached a maximum of over 950 and 1000 mm for Tengeru and Themi rainfall stations,

**Table 2.** Mean river level data (m) for the past 30 years in the major rivers at Kikuletwa Catchment area.

| River | Year | | |
|---|---|---|---|
| | 1980-1990 | 1991-2000 | 2001-2010 |
| Malala | 0.14 | 0.12 | 0.15 |
| Maji ya Chai | 0.12 | 0.13 | 0.16 |
| Magadrisho | 0.12 | 0.13 | 0.21 |
| Kikuletwa | 0.86 | 0.84 | 0.75 |
| Karangai | 0.61 | 0.60 | 0.56 |

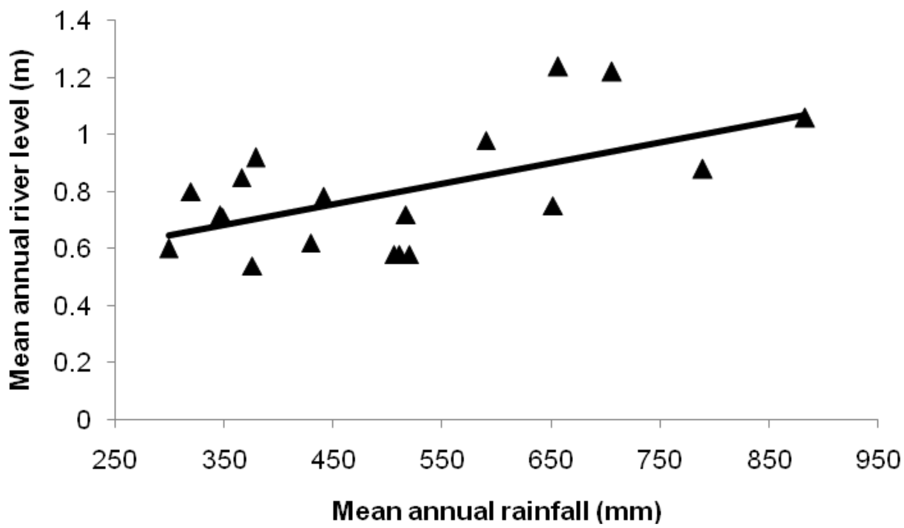


**Figure 2.** Correlation between water level and mean rainfall for Kikuletwa River.

respectively in the last decade (2001-2010). The rainfall pattern for Themi station showed an increase in the amount of rainfall for the past 30 years (Table 1).

The data on average river level for the major selected rivers were summarized on the ten year interval and are presented in Table 2. The river level data at the catchment fluctuated over the study period (Table 2). In particular, there was a consistent decline in river level in the two major rivers, Kikuletwa and Karangai (Table 2). There was a significant positive correlation between mean annual river level for Kikuletwa river and mean annual rainfall in the past three decades (Pearson's correlation: = 0.58, df =17, p = 0.009; Figure 2).

Although, the annual mean river level showed a decrease with increased mean annual temperature for Kikuletwa river, this was not significant (Pearson's correlation: = -0.31, df =15, p = 0.22; Figure 3).

### Key findings from questionnaire and FGD

The eight villages covered by this study face a variety of water shortage and environmental challenges. Overall, water shortage was the most frequently cited village problem (Table 3). The reason for low water supply was reportedly in part due to the large fluctuations in rainfall patterns, including severe drought in some years.

Environmental destruction is another major source of environmental stress. Trees are commonly cut to make charcoals which are then used as cooking fuel. Wood harvesting is also done in the area and used for construction materials. Cleared land is used for crop cultivation and for pasture, providing short-term economic opportunity for households suffering from poverty and food insecurity. More than 70% of the heads of household in the study area are farmers (Figure 4). The next largest occupational category in the Kikuletwa Catchment area is livestock keeping, followed by fishing.

## DISCUSSION

Kikuletwa and Ruvu catchments have a series of large springs in a semi-circular band to the south of Mt Meru and Mt Kilimanjaro. These springs are recharged by groundwater from volcanic aquifers that act like artesian wells (PBWB, 2002). The major rivers in the Kikuletwa catchment are Kikuletwa and Karangai (Figure 1). The

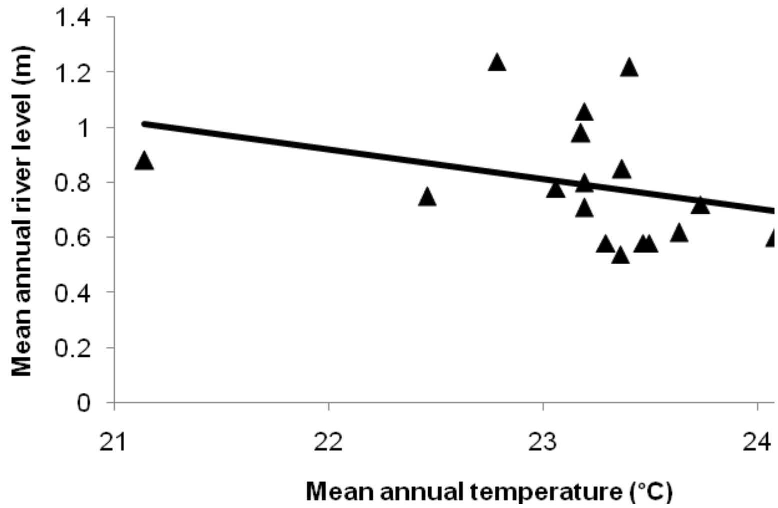


**Figure 3.** Correlation between river level and mean temperature for Kikuletwa River.

**Table 3.** Ranking of problem in top three by villagers from Kikuletwa Catchment area.

| Problem | FGD responses (%) | | |
|---|---|---|---|
| | Village leaders | Men | Women |
| Water shortage | 19 | 25 | 28 |
| Deforestation | 3 | 5 | 7 |
| Soil erosion | 8 | 2 | 5 |
| Food shortage | 7 | 1 | 6 |

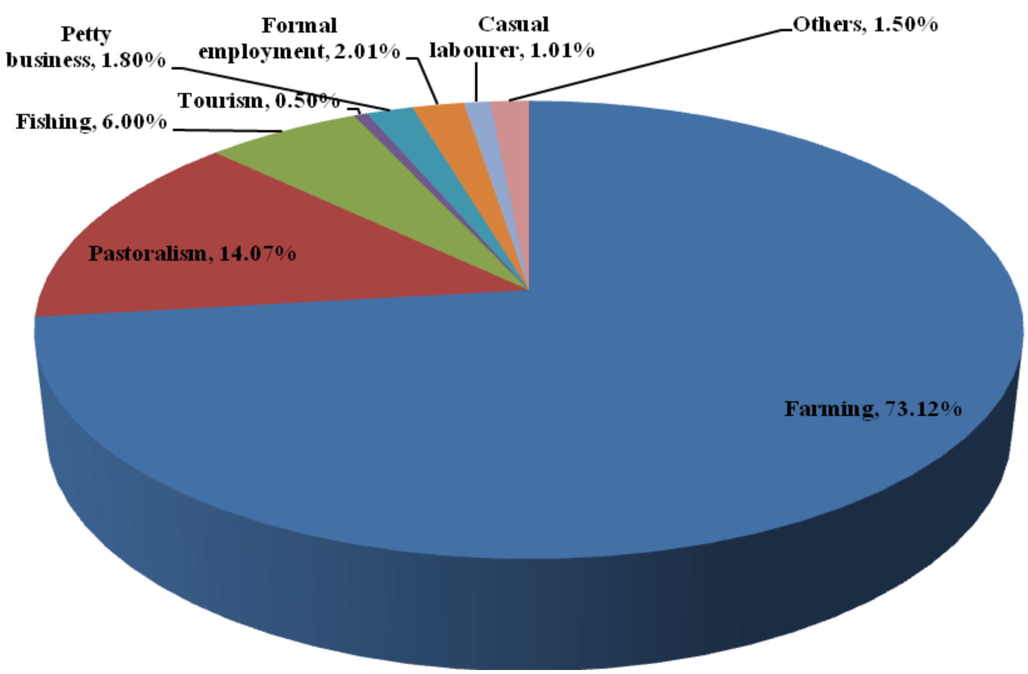


**Figure 4.** Occupation of heads of the household in Kikuletwa Catchment area.

two rivers have their major tributaries that include Maji ya chai, Magadrisho, Karangai, Malala, Usa, Kikafu, Kware and Makumira.

As noted, climate variation has a large effect on hydrology and, consequently, on the water available for human and ecosystem use in Kikuletwa Catchment area. The close association between river level and temperature in the catchment suggest that there are significant effects of climate change on water resources at Kikuletwa Catchment area. The results are consistent with other previous studies (IPCC, 1998, 2001a,b, 2007) that showed the projections of decreased mean annual rainfall and decreased stream flow in Africa and water flow in the two other key basins (Wami-Ruvu and Pangani) in the northern parts of Tanzania (de Wit and Stankiewicz, 2006). The de Wit and Stankiewicz's (2006) study further indicated that other drivers of climate and water resources, such as land use change and environmental destruction could often be considered as additional factors that would potentially reduce water resources in Pangani Basin.

Also, according to other climate change studies done in Tanzania, it is predicted that climate change will provoke a general shift in forest ecosystems, in terms of changing forest types and species and distribution of forests (Mwandosya, 2006). Indirect impacts are also expected as the carbon dioxide concentration in the atmosphere doubles: subtropical thorn woodlands will be completely replaced and subtropical dry forests and subtropical moist forests will decline by 61.4 and 64.3%, respectively (URT, 2003).

In their study on the slopes of Mount Kilimanjaro, Munishi et al. (2009) indicated that the combined cover of closed and open forests decreased by 68% while closed and open forests decreased by 56 and 64%, respectively, due to forest clearing and climate change.

Another study by Hemp (2009) indicated that during the last 70 years, Mount Kilimanjaro has lost nearly one-third of its forest cover, in the upper areas caused by climate-driven fire and clearing. The loss of 150 $km^2$ of cloud forest- the most effective source in the upper montane and subalpine fog interception zone- caused by fire during the last three decades means a considerable reduction in cloud forests and water yield (Hemp, 2009). The cloud forests are of great importance for watersheds in East Africa (Hemp, 2006, 2009). In addition to the function of filtering and storing water, the upper montane and subalpine cloud forests have a high potential of collecting cloud water. Fog interception increases with altitude, and so does its contribution to water yield on higher altitudes of Kilimanjaro (Hemp, 2005). Thus, the loss of cloud forests due to climate induced fires as well as the loss of montane forest due to clearing, causes a considerable reduction and enhanced variability of water yields of the Kilimanjaro catchments.

As a consequence, Hemp (2005) study showed that annual precipitation on Mount Kilimanjaro has decreased by 600-1200 mm over the last 120 years while since 1976, temperatures have increased drastically. Both temperature and rainfall changes do not only expose rivers to vulnerability of water yields but also water demand to become more aggressive and thus, increasing irrigation demand along the slopes of the mountain, resulting in a potentially much decrease in the river level on the main rivers in the catchment area.

Although, the results of our study indicated an upward trend in precipitation (from the two rain stations) during the past three decades, there was a consistent decline in river level in the main rivers of Kikuletwa Catchment area (Table 2). The reasons for decrease in river level in Kikuletwa and Karangai rivers in the study area could be increase in streamflow water demand for both domestic and agricultural/livestock uses.

Agricultural activities in the Kikuletwa catchment depend on rainfall and irrigation and since precipitation decreases from the lower forest boundary of the mountains down to the plains, then most of the areas just few kilometers from the lower elevations are semi-arid in nature requiring irrigation for agriculture production. Irrigation activities are also practiced in highlands, through traditional furrows (mifongo), and in the lowlands where most of the large scale plantation occurs (Munishi et al., 2009).

The agricultural sector is the leading sector of the economy of Tanzania and accounts for over half of the gross domestic product (GDP) and export earnings (World Bank, 2002; Agrawal et al., 2003). The livelihood of more than 80% of the population that lives in rural areas depends on agriculture (URT, 2001; World Bank, 2002). The performance of agriculture is therefore a major factor in determining livelihood fortunes. Given the importance of agriculture for gross domestic product (GDP), employment, and livelihoods in many developing countries, the impacts of climate change on water resources (and ultimately on agriculture) agriculture are likely to reverberate throughout the economies of these countries including Tanzania.

In combination with an increase in the frequency and severity of drought in lowland areas, limited water supply may force human and livestock population to move upstream towards higher altitudes, with consequences more harmful extending for long term due to the loss of the catchments and water sources in the upper elevation.

The increase in human and livestock numbers and related augmented water demand, particularly in the catchment area and large fluctuations in rainfall patterns, including severe droughts, are expected to be an ongoing problem in rural northern Tanzania, particularly if forest and grassland resources continue to be used intensively by the human population.

Drought is expected to increase in frequency and severity in the future as a result of climate change, mainly as a consequence of not only decreases in regional precipitation but also because of increasing evaporation driven by forest clearing that exacerbates global warming (Sheffield et al., 2012).

Global warming, climate change and rising sea level are expected to intensify the resource sustainability issue in many water stressed regions of the world by reducing the annual supply of renewable fresh water (Neff et al., 2000; WMO, 2013). Deforestation on mountain foothills raises mean cloud condensation level that results in a gradual shrinking of the cloud zone. A similar effect is caused by global warming and drying of the air (Hemp, 2009; Seneviratne, 2012). In addition to changes in the water balance of the mountain, loss of cloud cover may have added to the observed general decreasing trend in precipitation during the last century.

The eight villages covered by this study face a variety of water shortage and environmental challenges that are intertwined with the causes and consequences of a changing climate. Severe droughts and periodic flooding are expected to affect the region in the following years (Oxfam, 2012; WMO, 2013). Access to water is the primary natural resource concern in Pangani Basin and Kikuletwa catchment villages and a lack of infrastructure for storing and directing water during rainy periods limits opportunities for harvesting water for irrigation and other household uses.

As in much of sub-Saharan Africa, water shortages, loss of wooded area, and land degradation present daily obstacles to these households' pursuit of economic well-being which in turn often contributes to environmental deterioration (Oxfam, 2012; Sheffield et al., 2012). With majority of the households in the area being farmers (more than two-thirds) and livestock keepers in the study area (Figure 4), environmental degradation combined with climate change are likely to fundamentally alter the water (primary) resources used by those who engage in agriculture. Shifting weather patterns, deteriorating soil quality and loss of pasture may often result in lower yields and increase the uncertainty faced by farming households.

If environmental destruction coupled with loss of cloud cover continued over a long time, these trends are likely to affect millions of people and livestock living along the Pangani River and its basin, by far accelerating the problem of water scarcity. Research on the trends in migration and increase in the population along the river stream could be a major focus to provide more evidence on this aspect.

In general, agricultural activities were cited as the main contributors of the water shortage problem. As reported in Table 3, nearly every village that participated in focus groups ranked poor water supply in the top three village problems. Also, the results from focused group discussion revealed that access to water for drinking and other household uses is often limited, can require traveling significant distance to collect and can be of poor quality. According to interviews from the eight villages in the study area, the households from one village can have access to two nearest sources of water and most villagers (from five villages) reported only one source of water (shallow wells); and three reported two sources.

While some villages have a water source within the village, others must travel long distances to get water from underground pipes. During the FGD, it was also observed that the quality and quantity of water in Pangani basin was diminishing. For example in the FGD two village leaders expressed the challenges their families face in getting water for domestic use. The village leaders said that the shallow well serves almost half the population of villagers, so members of the household almost wake up as early as 2:00 am, to collect water and return home in the afternoon. Sometimes it does not matter if one is as early as that because there would be a long queue of women waiting to fetch water and by the time their turn comes, there would be no more water in the well. And whoever comes later than that usually does not get water and will have to wait until when enough would have collected in the well again. The quality of water also has also been dropping overtime in the area. 85% of household respondents reported the water from the wells is muddy, salty, brownish and/or polluted by debris. In areas near the coast where Pangani River discharges its water in the Indian Ocean, piped water is reported to be salty, due to rise in sea levels as a result of climate change.

Several measures for mitigating the effects of climate change in the area were identified from the discussion held with the stakeholders at Kikuletwa Catchment. The most measures that were identified as common strategies in the area included: migration, cultivation of drought resistant and early maturing crops, diversification of income generating activities, conservation and protection of river catchments. The results from FGD clearly shows that stakeholders and communities in the study area are very much willing to respond to long term mitigation measures that would ensure the sustainability in their livelihoods.

## Conclusion

The results from this study suggest an association between rainfall and river level in the Kikuletwa River. Considering the aspect of rainfall and river water level, the study showed significant effects of climate change on water resources in the study area. Also, data from household surveys and focus groups provide a snapshot of population living in water scarcity areas in spite of the continued decrease in the available water resources. The environmental destruction continues to increase in the catchment, while agriculture and fuel wood consumption is the major cause. This has been linked to a loss of clean water resources in some parts of the Pangani Basin. Based on the questionnaire survey, FGD and participant observation, this study has also provided base-line information on household use of water resources under the climate change and how this affects economic activities of local people. To mitigate climate change and provide effective adaptation measures, it is imperative to periodically repeat community surveys in the climate-change affected areas.

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*Full Length Research Paper*

# Heavy metal content of selected African leafy vegetables planted in urban and peri-urban Nairobi, Kenya

**Mutune, A. N.*, Makobe, M. A. and Abukutsa-Onyango, M. O. O.**

Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000 - 02000. Nairobi, Kenya.

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**African indigenous vegetables planted along Nairobi Rivers are suspected to absorb metals from industrial and domestic effluent. Ten (10) of the commonest vegetables in Kenyan markets grown along these rivers and the soils in their rhizosphere from 25 sites were analyzed for Pb, Cu, Zn, Cd and Cr. Soils were air-dried then leached using 0.05 M EDTA, filtered and analysed in AAS. Vegetables were oven-dried, ground, ashed then analysed in AAS. In both soil and vegetables, the metal concentration was generally in the order Zn > Cu > Pb > Cd >Cr. In soil the concentrations were Pb 0.57 - 20 mg/kg, Cu 3.59 - 75.37 mg/kg, Zn 14.62 - 198.3 mg/kg, Cr 0.03 - 1.4 mg/kg and Cd 0 - 2.6 mg/kg. In vegetables the values were Pb 0 - 2.4 mg/kg, Cu 0.52 - 21.34 mg/kg, Zn 20.13 - 89.85 mg/kg, Cd 0 - 3.02 mg/kg and Cr 0 - 1.24 pp. There were significant differences within vegetables at each site (P<0.05). In most sites, there was a positive correlation of soil metal content with that in vegetables. The metal concentrations in soil were within permissible levels allowable by WHO/FAO except for a few instances in Cd. In vegetables all metals except Cu were in a few sites higher that the recommended limits. Government clean-up activities and monitoring of waste disposal is recommended for potential agricultural land.**

**Key words:** African Indigenous vegetables, heavy metals, pollution, urban and peri - urban agriculture, Nairobi.

## INTRODUCTION

Nairobi, like other cities in the developing countries is expanding tremendously without proper planning of utilities, safety and regard to environment, making residents dump waste into rivers and on land (Yebpella et al., 2011). Wastes may contain heavy metals among other contaminants (Olowoyo et al., 2011; Tiwari et al., 2011; Sinha et al., 2010). Toxic metal sources include ordinary activities of industrialization, civilization, agriculture and natural sources (Olowoyo et al., 2011; Kisamo, 2003). Heavy metal contaminants in soil can be absorbed by plants that are consumed by humans (Mutune et al., 2013; Ghosh and Singh, 2005; Salt et al., 1995). Heavy metals such as cadmium, chromium, lead, copper and zinc have been obtained in vegetables planted or consumed within urban areas sometimes in more than allowable limits (Yebpella et al., 2011; Salariya et al., 2002). Some plants such as *Brassica* vegetables have been shown to hyperaccumulate metals in their edible parts (Kumar et al., 2007). Copper and zinc are essential micronutrients obtained from vegetables (Sinha et al., 2010; Iyaka, 2007) but at high levels they cause oxidative stress through redox reactions (Sinha et al., 2010; Ghosh and Singh, 2005). Lead also causes oxidative stress and in young children it causes mental retardation (ATSDR,

*Corresponding author. E-mail: nadelaide@yahoo.com.

**Table 1.** Sites from where vegetables and soils were collected for metal analysis.

| Code | Site description | Code | Site description |
|---|---|---|---|
| S1 (IA) | Mukurwa Kwa Njenga along river | S14 (RR) | Githurai Bridge |
| S2 (IA) | Kware | S15 (SA) | Nairobi West Prison Farm |
| S3 (IA) | Donholm bridge | S16 (SA) | Langata Estate |
| S4 (SA) | Kayole farm | S17 (OF) | Kawangware |
| S5 (RR) | Komarock Junction road | S18 (OF) | Kikuyu town |
| S6 (OF) | Saika | S19 (OF) | Karura forest |
| S7 (SA) | Njiru bridge | S20 (OF) | Kiambu town |
| S8 (SA) | Ruai | S21 (SA) | Ruiru river near town |
| S9 (SA) | Ruai near treatment plant | S22 (SA) | Ruiru river near town |
| S10 (RR) | Kariobangi bridge | S23 (RR) | Juja bridge |
| S11 (OF) | Korogocho | S24 (OF) | Juja farm |
| S12 (RR) | Mwiki River bridge | S25 (OF) | KM |
| S13 (OF) | Mwihoko | | |

IA - Industrial area; SA - sewer area; RR - road reserve; OF - ordinary farm.

2007). Chronic exposure to cadmium causes glomerula damage and also alters Zn, Cu and Se metabolism (ATSDR, 2012) while some oxidative forms of chromium (Cr VI) are carcinogenic.

In addition to toxicity, heavy metal deficiencies also occur therefore knowledge of their amounts in vegetables for dietary supply is imperative (Iyaka, 2007). The high population of the Nairobi City and high cost of living has forced urbanites to farm within the city for consumption and income generation (Shackleton et al., 2009). Water and soil in cities are rich in nutrients such as N, P, K, S and Mg from waste which makes vegetables large and appealing. Making urban agriculture environmentally and health wise sustainable is a major constraint. There is need for research to address the constraint and help to inform relevant policy interventions. The present study aims at investigating the concen-trations of selected heavy metals in ten common vegetables and the soil where they are planted in.

## METHODOLOGY

The chemicals used during this study were of analytical grade and water used for rinsing glassware was distilled.

### Collection of vegetables

The vegetables collected were African nightshade (*Solanum villosum* V1), Swiss chard (*Beta vulgaris* V2), African kale (*Brassica carinata* V3), spiderplant (*Cleome gynandra* V4), Amaranths (*Amaranthus sp* V5), pumpkin leaves (*Curcubita moschata* V6), cowpea leaves (*Vigna unguiculata* V7), jute mallow (*Corchorus olitorius* V8), slenderleaf (*Crotalaria* sp. V9) and kale (*Brassica oleracea* var. Acephala V10). Collection was done in 25 sites which were ranked into four categories: industrial area (IA), road reserve (RR), sewage area (SA) and ordinary farm (OF). The industrial area was along Nairobi River and its tributaries, and all vegetables planted there were watered from these rivers which are adjacent to high manufacturing and other industrial activities. The road reserve sites were areas near roads, at least within 100 m from the roads. Sewage area sites were evidently watered with river water that contained lots of sewage effluent. Ordinary farms were far from any source of contamination, where activities are low. The sites are represented in Table 1. The vegetables were packed in polythene bags and packed in cooler boxes. In the laboratory, samples were thoroughly washed and rinsed with distilled water before drying at 70°C for three days, then powdered using a miller.

### Soil collection

Top soil (0-15 cm depth) samples were obtained from each of the points where vegetables were collected. Sampling was done in a zigzag (Okalebo et al; 2002) of 5 cores across the field, avoiding areas of obvious interference like litter, manure and rocks. The sites ranged from 50 to more than 100 $m^2$. The five samples from each site, each about 0.5 kg, were composted and air dried at 25°C for about 1 month, sieved to <2 mm, then 3 replicates were obtained from each composite for analysis.

### Digestion of samples

Soil mineral extraction was done using 0.05 M EDTA disodium salt according to Gupta (1999). Five grams of soil were vortexed with 25 ml EDTA for 60 min at 120 rpm. The supernatant was filtered through Whatman No. 42 paper, and topped up to 50 ml using distilled water and stored in a cold room at -20°C. Soil was extracted using EDTA because only extractable metal is bioavai-lable and mobile in reference to plants (Sinha et al., 2010). EDTA has a strong chelating ability for different heavy metals (Tandy et al., 2004).

Five grams of vegetable powder was weighed into a silica cru-cible. It was charred to remove carbon in a block digester at 200°C

**Table 2.** Heavy metal content (ppm) of soils from the sites where vegetables were collected.

| Site | Pb | Zn | Cu | Cr | Cd |
|---|---|---|---|---|---|
| S1 (IA) | 1.70[e*] | 42.96[e] | 6.43[d] | 0.03[c] | 0.222[d] |
| S2 (IA) | 20.94[a] | 196.00[a] | 70.96[a] | 1.41[a] | 2.644[a] |
| S3 (IA) | 16.33[b] | 198.30[a] | 75.37[a] | 0.23[b] | 1.731[b] |
| S4 (SA) | 9.43[c] | 190.05[a] | 45.61[b] | 0.12[c] | 0.2279[d] |
| S5 (RR) | 0.66[e] | 29.42[e] | 9.22[d] | 0.05[c] | 0.5571[d] |
| S6 (OF) | 0.57[e] | 43.45[e] | 8.29[d] | 0.09[c] | 0.0333[d] |
| S7 (SA) | 0.94[e] | 40.34[e] | 10.47[d] | 0.14[bc] | 0.00[d] |
| S8 (SA) | 0.67[e] | 13.01[h] | 5.77[e] | 0.18[b] | 0.2629[d] |
| S9 (SA) | 5.40[d] | 105.08[c] | 18.17[c] | 0.17[b] | 0.7146[c] |
| S10 (RR) | 2.40[e] | 110.14[c] | 21.97[c] | 0.09[bc] | 0.1279[d] |
| S11 (OF) | 1.88[e] | 127.87[b] | 12.61[d] | 0.07[c] | 0.0108[d] |
| S12 (RR) | 0.78[e] | 16.63[h] | 11.18[d] | 0.06[c] | 0.0758[d] |
| S13 (OF) | 2.42[e] | 88.77[d] | 18.08[cd] | 0.06[c] | 0.07[d] |
| S14 (RR) | 2.83[e] | 47.65[f] | 3.59[e] | 0.11[bc] | 0.08[d] |
| S15 (SA) | 1.28[e] | 49.81[f] | 6.54[d] | 0.18[b] | 0.1671[d] |
| S16 (SA) | 2.18[e] | 125.79[b] | 18.04[c] | 0.07[bc] | 0.0084[d] |
| S17 (OF) | 1.22[e] | 14.62[h] | 10.58[d] | 0.10[bc] | 0.0129[d] |
| S18 (OF) | 0.75[e] | 55.68[g] | 15.70[c] | 0.07[bc] | 0.00**[d] |
| S19 (OF) | 1.75[e] | 42.99[g] | 6.38[d] | 0.25[b] | 0.00[d] |
| S20 (OF) | 2.12[e] | 117.72[b] | 17.45[c] | 0.08[bc] | 0.00[d] |
| S21 (SA) | 2.20[e] | 109.13[c] | 22.00[c] | 0.16[bc] | 0.105[d] |
| S22 (SA) | 1.91[e] | 133.57[b] | 15.62[cd] | 0.20[b] | 0.041[d] |
| S23 (RR) | 0.86[e] | 20.20[h] | 12.56[d] | 0.13[bc] | 0.0458[d] |
| S24 (OF) | 0.83[e] | 17.42[h] | 11.98[d] | 0.21[b] | 0.0675[d] |
| S25 (OF) | 1.93[e] | 111.62[c] | 13.78[d] | 0.15[bc] | 0.1154[d] |
| S.E. | 0.043 | 3.28 | 1.18 | 0.03 | 0.09 |

*Alphabetical letters indicate significance of variation within each metal among the collection sites; **0 value means below detection limit.

until all smoke had gone. The sample was then dry-ashed at 550°C in a muffle furnace for 14 h (method adapted from Okalebo et al., 2002). To the ash, 15 ml of 6 N HCl was added and the mixture heated for about 10 min at 250°C on a hot plate in order to digest the minerals in the ash. The resulting digest was filtered using Whatmans No. 42 filter paper. The filtrate was topped up to 50 ml using distilled water and stored in plastic bottles in a cold room till analysis.

#### Heavy metal analysis

Atomic Absorption Flame Emission Spectrophotometer (Shimadzu AAS-6200) was used to quantify heavy metal content for soil and vegetable samples. Calibration was done by running standards at concentrations of 0, 1, 1.5, 2 and 2.5 mg/kg. Hydrochloric acid (6 N) was used as a blank to zero the AAS.

#### Data analysis

Data on metal content obtained from the AAS was analyzed for variance using ANOVA and multiple mean comparisons were done using Tukeys at 5% level. Pearson's Product Moment was used to correlate the amount of metal in soil to that in the plant.

## RESULTS AND DISCUSSION

### Heavy metals in soils

The soil metal concentrations for each element and site are listed in Table 2. Soil metal concentration was significantly different in the different sites. The trend for the mean percentage for metals was Zn > Cu > Pb > Cd > Cr. EDTA-extractable Pb ranged from 0.57 to 20.94±0.43 mg/kg. The highest levels were in industrial area (sites 2, 3 and 4). This may be explained by occasional fuel spills and other waste flowing from the industrial area. Factories in this area include paint, vehicle batteries that may contain lead oxide, glass that may contain lead, and fuel some of which still contains lead. Sewage area where the effluent from the main sewer line of the city is let into the river contained up to 5.4 mg/kg. Soil Pb levels above 20 mg/kg are toxic to plants (Audu and Lawal, 2006), the highest obtained in this study.

Cu values were 3.59 to 75.37±1.18 mg/kg, with industrial area sites registering the highest levels. Copper has extensive use in industries, domestic items and farms such as coin money, electrical wiring, water and fabric treatment and fungicides. Taber (2009) suggests a 120 mg/kg higher limit in soil. It is found in soil either from natural or anthropogenic sources through water or dumping. Soil Cu content was much less as compared to earlier studies by Kimani (2007) (0 - 198 mg/kg) working on a dumpsite area in Kenya, but higher than Yebpella et al. (2011) (2.41 - 7.39 mg/kg) working on sites along a Nigerian river. EDTA-extractable Zn content ranged between 13.01 and 198.03±3.28 mg/kg. Industrial area sites had very high Zn contents as compared to other sites. Zinc industrially is used for galvanization, in dry cell batteries, cosmetics and medicines (ATSDR, 2005). Although some soils in ordinary farm sites had deficient Zn content, none had higher content than the recommended 30 - 300 mg/kg (Taber, 2009). Values in the study were lower than that of Kimani (2007) who analyzed soil around a dumpsite (175 - 1150 mg/kg).

Extractable Cd values were 0 to 2.64±0.09 mg/kg. Similarly, the highest values were at the industrial area region. Cadmium has wide usage in batteries, PVC plastics, cigarettes and paint pigments. Chromium concentration ranged from 0.03 to 1.4±0.03 mg/kg with industrial areas as the highest; none was above the recommended 100 mg/kg. Both Cd and Cr were however below detection limit in many sites. From the results, the highest values for all metals were at industrial area, followed by sewage area implying that metal content was

**Table 3.** Pb content of vegetables collected from Nairobi urban and peri-urban sites.

| Site | Vegetable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| S1 (IA) | $0.97^{f}$** | $1.20^{hi}$ | | $0.86^{e}$ | $0.61^{cdefg}$ | | $0.65^{abc}$ | $0.67^{ab}$ | $0.55^{a}$ | $0.82^{bcde}$ |
| S2 (IA) | * | $1.88^{j}$ | 1.17c | $2.10^{g}$ | $2.41^{k}$ | $2.56^{k}$ | | | | $0.66^{abcde}$ |
| S3 (IA) | | $0.70^{defg}$ | 0.77b | $2.44^{g}$ | $1.74^{j}$ | $1.48^{j}$ | $1.63^{de}$ | | | $0.47^{abc}$ |
| S4 (SA) | $0.14^{a}$ | $0.79^{efgh}$ | 0.35a | | $1.56^{j}$ | $0.56^{bcdefg}$ | $0.58^{abc}$ | $0.62^{ab}$ | | $0.61^{abcde}$ |
| S5 (RR) | $0.28^{ab}$ | $0.28^{abcd}$ | | | $0.50^{bcdefg}$ | $0.63^{cdefg}$ | $0.78^{abc}$ | $0.73^{ab}$ | $0.54^{a}$ | $0.39^{abc}$ |
| S6 (OF) | $0.46^{abcd}$ | $0.17^{ab}$ | | $0.85^{de}$ | $0.41^{bcde}$ | $0.60^{cdefg}$ | $0.61^{abc}$ | $0.95^{b}$ | $0.58^{a}$ | $0.94^{cdef}$ |
| S7 (SA) | $0.40^{abc}$ | $0.50^{abcdef}$ | | $0.86^{de}$ | $0.65^{cdefg}$ | | $0.57^{abc}$ | | | $0.29^{ab}$ |
| S8 (SA) | $0.30^{ab}$ | $0.92^{fghi}$ | | $0.87^{e}$ | $0.98^{i}$ | $1.80^{j}$ | $0.93^{bc}$ | $0.25^{a}$ | | $0.68^{abcde}$ |
| S9 (SA) | $0.55^{bcde}$ | $1.20^{hi}$ | $0.61^{ab}$ | $1.32^{f}$ | $1.69^{j}$ | $0.85^{ghi}$ | $0.95^{bc}$ | $1.97^{c}$ | $0.94^{b}$ | $0.37^{abc}$ |
| S10 (RR) | $0.43^{abcd}$ | $0.25^{abcd}$ | | $0.30^{ab}$ | $0.09^{a}$ | $1.71^{j}$ | $2.02^{e}$ | $1.49^{c}$ | $0.58^{a}$ | $1.46^{fg}$ |
| S11 (OF) | $0.86^{ef}$ | $1.04^{ghi}$ | $1.22^{c}$ | $1.27^{f}$ | $1.51^{j}$ | $1.12^{i}$ | $1.02^{bcd}$ | | | $0.55^{abcde}$ |
| S12 (RR) | | $0.43^{abcde}$ | | $0.24^{a}$ | $0.27^{ab}$ | $0.59^{bcdefg}$ | $0.72^{abc}$ | $0.52^{ab}$ | | $1.56^{g}$ |
| S13 (OF) | $0.77^{def}$ | $0.66^{defg}$ | $0.42^{a}$ | | $0.41^{bcde}$ | $2.53^{k}$ | $0.25^{a}$ | | | |
| S14 (RR) | $0.93^{f}$ | | | | $0.63^{cdefg}$ | $0.76^{cdefg}$ | $0.99^{bc}$ | | | $0.74^{abcde}$ |
| S15 (SA) | $0.49^{abcd}$ | $0.17^{ab}$ | | $0.48^{abc}$ | $0.41^{bcde}$ | $0.42^{abcde}$ | $0.64^{abc}$ | | | $0.41^{abc}$ |
| S16 (SA) | | $1.36^{i}$ | | $0.60^{bcde}$ | $0.96^{hi}$ | | | | | $0.44^{abc}$ |
| S17 (OF) | $0.40^{abc}$ | $0.09^{a}$ | | | $0.80^{ghi}$ | $0.16^{a}$ | | | | $0.51^{abcd}$ |
| S18 (OF) | $0.30^{ab}$ | $0.41^{abcde}$ | | | $0.66^{defgh}$ | | | | | $1.05^{defg}$ |
| S19 (OF) | $0.86^{ef}$ | $1.19^{hi}$ | $1.22^{c}$ | $1.27^{f}$ | $1.51^{j}$ | $1.12^{i}$ | $1.09^{bcd}$ | | $0.48^{a}$ | $0.55^{abcde}$ |
| S20 (OF) | $0.16^{a}$ | $0.55b^{cdef}$ | $0.45^{a}$ | $0.29^{ab}$ | $0.37^{abcd}$ | $1.19^{i}$ | $0.53^{ab}$ | | | $0.18^{a}$ |
| S21 (SA) | $0.24^{ab}$ | | $0.44^{a}$ | | $0.68^{efghi}$ | | | | | $0.42^{abc}$ |
| S22 (SA) | $0.72^{cdef}$ | $0.20^{abc}$ | | | $0.68^{efghi}$ | $0.14^{a}$ | $1.18^{cd}$ | $0.75^{ab}$ | | $0.85^{bcde}$ |
| S23 (RR) | $1.03^{f}$ | $0.63^{cdefg}$ | $0.39^{a}$ | $0.65^{cde}$ | $0.75^{fghi}$ | $0.83^{ghi}$ | $1.18^{cd}$ | $0.82^{b}$ | $0.50^{a}$ | $1.09^{efg}$ |
| S24 (OF) | $0.44^{abcd}$ | $0.70^{defg}$ | | $0.52^{abcd}$ | $0.34^{abc}$ | | $0.46^{ab}$ | | | $1.09^{efg}$ |
| S25 (OF) | $0.33^{ab}$ | $0.43^{abcde}$ | | | $0.49^{bcdef}$ | $1.18^{hi}$ | $0.52^{ab}$ | $0.75^{ab}$ | | $1.56^{g}$ |
| S.E. | 0.043 | 0.103 | 0.186 | 0.076 | 0.069 | 0.067 | 0.144 | 0.113 | 0.071 | 0.128 |

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

significantly lowered by dilution as water flows downstream and progressively reduced dumping of industrial waste.

## Heavy metals in vegetables

Metal content in vegetables had a similar trend with that in soil (Zn > Cu > Cd >Pb > Cr). There was a significant difference in the amount of Pb within vegetables at all sites. The highest Pb content (Table 3) of 2.4 mg/kg was in spiderplant and Pumpkin from sites 3 and 2 (industrial area). The lowest was 0.09 mg/kg in spinach from an ordinary farm and pumpkin from sewage area.

Copper concentration was also significantly different in vegetables from different sites (Table 4). The highest was 21.34 mg/kg in pumpkin from industrial area and the lowest was 0.5 mg/kg in cowpea from a road reserve. According to Taber (2009) and Mills and Jones (1991), normal Cu content in plants should range from 2 - 20 mg/kg, and CAC (2001) sets it at 40 mg/kg therefore the concentrations in this study were within acceptable range. Many vegetables contained lower than 2 mg/kg which is the recommended lower limit of Cu in plant tissue because some soils were deficient; or when they had sufficient Cu, a pH imbalance or an excess of other nutrients such as phosphorous which were not determined in this study could have limited absorption by vegetables (Mills and Jones, 1991).

Zinc concentration in vegetables also varied significantly (Table 5). The highest was 89.85 mg/kg in African Kale from site 2 (industrial area) and the lowest was 20.13 mg/kg from Amaranth and cowpea from ordinary farms. Normal Zn content in vegetables ranges should range within 25 - 300 mg/kg (Taber, 2009). These results were slightly higher than those of Jung (2008) who found

**Table 4.** Cu content of vegetables collected from Nairobi urban and peri-urban sites.

| Site | Vegetable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| S1 (IA) | 1.86$^{a}$ | 2.72$^{bcd}$ | | 4.82$^{d}$ | 11.35$^{i}$ | | 7.11$^{hi}$ | 4.86$^{b}$ | 7.35$^{c}$ | 8.10$^{j}$ |
| S2 (IA) | | 11.60$^{h}$ | 11.03$^{e}$ | 18.00$^{h}$ | 21.34$^{l}$ | 19.93$^{i}$ | 12.28$^{k}$ | | | 8.76$^{i}$ |
| S3 (IA) | | 12.24$^{h}$ | 13.29$^{f}$ | 14.42$^{g}$ | 18.89$^{k}$ | 20.26$^{i}$ | | | | 11.74$^{k}$ |
| S4 (SA) | 1.91$^{a}$ | 1.75$^{ab}$ | 1.17$^{a}$ | | 2.22$^{bc}$ | 4.74$^{d}$ | 0.93$^{abc}$ | 6.47$^{c}$ | | 3.28$^{e}$ |
| S5 (RR) | 7.74$^{f}$ | 9.40$^{g}$ | | | 6.79$^{h}$ | 8.16$^{f}$ | 9.21$^{j}$ | 9.81$^{d}$ | 11.34$^{d}$ | 5.11$^{fg}$ |
| S6 (OF) | 7.87$^{f}$ | 9.56$^{g}$ | | 3.37$^{c}$ | 2.92$^{cd}$ | 2.36$^{bc}$ | 2.50$^{efg}$ | 1.91$^{a}$ | 7.31$^{c}$ | 1.97$^{bc}$ |
| S7 (SA) | 3.43$^{bc}$ | 7.79$^{f}$ | 4.40$^{c}$ | 6.41$^{e}$ | 1.60$^{ab}$ | | | | | 2.31$^{cd}$ |
| S8 (SA) | 14.88$^{h}$ | 9.11$^{fg}$ | | 10.89$^{f}$ | 15.54$^{j}$ | 16.84$^{h}$ | 14.07$^{l}$ | 18.01$^{f}$ | | 14.77$^{l}$ |
| S9 (SA) | 6.78$^{e}$ | 9.37$^{g}$ | 3.84$^{c}$ | 10.48$^{f}$ | 1.47$^{ab}$ | 10.48$^{g}$ | 1.40$^{abcde}$ | 3.92$^{b}$ | 2.5$^{a}$ | 1.22$^{ab}$ |
| S10 (RR) | 3.93$^{c}$ | 3.44$^{cde}$ | | 2.82$^{bc}$ | 3.55$^{def}$ | 3.91$^{d}$ | 1.96$^{cde}$ | 8.70$^{d}$ | 3.24$^{b}$ | 8.66$^{i}$ |
| S11 (OF) | 1.72$^{a}$ | 2.07$^{abc}$ | 1.26$^{a}$ | 1.88$^{ab}$ | 2.38$^{bc}$ | 2.45$^{bc}$ | 1.88$^{bcde}$ | | | 5.57$^{g}$ |
| S12 (RR) | | 1.23$^{a}$ | | 10.12$^{f}$ | 1.34$^{a}$ | 0.75$^{a}$ | 0.52$^{a}$ | 3.65$^{b}$ | | 2.83$^{cde}$ |
| S13 (OF) | 9.13$^{g}$ | 1.72$^{ab}$ | 2.16$^{b}$ | | 3.92$^{ef}$ | 7.94$^{f}$ | 3.58$^{g}$ | | | |
| S14 (RR) | 5.88$^{d}$ | | | | 3.99$^{ef}$ | 3.45$^{cd}$ | 0.63$^{a}$ | | | 1.96$^{bc}$ |
| S15 (SA) | 7.33$^{ef}$ | 2.83$^{bcde}$ | | 1.32$^{a}$ | 3.09$^{cde}$ | 1.82$^{ab}$ | 0.77$^{ab}$ | | | 6.59$^{h}$ |
| S16 (SA) | | 11.27$^{h}$ | | 1.22$^{a}$ | 1.26$^{a}$ | | | | | 2.47$^{cde}$ |
| S17 (OF) | 7.21$^{ef}$ | 3.69$^{de}$ | | | 3.91$^{ef}$ | 6.47$^{e}$ | | | | 2.07$^{bc}$ |
| S18 (OF) | 2.97$^{b}$ | 4.29$^{e}$ | 1.26$^{a}$ | | 5.73$^{g}$ | | | | | 4.64$^{f}$ |
| S19 (OF) | 1.72$^{a}$ | 2.07$^{abc}$ | | 1.88$^{ab}$ | 2.38$^{bc}$ | 2.45$^{bc}$ | 1.88$^{bcde}$ | | 3.37$^{b}$ | 5.57$^{g}$ |
| S20 (OF) | 1.66$^{a}$ | 8.05$^{fg}$ | 6.12d | 1.08$^{c}$ | 2.84$^{cd}$ | 1.67$^{ab}$ | 1.35$^{abcd}$ | | | 1.35$^{ab}$ |
| S21 (SA) | 7.80$^{f}$ | | | | 7.54$^{h}$ | | 3.40$^{fg}$ | | | 3.18$^{de}$ |
| S22 (SA) | 5.73$^{d}$ | 4.26$^{de}$ | | | 5.73$^{g}$ | 1.86$^{ab}$ | 6.42$^{h}$ | 15.79$^{e}$ | | 0.77$^{a}$ |
| S23 (RR) | 9.13$^{g}$ | 1.07$^{a}$ | 3.84c | 11.27$^{f}$ | 1.24$^{a}$ | 7.49$^{ef}$ | 11.27$^{k}$ | 3.79$^{b}$ | 2.37$^{a}$ | 9.13$^{i}$ |
| S24 (OF) | 3.80$^{bc}$ | 3.91$^{de}$ | | 1.72$^{ab}$ | 4.40$^{f}$ | | 7.93$^{i}$ | | | 9.13$^{i}$ |
| S25 (OF) | 1.72$^{a}$ | 2.07$^{abc}$ | | | 2.38$^{bc}$ | 2.45$^{bc}$ | 2.30$^{def}$ | 15.79$^{e}$ | | 5.57$^{g}$ |
| S.E. | 0.072 | 0.35 | 0.065 | 0.249 | 0.2109 | 0.326 | 0.2556 | 0.331 | 0.173 | 0.2 |

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

**Table 5.** Zn content of vegetables collected from Nairobi urban and peri-urban sites.

| Site | Vegetable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| S1 (IA) | 31.23$^{f}$ | 44.43$^{i}$ | | 54.46$^{e}$ | 33.76$^{e}$ | | 38.12$^{fgh}$ | 43.01$^{a}$ | 38.45$^{d}$ | 54.48$^{j}$ |
| S2 (IA) | | 59.33$^{k}$ | 89.85$^{g}$ | 81.15$^{h}$ | 80.55$^{l}$ | 61.38$^{i}$ | 55.76$^{l}$ | | | 55.6$^{j}$ |
| S3 (IA) | | 43.86$^{hi}$ | 82.45$^{f}$ | 53.56$^{e}$ | 44.34$^{g}$ | 64.41$^{k}$ | | | | 56.49$^{j}$ |
| S4 (SA) | 26.32$^{cde}$ | 60.62$^{l}$ | 54.43$^{c}$ | | 22.44$^{b}$ | 47.76$^{gh}$ | 31.45$^{cd}$ | 32.27$^{c}$ | | 33.14$^{d}$ |
| S5 (RR) | 29.24$^{e}$ | 47.32$^{j}$ | | | 43.88$^{f}$ | 44.5$^{fg}$ | 50.24$^{k}$ | 47.7$^{f}$ | 30.64$^{b}$ | 33.73$^{d}$ |
| S6 (OF) | 35.24$^{gh}$ | 43.76$^{hi}$ | | 52.11$^{d}$ | 53.44$^{i}$ | 42.43$^{ef}$ | 45.67$^{ijk}$ | 46.54$^{f}$ | 40.52$^{e}$ | 31.11$^{c}$ |
| S7 (SA) | 23.15$^{b}$ | 34.02$^{bcd}$ | | 26.75$^{a}$ | 26.82$^{cd}$ | | 45.79$^{ijk}$ | | | 31.32$^{c}$ |
| S8 (SA) | 25.05$^{bc}$ | 34.56$^{cd}$ | | 87.42$^{i}$ | 37.47$^{f}$ | 45.73$^{g}$ | 40.99$^{ghi}$ | 30.27$^{c}$ | | 55.79$^{j}$ |
| S9 (SA) | 21.3$^{a}$ | 26.81$^{a}$ | 52.22$^{c}$ | 56.77$^{f}$ | 62.08$^{k}$ | 39.44$^{cde}$ | 35.88$^{defg}$ | 24.55$^{a}$ | 32.22$^{c}$ | 41.83$^{g}$ |
| S10 (RR) | 31.98$^{f}$ | 54.35$^{l}$ | 50.68$^{bc}$ | 53.88$^{e}$ | 48.73$^{ij}$ | 42.69$^{ef}$ | 44.87$^{ij}$ | | | 38.57$^{f}$ |
| S11 (OF) | 38.73$^{i}$ | 39.19$^{e}$ | 70.44$^{e}$ | 56.25$^{f}$ | 45.11$^{h}$ | 76.7$^{k}$ | 37.11$^{efgh}$ | | | 44.81$^{h}$ |
| S12 (RR) | | 37.18$^{de}$ | | 58.45$^{f}$ | 25.18$^{c}$ | 22.42$^{a}$ | 36.95$^{efgh}$ | 23.63$^{c}$ | | 52.76$^{i}$ |
| S13 (OF) | 33.08$^{fg}$ | 45.68$^{ij}$ | 47.46$^{b}$ | | 32.44$^{de}$ | 32.63$^{b}$ | 26.44$^{cd}$ | | | 33.45$^{d}$ |
| S14 (RR) | 35.05gh | | | | 52.55i | 27.13c | 32.65cde | | | 35.77e |

**Table 5.** Contd.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S15 (SA) | 35.14$^{gh}$ | 41.16$^{ef}$ | | 48.46$^{c}$ | 41.33$^{g}$ | 43.56$^{ef}$ | 22.05$^{b}$ | | | 41.22$^{g}$ |
| S16 (SA) | | 43.61$^{ghi}$ | | 74.32$^{g}$ | 63.56$^{k}$ | | | | | 44.22$^{h}$ |
| S17 (OF) | 47.51$^{k}$ | 32.83$^{bc}$ | | | 45.56$^{h}$ | 42.46$^{ef}$ | | | | 32.36$^{cd}$ |
| S18 (OF) | 35.11$^{gh}$ | 41.27$^{efg}$ | | | 21.56$^{a}$ | | | | | 37.39$^{f}$ |
| S19 (OF) | 31.98$^{f}$ | 54.35$^{l}$ | 79.88$^{f}$ | 49.63$^{c}$ | 51.39$^{i}$ | 50.24$^{h}$ | 28.41$^{d}$ | | 30.28$^{b}$ | 50.38$^{i}$ |
| S20 (OF) | 27.24$^{cde}$ | 36.34$^{d}$ | | 44.75$^{b}$ | 37.69$^{f}$ | 41.16d$^{ef}$ | 35.5$^{e}$ | 43.12$^{e}$ | 32.71$^{c}$ | 33.46$^{d}$ |
| S21 (SA) | 37.15$^{hi}$ | | 56.27$^{cd}$ | | 22.47$^{b}$ | | | | | 58.28$^{k}$ |
| S22 (SA) | 26.92$^{cde}$ | 59.08$^{S}$ | | | 28.54$^{d}$ | 35.48$^{c}$ | 20.45$^{a}$ | 36.56$^{d}$ | | 21.91$^{a}$ |
| S23 (RR) | 33.73$^{fg}$ | 36.19$^{d}$ | 60.43$^{d}$ | 57.72$^{f}$ | 25.18$^{c}$ | 24.15$^{b}$ | 36.76$^{efgh}$ | 32.65$^{c}$ | 28.31$^{a}$ | 35.51$^{e}$ |
| S24 (OF) | 27.23$^{cde}$ | 43.03$^{fgh}$ | | 45.68$^{b}$ | 20.13$^{a}$ | | 41.46$^{hi}$ | 35.06$^{d}$ | | 35.51e |
| S25 (OF) | 42.50$^{j}$ | 31.98$^{b}$ | 61.45$^{d}$ | | 50.48$^{i}$ | 50.33$^{h}$ | 38.96$^{fgh}$ | | | 50.38$^{i}$ |
| S.E. | 0.654 | 0.547 | 0.606 | 0.401 | 0.515 | 1.003 | 1.163 | 0.306 | 0.173 | 0.3462 |

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

that vegetables had a Zn range of 18 - 52 mg/kg, and was highest in mining sites. Mean Zn values were very high as compared to Iyaka (2007) who got 7 mg/kg Zn in spinach in a similar study, and Yebpella et al. (2011), who got the highest value of 26.7 mg/kg while working on a site irrigated with contaminated river water. Zinc is least toxic among the heavy metals in this study; its deficiency could be more detrimental than toxicity (Kumar et al., 2007). CAC (2001) sets the limit of its intake at 60 mg/kg while Nair et al. (1997) puts it at 150 mg/kg, therefore the content in this study may be acceptable.

Cadmium concentration in vegetables was significantly different in vegetables from different sites (Table 6). The highest was 3.02 mg/kg noted in African Kale followed by 2.5 mg/kg in spider plant both from Industrial area. In all vegetables, the Cd concentration was consistently highest in Industrial area and sewage area.

Although in most vegetables, Cd was not above the dietary recommended limit in vegetables (0.2 mg/kg) (Yebpella et al., 2011), continued low-intake of oral Cd may cause negative gastrointestinal, musculoskeletal, renal and neurological effects (Kumar et al., 2007). Chromium concentration was the lowest of all the metals in the vegetables (Table 7). The highest noted was 1.24 mg/kg in spider plant followed by 1.19 mg/kg in spinach both from Industrial area.

## Correlation of soil and vegetable heavy metal concentrations

Simple correlation was carried out to establish whether the heavy metal concentration in vegetables was a function of the amount in soil where they were grown. At $P < 0.05$ of most metals there was a significant positive linear relationship between the heavy metal in soil and that in vegetable leaves (Table 8). There was a stronger linear relationship in Cu, Cd and Cr for most vegetables and soils. Jung (2008) through a multiple regression using several factors determined that soil metal content was the principal determinant of plant tissue metal content.

In cases where soil metal was less than vegetable content other metal sources such as dumped items could be implicated. In a few instances such as Zn in African Nightshade and Jute mallow, and Pb in kale the relationship was negative implying that the plant accumulated the metals in leaves or the amount of the metals in the field at some point were higher than at the time of sampling. Factors that were not tested in this study that would account for the negative correlation include soil pH, cation exchange capacity, organic matter content, types and varieties of vegetables, and vegetable age (Jung, 2008).

## Conclusion

From this study, the most elevated soil metal concentrations were found nearest to industrial area with average of 20.94, 198.3, 75.37, 2.64 and 2.1 mg/kg for Pb, Zn, Cu, Cd and Cr, respectively. Most vegetables planted in these sites of the study area are within safe limits although some exceed.

This notwithstanding, longterm metal exposure by regular consumption of such locally grown vegetables poses potentially health problems to animal and humans. Further cleaning of the rivers needs to be done, and curtailing of all effluents and dumping of solid waste should be done to minimize contaminant leakage into water and soil that may be used for agriculture.

**Table 6.** Cd content of vegetables collected from Nairobi urban and peri-urban sites.

| Site | Vegetable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| S1 (IA) | 0.15$^{bcd}$ | 0.24$^{h}$ | | 0.27$^{cd}$ | 0.16$^{e}$ | | 0.11$^{bc}$ | 0.14$^{d}$ | 0.05$^{a}$ | 0.05$^{ab}$ |
| S2 (IA) | | 1.95$^{j}$ | 2.04$^{c}$ | 2.54$^{f}$ | 1.77$^{i}$ | 1.81$^{g}$ | 1.53$^{g}$ | | | 0.36$^{fg}$ |
| S3 (IA) | | 2.07$^{k}$ | 3.02$^{d}$ | 2.01$^{e}$ | 1.52$^{h}$ | 1.66$^{f}$ | | | | 1.58$^{h}$ |
| S4 (SA) | 0.07$^{abc}$ | 0.09$^{cde}$ | 0.11$^{a}$ | | 0.04$^{abc}$ | 0.06$^{ab}$ | 0.13$^{cd}$ | 0.12$^{cd}$ | | 0.34$^{fg}$ |
| S5 (RR) | 0.21$^{de}$ | 0.32$^{i}$ | | | 0.32$^{f}$ | 0.42$^{e}$ | 0.21$^{ef}$ | 0.15$^{d}$ | 0.10$^{b}$ | 0.21$^{de}$ |
| S6 (OF) | 0.02$^{a}$ | 0.03$^{ab}$ | | 0.04$^{ab}$ | 0.04$^{abcd}$ | 0.06$^{ab}$ | 0.03$^{a}$ | 0.02$^{a}$ | 0.12$^{b}$ | 0.04$^{ab}$ |
| S7 (SA) | 0.03$^{a}$ | 0$^{a}$ | | 0$^{a}$ | 0$^{a}$ | | 0.00$^{a}$ | | | 0.00$^{a}$ |
| S8 (SA) | 0.23$^{de}$ | 0.11$^{cdef}$ | | 0.02$^{ab}$ | 0.02$^{ab}$ | 0.11$^{bc}$ | 0.05$^{ab}$ | 0.09$^{bc}$ | | 0.00$^{a}$ |
| S9 (SA) | 0.22$^{de}$ | 0.33$^{i}$ | 0.39$^{b}$ | 0.43$^{d}$ | 0.42$^{g}$ | 0.24$^{d}$ | 0.19$^{de}$ | 0.32$^{f}$ | 0.31$^{c}$ | 0.40$^{g}$ |
| S10 (RR) | 0.03$^{a}$ | 0.16$^{fg}$ | | 0.20$^{bc}$ | 0.14$^{de}$ | 0.06$^{ab}$ | 0.03$^{a}$ | 0.05$^{ab}$ | 0.07$^{a}$ | 0.05$^{ab}$ |
| S11 (OF) | 0.04$^{a}$ | 0.07$^{bcd}$ | 0.06$^{a}$ | 0.10$^{abc}$ | 0.15$^{e}$ | 0.03$^{ab}$ | 0.00$^{a}$ | | | 0.08$^{ab}$ |
| S12 (RR) | | 0.15$^{fg}$ | | 0.11$^{abc}$ | 0.16$^{e}$ | 0.19$^{cd}$ | 0.25$^{f}$ | 0.21$^{e}$ | | 0.25$^{ef}$ |
| S13 (OF) | 0.06$^{abc}$ | 0.14$^{efg}$ | 0.06$^{a}$ | | 0.08$^{abcde}$ | 0.10$^{abc}$ | 0.21$^{ef}$ | | | |
| S14 (RR) | 0.06$^{ab}$ | | | | 0.03$^{ab}$ | 0.13$^{bcd}$ | 0.14$^{cd}$ | | | 0.07$^{ab}$ |
| S15 (SA) | 0.07$^{abc}$ | 0.09$^{cde}$ | | 0.15$^{abc}$ | 0.27$^{f}$ | 0.17$^{cd}$ | 0.14$^{cd}$ | | | 0.20$^{cde}$ |
| S16 (SA) | | 0.26$^{h}$ | | 0.17$^{abc}$ | 0.17$^{e}$ | | | | | 0.13$^{bcd}$ |
| S17 (OF) | 0.30$^{e}$ | 0.03$^{ab}$ | | | 0.04$^{abc}$ | 0.00$^{a}$ | | | | 0.00$^{a}$ |
| S18 (OF) | 0.03$^{a}$ | 0.06$^{bc}$ | | | 0.03$^{ab}$ | | | | | 0.00$^{a}$ |
| S19 (OF) | 0.01$^{a}$ | 0$^{a}$ | 0.00$^{a}$ | 0$^{a}$ | 0$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | | 0.15$^{b}$ | 0.03$^{ab}$ |
| S20 (OF) | 0.06$^{abc}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | | | 0.00$^{a}$ |
| S21 (SA) | 0.10$^{abc}$ | | 0.07$^{a}$ | | 0.11$^{bcde}$ | | | | 0.10$^{b}$ | 0.08$^{ab}$ |
| S22 (SA) | 0.03$^{a}$ | 0.08$^{cd}$ | | | 0.08$^{abcde}$ | 0.09$^{abc}$ | 0.05$^{ab}$ | 0.09bc | | 0.03$^{ab}$ |
| S23 (RR) | 0.03$^{a}$ | 0.08$^{cd}$ | 0.05$^{a}$ | 0.07$^{ab}$ | 0.10$^{bcde}$ | 0.06$^{ab}$ | 0.01$^{a}$ | 0.07b | 0.04$^{a}$ | 0.05$^{ab}$ |
| S24 (OF) | 0.03$^{a}$ | 0.13$^{defg}$ | | 0.09$^{abc}$ | 0.13$^{cde}$ | | 0.06$^{ab}$ | 0.07b | | 0.04$^{ab}$ |
| S25 (OF) | 0.16$^{cd}$ | 0.16$^{g}$ | | | 0.13$^{cde}$ | 0.09$^{abc}$ | 0.10$^{bc}$ | | | 0.09$^{abc}$ |
| S.E. | 0.032 | 0.01232 | 0.0646 | 0.04104 | 0.0224 | 0.024 | 0.0142 | 0.0094 | 0.017 | 0.0261 |

*Blanks indicate that the vegetable was missing in a site;**alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

**Table 7.** Cr content of vegetables collected from Nairobi urban and peri-urban sites.

| Site | Vegetable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| S1 (IA) | 0$^{a}$ | 0.02$^{a}$ | | 0.02$^{a}$ | 0.02$^{a}$ | | 0$^{a}$ | 0.02$^{a}$ | 0.02$^{a}$ | 0.03$^{ab}$ |
| S2 (IA) | | 1.19$^{e}$ | 1.08$^{b}$ | 1.24$^{c}$ | 0.96$^{i}$ | 0.26$^{g}$ | 0.34$^{g}$ | | | 0.07$^{bcd}$ |
| S3 (IA) | | 0.12$^{abc}$ | 0.12$^{a}$ | 0.20$^{a}$ | 0.16$^{cdef}$ | 0.12$^{cde}$ | | | | 0.00$^{a}$ |
| S4 (SA) | 0.11$^{bc}$ | 0.18$^{bcd}$ | 0.14$^{a}$ | | 0.29$^{g}$ | 0.13$^{def}$ | 0.08$^{bcde}$ | 0.11$^{cd}$ | | 0.07$^{bcd}$ |
| S5 (RR) | 0$^{a}$ | 0.05$^{ab}$ | | | 0.08$^{abc}$ | 0.08$^{bcd}$ | 0$^{a}$ | 0.12$^{cd}$ | 0.07$^{b}$ | 0.06$^{bc}$ |
| S6 (OF) | 0.1$^{abc}$ | 0.07$^{ab}$ | | 0.07$^{a}$ | 0.10$^{abcd}$ | 0.11$^{cde}$ | 0.04$^{abc}$ | 0.06$^{ab}$ | 0.13$^{c}$ | 0.06$^{bcd}$ |
| S7 (SA) | 0.04$^{ab}$ | 0.24$^{cd}$ | | 0.03$^{a}$ | 0.05$^{ab}$ | | 0.05$^{bcd}$ | | | 0.07$^{bcd}$ |
| S8 (SA) | 0.023$^{ab}$ | 0.05$^{ab}$ | | 0.23$^{a}$ | 0.18$^{def}$ | 0.07$^{abc}$ | 0$^{a}$ | 0.03$^{a}$ | | 0.08$^{cde}$ |
| S9 (SA) | 0.06$^{ab}$ | 0.14$^{abc}$ | 0.50$^{ab}$ | 0.13$^{a}$ | 0.17$^{cdef}$ | 0.13$^{cdef}$ | 0.05$^{bcd}$ | 0.14$^{d}$ | 0.04$^{ab}$ | 0.04$^{abc}$ |
| S10 (RR) | 0.02$^{ab}$ | 0.16$^{abcd}$ | | 0.03$^{a}$ | 0.13$^{bcde}$ | 0.05$^{ab}$ | 0.03$^{ab}$ | 0.06$^{ab}$ | 0.12$^{c}$ | 0.05$^{bc}$ |
| S11 (OF) | 0.06$^{ab}$ | 0.04$^{ab}$ | 0.00$^{a}$ | 0.06$^{a}$ | 0.10$^{abcd}$ | 0.09$^{bcde}$ | 0.04$^{abc}$ | | | 0.04$^{abc}$ |
| S12 (RR) | | 0.04$^{ab}$ | | 0.02$^{a}$ | 0.12$^{bcd}$ | 0.07$^{abcd}$ | 0.09$^{de}$ | 0.03$^{a}$ | | 0.05$^{bc}$ |
| S13 (OF) | 0.03$^{ab}$ | | 0.05a | | 0.08$^{abc}$ | 0.07$^{abcd}$ | 0$^{a}$ | | | |
| S14 (RR) | 0.09abc | 0.04ab | | | 0.17cdef | 0.14ef | 0.03ab | | | 0.06bc |

**Table 7.** Contd.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S15 (SA) | $0.17^{c}$ | 0.14abcd | | $0.18^{a}$ | $0.21^{efg}$ | $0.18^{f}$ | $0.16^{f}$ | | | $0.10^{def}$ |
| S16 (SA) | | $0.04^{ab}$ | | $0.09^{a}$ | $0.11^{abcd}$ | | | | | $0.03^{ab}$ |
| S17 (OF) | $0.03^{ab}$ | $0.13^{abc}$ | | | $0.14^{bcdef}$ | $0.05^{ab}$ | | | | $0.35^{g}$ |
| S18 (OF) | $0.05^{ab}$ | $0.07^{ab}$ | | | $0.09^{abcd}$ | | | | | $0.00^{a}$ |
| S19 (OF) | $0.09^{abc}$ | $0.19^{bcd}$ | $0.10^{a}$ | $0.17^{a}$ | $0.23^{fg}$ | $1.09^{h}$ | $0.06^{bcde}$ | | $0.08^{b}$ | $0.11^{def}$ |
| S20 (OF) | $0.08^{abc}$ | $0.17^{abcd}$ | $0.10^{a}$ | $0.75^{b}$ | $0.08^{abc}$ | $0.08^{bcd}$ | $0.03^{ab}$ | | | $0.03^{ab}$ |
| S21 (SA) | $0.04^{ab}$ | | 0.09a | | $0.23f^{g}$ | | | | | $0.07^{bcd}$ |
| S22 (SA) | $0.09^{abc}$ | $0.29^{d}$ | | $0.10^{a}$ | $0.47^{h}$ | $0.01^{a}$ | $0.10^{e}$ | $0.11^{cd}$ | | $0.13^{f}$ |
| S23 (RR) | $0.53^{d}$ | $0.13^{abc}$ | $0.16^{a}$ | $1.22^{c}$ | $0.10^{abcd}$ | $0.05^{ab}$ | $0.07^{bcde}$ | $0.09^{bc}$ | $0.07^{b}$ | $0.05^{bc}$ |
| S24 (OF) | $0.09^{abc}$ | $0.09^{ab}$ | | | $0.09^{abcd}$ | | $0.08^{bcde}$ | $0.13^{d}$ | | $0.08^{cde}$ |
| S25 (OF) | $0.08^{abc}$ | $0.10^{abc}$ | | | $0.11^{abcd}$ | $0.12^{cde}$ | $0.09^{cde}$ | | | $0.12^{ef}$ |
| S.E. | 0.023 | 0.0123 | 0.065 | 0.05 | 0.0218 | 0.014 | 0.0114 | 0.0094 | 0.0093 | 0.001 |

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

**Table 8.** Correlation between heavy metals in soil and vegetables.

| Heavy metal | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pb | | | | | | | | | | |
| R | -0.0192 | 0.551 | 0.4326 | 0.8249 | 0.7064 | 0.6122 | 0.4571 | 0.0304 | 0.4024 | -0.2055 |
| P value | 0.9341 | 0.0059 | 0.2118 | <0.001 | <0.001 | 0.0053 | 0.0427 | 0.9293 | 0.5018 | 0.3469 |
| Cd | | | | | | | | | | |
| R | 0.5777 | 0.9518 | 0.887 | 0.9858 | 0.9752 | 0.9692 | 0.9639 | 0.7537 | 0.8874 | 0.949 |
| P value | 0.0061 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.0074 | 0.0446 | <0.001 |
| Cr | | | | | | | | | | |
| R | 0.2679 | 0.9683 | 0.9199 | 0.6866 | 0.9173 | 0.2115 | 0.8964 | 0.6736 | 0.5583 | 0.1188 |
| P value | 0.2404 | <0.001 | <0.001 | 0.0033 | <0.001 | 0.3848 | <0.001 | 0.0231 | 0.3281 | 0.5892 |
| Cu | | | | | | | | | | |
| R | 0.6121 | 0.6358 | 0.9324 | 0.7538 | 0.8518 | 0.9053 | 0.6356 | 0.5962 | 0.8119 | 0.5817 |
| P value | 0.0032 | 0.0011 | <0.001 | <0.001 | <0.001 | <0.001 | 0.0026 | 0.0529 | 0.0951 | 0.0036 |
| Zn | | | | | | | | | | |
| R | -0.4961 | 0.0385 | 0.6797 | 0.49 | 0.3507 | 0.174 | 0.4965 | -0.0357 | 0.1459 | 0.5341 |
| P value | 0.0222 | 0.8615 | 0.0306 | 0.054 | 0.0856 | 0.4762 | 0.026 | 0.9171 | 0.8149 | 0.0087 |

P is at 5% and R is the correlation coefficient.


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African Journal of Environmental Science and Technology

*Full Length Research Paper*

# Removing carbon dioxide from a stationary source through co-generation of carbonate/bicarbonate: The case of Mugher cement factory

**Getachew Dagnew Gebreeyessus[1]*, Tassisa Kaba[2] and Bhagwan Singh Chandravanshi[3]**

[1]Department of Environmental Health Sciences, Haramaya University, P.O. Box 235, Harar, Ethiopia.
[2]School of Chemical and Bio-Engineering, Addis Ababa Institute of Technology, Addis Ababa University, P.O. Box 385, Addis Ababa, Ethiopia.
[3]Department of Chemistry, Faculty of Sciences, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia.

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**The cement industries alone emit 5% of the world's total green house gases. In Ethiopia, the current $CO_2$ emission from this sector is about five fold of the countries overall $CO_2$ emission in 2002. Mugher cement factory (MCF), a case study plant in this paper, alone emits 463,844 tons of $CO_2$/year on average based on emission test and mass balance performed. Yet it accounts for less than 3% of the current $CO_2$ emission from this particular industry in the country. Of those technical approaches, separation of $CO_2$ before it joins the immediate atmosphere is getting wide spread interest. In relation to this, experiment on absorption of $CO_2$ is conducted to determine the effect of flow rate of the gas sample, concentration of the sodium hydroxide, flow rate of solvent and temperature of absorbent on absorption of $CO_2$ using the "Armfield" gas absorption column followed by the titrimetric analysis. Except temperature of solvent, all study variables showed strong relation with the amount of carbon dioxide absorbed (with a P-value < 0.05). Uniquely, this study has evaluated the potential for sodium bicarbonate production from the $CO_2$ absorbed using gravimetric analysis. It is also possible to recover over 28% crystal sodium bicarbonate.**

**Key words:** Green house gas, $CO_2$, absorption, caustic soda, sodium bicarbonate.

## INTRODUCTION

It is estimated that the global average temperature will rise between 1.4-5.8°C by the year 2100. The contributors to greenhouse effects are carbon dioxide ($CO_2$), chlorofluorocarbons (CFCs), methane ($CH_4$) and nitrous oxide ($N_2O$). The contribution of each gas to the greenhouse effects is $CO_2$- 55%, CFCs- 24%, $CH_4$- 15% and $N_2O$- 6% (Moazzem et al., 2012). The cement industry alone emits about 5% of the world's $CO_2$ emission (IPCC, 2005; Huntzinger and Eatmon, 2009).

Hydraulic (chiefly portland) cement, the binding agent in concrete and most mortars, is an important construction material. Portland cement is made primarily from finely ground clinker, a manufactured intermediate product that is composed predominantly of hydraulically active calcium silicate minerals formed through high-temperature burning of limestone and other materials in a

*Corresponding author. E-mail: getachewdagn@yahoo.com.

**Abbreviations:** **$C_N$_aver,** Average sodium carbonates concentration (g-mole/litters); **$CO_2$_Xaver,** average carbon dioxide absorption rate by the liquid (g-mole/second); **$Q_g$**, gas flow rate (litter/minute); **$Q_l$,** liquid flow rate (litter/minute); **Rab,** rate of absorption (mole/second); **GJ,** Giga-Joule; **Gt/y,** Giga-ton /year; **MCF,** Mugher Cement Factory; **Conc,** concentration (mole).

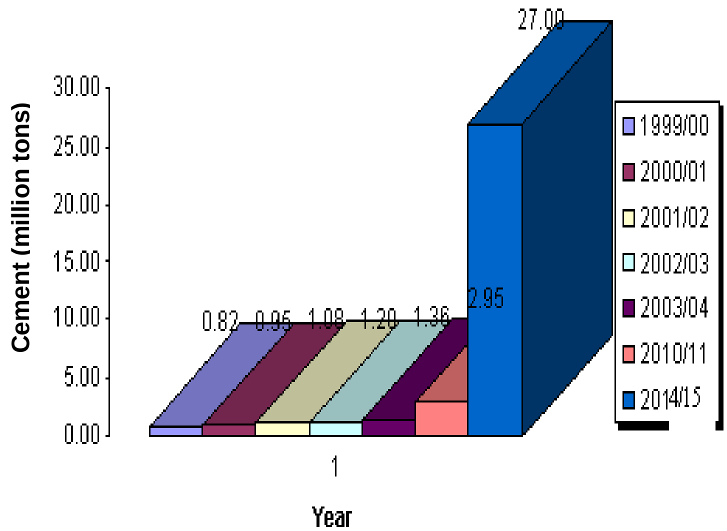


**Figure 1.** Cement production trend of Ethiopia in unit of tons per year with plan.

kiln. This process typically requires approximately 3.2 to 6.3 GJ of energy and 1.7 tons of raw materials (chiefly limestone) per ton of clinker produced and is accompanied by significant emissions of, in particular $CO_2$, but also nitrogen oxides, sulfur oxides and particulates. The overall level of $CO_2$ output, about 1t on/ton of clinker, is almost equally contributed by the calcinations of limestone and the combustion of fuels and this makes the cement industry one of the top two manufacturing industry sources of this greenhouse gas (Van Oss and Pandovani, 2003).

The concentration of $CO_2$ in the flue gases of cement plants is between 15-30% volume by volume, which is higher than in flue gases from power and heat production (3-15% by volume). Therefore, in principle, the post-combustion technologies for $CO_2$ capture could be applied to cement production plants (Hendrik et al., 2000).

Cement production sector is booming these days in Ethiopia (Figure 1) to meet the current demand for massive construction of infrastructures, which is mushrooming from time to time and related as well to economic growth of the country. The current average cement production of the country is about 2.95 million tons per year. It is expected to reach 27 million tons by 2017/18 and all needs attention on $CO_2$ emissions according to Ethiopian Investment Agency, (2011). In other words, by the year 2019/20 the cement production of the country could double India's current production.

Among several techniques for $CO_2$ separation, chemi=-cal solvent scrubbing, physical solvent scrubbing, adsorption, membranes, cryogenics and solid sorbents are the major ones. Gas absorption, as applied to the control of air pollution, is found feasible with regards to the removal of one or more pollutants from a contaminated gas stream by treatment with a liquid, though the cost implied (Mohammad et al., 2007), is also an issue. The necessary condition is the solubility of these pollutants in the absorbing liquid.

Of those gas absorption equipments, the packed column as applied in this study is by far the most commonly used for the absorption of gaseous pollutants (Reynolde et al., 2002). Currently the favoured method for post-combustion removal of $CO_2$ from flue gases uses chemical solvents. Generally, $CO_2$ capture from cement plants is more efficient than that from pulverized coal fired power plant or related others (Shuangzhen and Xiaochun, 2012). A sodium hydroxide solution provides a liquid sorbent that is more easily cycled through a piping system than a calcium hydroxide suspension in absorbing $CO_2$. Sodium hydroxide solution is selected as absorbent in this study due to availability as matter of sustaining the solution and manageability. Its binding energy is strong enough and its reaction kinetics is fast enough to prevent the need for heating, cooling or pressurizing the air. Because $CO_2$ is so dilute, any such action would result in an excessive energy penalty. The hydroxide solution avoids all such complications (Davison and Thambimuthu, 2005).

In another scenario, $CO_2$ is used as input in various applications (Chapel et al., 1999) including industrial ones. Thus, this study has also considered the production of bicarbonate from the recovered $CO_2$.

This study has first characterized the flue gas composition of the case plant, MCF, and assembled material balance around the kiln. Thus, it determined the country's over all $CO_2$ emission from this particular sector. Following that, absorption experiment is conducted on the gas sample, which is 20% $CO_2$ on average, with dilute caustic soda solution. At the same time, it determined the carbonate and bicarbonate as desirable products using titrimetric and gravimetric analysis.

The objective of this study was to quantitatively determine the $CO_2$ emission from cement plants and direct the options to turn this green house gas to useful product by applying chemical absorption method. From doing so, the study can be considered as options to produce useful industrial products not from use of fossil fuel, thereby avoiding purchase of foreign currency. While at the same time, it evaluates the factors in chemical absorption of $CO_2$ to suggest the optimum.

## MATERIALS AND METHODS

### Chemicals

The method of wet scrubbing chosen to treat a given gaseous pollutant is always specific to the given pollutant present in the gas stream treated. A "standard" wet scrubber does not exist (Wang et al., 2004). However, dilute sodium hydroxide solution as solvent is used in this study. Hydrochloric acid and acetic acid were used for the titrimetric determination of carbon dioxide absorbed and gravimetric determination of the sodium bicarbonate produced. Barium chloride solution was used for titration process. Carbon dioxide is the analyte of interest in this study, and distilled water was used for the titration process. Reagent-methyl orange and phenolphthalein were used for end-point detection of the acid-base titration.

### Materials

In this study, a range of equipment and materials were used including gasbags, crucibles, oven, compressors, pumps, gas cylinders, heat exchangers, titration apparatus, analytical balance and reagent chemicals as well as gas analyzer.

Sampling has been made using pumping system built in the cement plant following particulate removal by the bag house and cooling by shell and tube method. The analysis of gas sample was made using a gas analyzer (LI-820 $CO_2$ Analyzer, LI-COR Europe).

Thermometer was used to monitor temperature of room and solvent. pH meter was used to monitor the basic level of the sodium hydroxide solution. Electronic balance is used in the weighing of pellets and crystals mainly. In addition, spoon, stopwatch, conical flask, volumetric flask, beakers, burette and burette stand, measuring cylinder, pipette, gasbags and other equipments were also used.

"Armfield" gas absorption column was used to run the experiment. Thermostat was used as regulated heat source to heat the solvent. The titrimetric determination of carbon dioxide absorbed and gravimetric determination of the sodium bicarbonate produced was performed in this study respectively using bunch of analytic chemistry wares.

### Experimental design

The response variable in this study was $CO_2$ separated followed by the bicarbonate produced. The study variables in this paper include temperature, concentration and flow rate of the liquid and flow rate of the gas. Each factor was checked at two levels: $T_1$, $T_2$, (°C) for temperature, $C_1$, $C_2$, (mg/l) for concentration, $Q_l/_1$, $Q_{l/2}$ for liquid flow as well as $Qg_1$ and $Qg_2$ all in lit/min for the gas flow rates. Thus, the type of experimental design involved was full factorial design.

### Experimental setup

Gas absorption experiment was carried out in vertical counter current packed column 75 mm in diameter in which there are two lengths of contacting column each 70 cm long. The liquid solvent was fed at the top of the column and was distributed over the surface of the packing by nozzle (Figures 2 and 3). Pressure tapping was provided at the base, centre and top of the column to determine pressure drops across the column jointly with other measurements in need.

Sampling points were provided for the gas at the same three points. The liquid outlet stream and feed solution were also equipped with sampling point. Suitable manometer measurement was included. The solvent is taken from a sump-tank and it is pumped into the column using a calibrated flow meter attached on the board.

Gas was taken from a pressure regulated cylinder through a calibrated flow meter, and mixed with air, supplied and monitored from a small compressor in a pre-determined (but variable) mixed ratio. The mixture was fed to the base of the tower, in which a liquid seal was provided. The exit gas leaves the top of the column. The apparatus is designed to absorb $CO_2$/air mixture into an aqueous NaOH solution flowing down the column.

The emission is first pre-treated with cyclone and bag house. The analyte and air is compressed to a cylinder from which regulated flow of gas is fed to absorber from bottom and the diluted caustic soda from top. Samples of liquid are analysed from the exit valves of the column ($S_1$, $S_2$ and $S_3$) while the bottom exist is further treated for carbonate/bicarbonate determination (Figure 2).

### Procedure and analysis

Initially, the characterized flue gas is simulated using the commercially available carbon dioxide in a given purity. This is achieved by mixing such commercial gases and the atmospheric air. Before the start of the absorption, the pressure regulated $CO_2$ cylinder located in a suitable storage rack was adjusted in rear side of the column. The gas was connected to the column by a low-pressure regulator that was located at the rear of the vertical backboard.

The predetermined molar solvent was prepared after weighing the commercial grade NaOH pellet mixed with distilled water. Thus, several runs with aqueous NaOH solution were made as specified by the design of experiment. After equilibrium stage was maintained, from using the gas and solvent flow rate regulation through their valves, samples of exit solvent as well as gas were collected. The exit sample from each run was tested five times using the arm field gas absorption manual on titration, coded as UOP7.

The amount of bicarbonate, which precipitates out of solution at sufficiently high concentration, was determined using gravimetric analysis (Olutoye and Mohammed, 2006). The data generated from conducted experiments was analyzed using software-STATISTICA Version 8 (Stat Soft.Inc.2008), Design-expert version 7.0.0 (Stat-Ease, Inc. 2005) and CHEMCAD 5.2.0.

## RESULTS AND DISCUSSION

### Characterization of $CO_2$ in the flue gas

The flu gas in cement industries is generated when

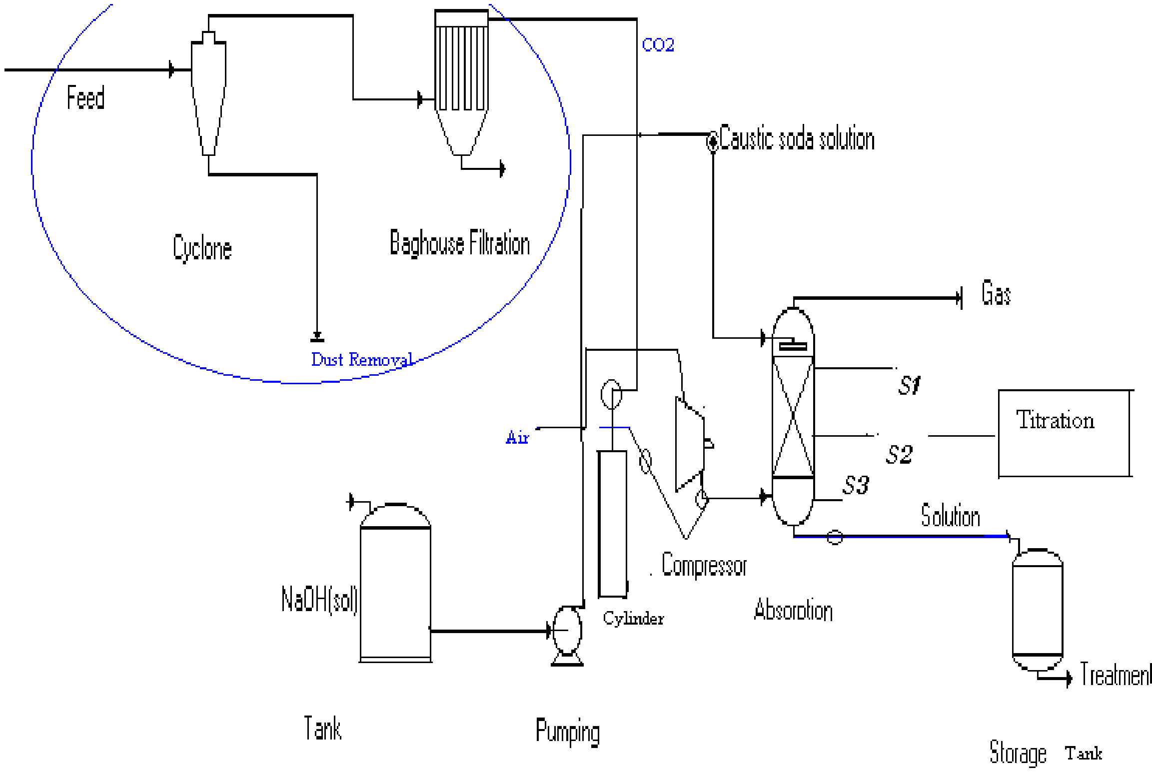


**Figure 2.** Process flow diagram showing the setup from sampling to absorption experiment.

**Figure 3.** The “Armfield” gas absorption experiment column at the mass transfer laboratory of the Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia.

making clinker mainly in the kiln at which high temperature roasting of calcium carbonate is achieved (Figure 4). The suspended particles with very high temperature rose up to bag houses where particles other than air are filtered. This exit gas then moves to cooling section where it looses its high temperature down to 45°C using shell and tube heat exchanger. The gas that already lost its warmth is tapped in to empty gasbags before it is tested for composition using the gas analyzer.

The analysis for composition of the ‘clean’ gas is made using gas analyses at the premises of The Federal Environmental Protection Authority of Ethiopia. The composition expressed in percentage by volume of those gases tested many times showed close results and the $CO_2$ is found to be 20% on average (Table 1).

## Mass balance

The cement process involves gas, liquid and solid flows with heat and mass transfer, combustion of fuel, reactions of clinker compounds and undesired chemical reactions that include sulfur, chlorine, and alkalis. It is important to understand these processes to optimize the operation of the cement kiln, diagnose operational problems, increase production, improve energy consumption and lower emissions (Figure 4).

The calcination and the fuel combustion chemistry

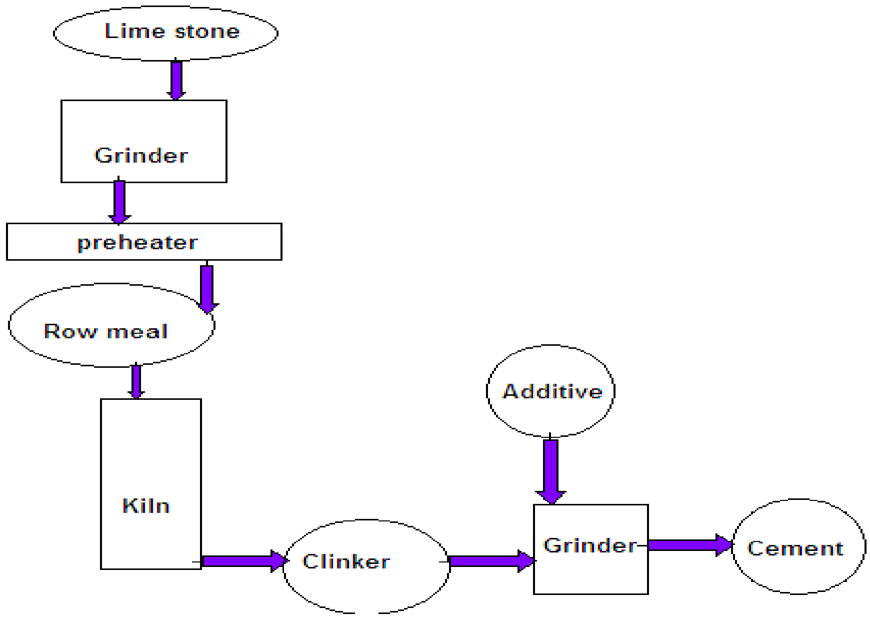


**Figure 4.** Simple schematic layout of central of cement making process at MCF (using CHEMCAD 5.2.0).

**Table 1.** Result of emitted gas analysis of MCF for $CO_2$ in percent by volume.

| Parameter analyzed | Sample gas bags (percentage by volume) | | | Average (percentage by volume) |
|---|---|---|---|---|
| | A | B | C | |
| Carbon dioxide ($CO_2$) | 20.0 | 19.8 | 20.2 | 20.0 |
| SOx | 0.4 | 0.45 | 0.4 | 0.4 |
| Total nitrogen | 78 | 78 | 80 | 78.7 |

involve the following reaction:

$$Ca\,CO_3 \xrightarrow[\text{Heat}]{} CaO + CO_2$$

Heavy fuel oil (solution) + $O_2 \longrightarrow CO_2 + SO_2 + NO + NO_2 + H_2O$ + heat

The heavy fuel oil consumption rate, based on four years average of most recently collected data, is 102.025 litters/ton of clinker, with working days of 261.24 days/year, production rate of 515382 tons of clinker/year. The row meal factor of the plant is about 1.73 and the row material is $CaCO_3$.

The 20.0% (percentage v/v) of the emission is contributed by $CO_2$ which conforms to the literature reports of 15-30% and is above average (Davison and Thambimuthu, 2005). From the mass balance performed on 1 kg clinker basis (Figure 5), it is clear that for every 1 kg of clinker formed almost 0.6 kg of $CO_2$ is released to the atmosphere from this study plant. This gives to current sub total annual average of 309,229.2 tons from calcining process alone. Additionally, 0.3 kg of $CO_2$ is emitted from combustion of fuel/1 kg of clinker produced. This figure shows that the emission of $CO_2$ from this particular sector alone in the country double and exceeds the overall country emission recorded by Ministry of Transports and Communications of Ethiopia for 2002 even though there are still new factories in buildup process. However, according to data by The World Bank Ethiopia, it is still least emitter of $CO_2$ per capita even within the sub Saharan region.

### The $CO_2$ absorption experiment

The rate of $CO_2$ absorption and hence bicarbonate formation is affected by such variables as the state of completion of the chemical reaction, the liquid flow rate, the absorbing surface area, the liquid temperature and the concentration of $CO_2$ gas (Treybal, 1981).

As per the design of experiments, 16 run for the factors

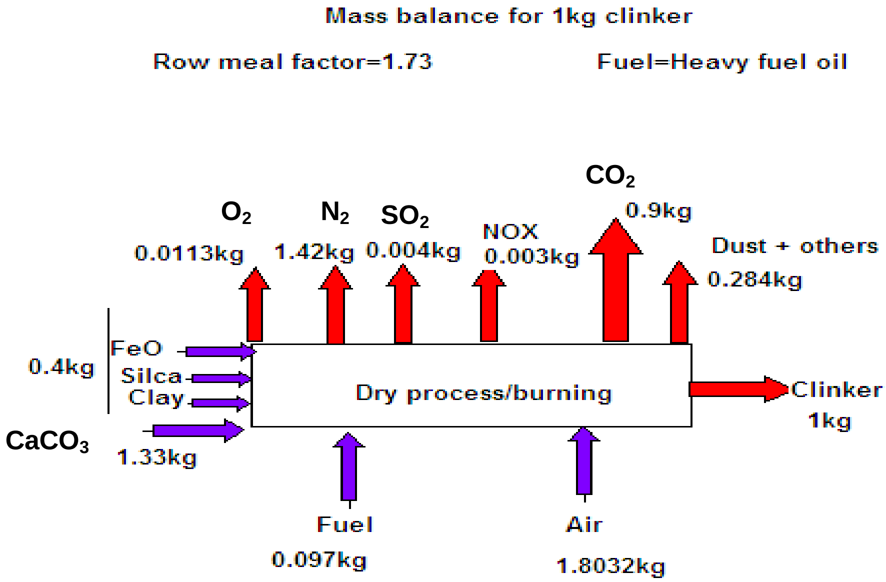


**Figure 5.** Summary of the mass balance performed for the case plant on 1 kg clinker basis (CHEMCAD 5.2.0).

**Table 2.** Summary of the results of the absorption experiment.

| Run | $C_N$_aver (g-mol/Lit) | $CO_2$_Xaver (g-mol/sec) | Conc (M), NaOH | $Q_{liq}$ Lit/min | $Q_{gas}$Lit /min | % $CO_2$ | % air | Temperature (°C) | Run time (min) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.06395 | 0.001599 | 0.2 | 1.5 | 4 | 16.7 | 83.3 | 22.8 | 13 |
| 2 | 0.0528 | 0.00129 | 0.2 | 1.5 | 5 | 20 | 80 | 22.8 | 13 |
| 3 | 0.0544 | 0.001118 | 0.2 | 1 | 5 | 20 | 80 | 23.2 | 14 |
| 4 | 0.0504 | 0.000946 | 0.2 | 1 | 4 | 16.7 | 83.3 | 23 | 14 |
| 5 | 0.0166 | 0.000818 | 0.2 | 1 | 5 | 20 | 80 | 47.2 | 14 |
| 6 | 0.00172 | 3.17E-05 | 0.1 | 1 | 5 | 20 | 80 | 25 | 14 |
| 7 | 0.0137 | 0.000343 | 0.1 | 1.5 | 5 | 20 | 80 | 44.6 | 12 |
| 8 | 0.00994 | 0.00028 | 0.1 | 1.5 | 5 | 20 | 80 | 23.6 | 11 |
| 9 | 0.0108 | 0.000181 | 0.1 | 1 | 5 | 20 | 80 | 43.6 | 12 |
| 10 | 0.023 | 0.000575 | 0.2 | 1.5 | 5 | 20 | 80 | 46.6 | 12 |
| 11 | 0.0166 | 0.000818 | 0.2 | 1 | 4 | 16.7 | 83.3 | 47.2 | 14 |
| 12 | 0.023 | 0.000575 | 0.2 | 1.5 | 4 | 16.7 | 83.3 | 46.6 | 12 |
| 13 | 0.0108 | 0.000181 | 0.1 | 1 | 4 | 16.7 | 83.3 | 43.6 | 12 |
| 14 | 0.0137 | 0.000343 | 0.1 | 1.5 | 4 | 16.7 | 83.3 | 44.6 | 12 |
| 15 | 0.00172 | 3.17E-05 | 0.1 | 1 | 4 | 16.7 | 83.3 | 25 | 14 |
| 16 | 0.01518 | 0.000566 | 0.1 | 1.5 | 4 | 16.7 | 83.3 | 23.6 | 11 |

of study: concentration of the caustic soda, gas flow rate, solvent flow rate and temperature of solution were conducted all at two levels. Data of interest including temperature of room, pH of solvent and others were recorded. The results of each run were tested/observed five times using the arm field gas absorption manual (titration) coded as UOP7. Each test was made after thermodynamic equilibrium conditions were attained, within 10-15 min based on velocity control on gas and solvent flow rates.

The titrimetric analysis for determining absorption rate for the exit liquid was made with standard method for neutralization of not reacted sodium hydroxide followed by the stochometric analysis, carbonate and bicarbonate. With this method it is assumed that there is no free $CO_2$ in the liquid and the absorption rate is determined after the concentration of NaOH and $NaCO_3$ are calculated (Table 2). Fast reaction kinetics and high affinity of $CO_2$ towards caustic soda kept the side reactions to a minimum that can be neglected for this paper.

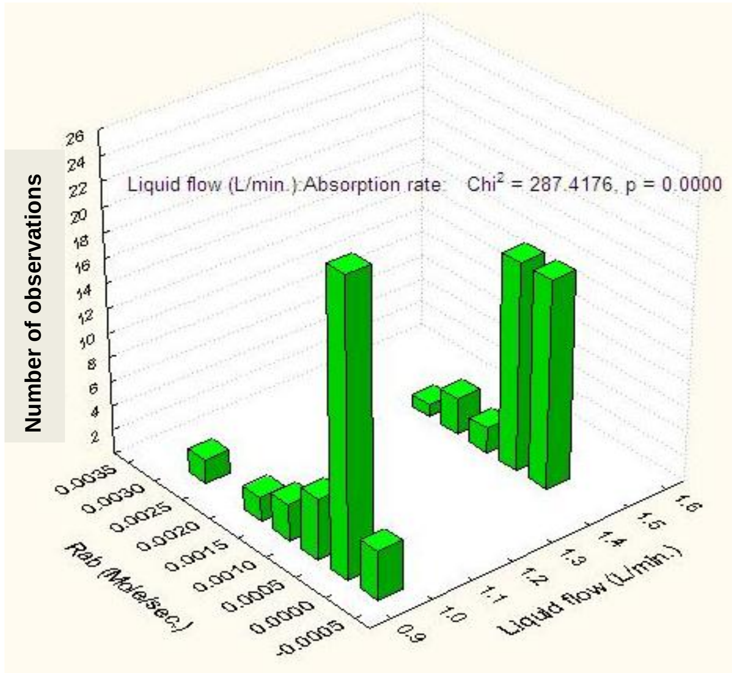


**Figure 6.** Bivariate histogram showing rate of absorption against liquid flow rate.

The amount of $CO_2$ absorbed across the column as measured from samples taken simultaneously from the sump tank feeding the column top and at the bottom outlet, is given by:

$$CO_{2\,absorbed} = liquid\ flow\ rate \times [(C_N)o - (C_N)i]$$

or

$$CO_{2\,absorbed} = liquid\ flow\ rate \times \frac{1}{2}[(C_N)i - (C_N)o]$$

Similarly, over a time period, θ seconds after a first sample is taken from the sampling point:

$$CO_{2\,absorbed} = liquid\ flow\ rate \times [(C_N)o - (C_N)i]$$

Where, the subscript 0 here is t=θ, and 'i' is time at t = 0

Caustic soda solution absorbs carbon dioxide by chemical reaction in two steps:

I. $NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$
II. $CO_2 + Na_2CO_3 + H_2O \longrightarrow NaHCO_3$

As shown by the above equations, 1 kg of pure sodium hydroxide absorbs 1.1 kg of carbon dioxide. One-half is absorbed in each step; however step I takes place much faster than step II. Obviously, each reaction has special characteristics that may affect the operation of an absorber; for example, reaction II is reversible in that sodium hydroxide will react with sodium bicarbonate to form sodium carbonate (Pflug et al., 1957).

## Liquid flow rate

The solvent flow rate selected as a study independent variable, set by the investigator, is shown to accompany statistically significant response (Figure 6). This result agrees with other study that showed the rate of $CO_2$ absorption to be directly proportional to the liquid flow rate on average. It is also evident that carbon dioxide absorption is a surface phenomenon; consequently, the contact area between the absorbing fluid and the gas has an important effect on the rate of absorption. A similar expression otherwise from literatures is also evidencing as stated like that at a fixed gas velocity, the gas-pressure drop increases with increased liquid rate, principally because of the reduced free cross section available for flow of gas resulting from the presence of the liquid (Pflug et al., 1957; Treybal, 1981; Lin and Chen, 2007; Thomsen, 2002). However, there are also deviant results ascribed to error.

## Liquid temperature

Absorption of a pollutant is enhanced by: lower temperatures, greater liquid-gas contact surfaces, higher liquid-gas ratios and higher concentration of the pollutant

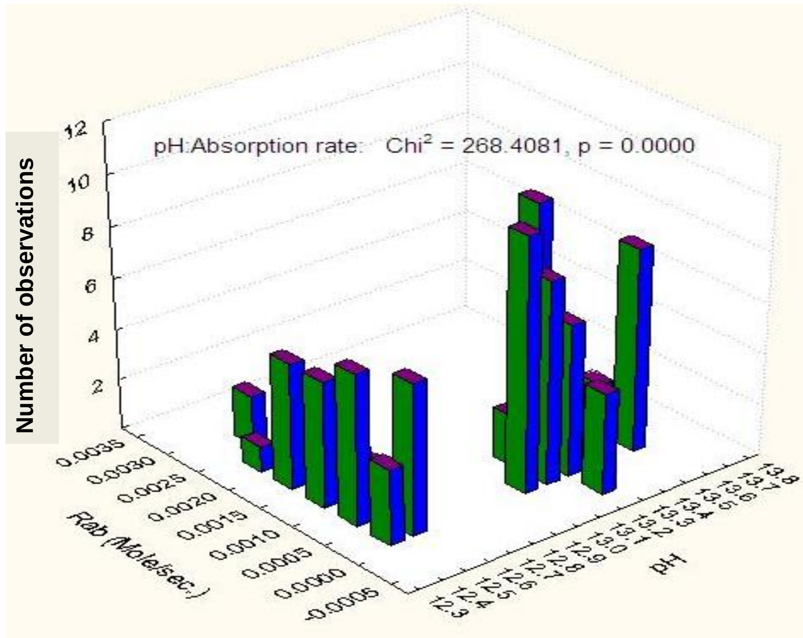


**Figure 7.** Bivariate histogram showing rate of absorption against pH of solvent.

in the gas phase (Davison and Thambimuthu, 2005). This study has also showed rate of absorption to be indirectly related to solvent temperature but it was not statistically significant. This could be explained thus: as the temperature of liquid increase the velocity at which the moving liquid goes through the absorption column also increases. That implies the retention time would be low and hence absorption of the gas decreases as well affecting the overall rate of absorption. However, some investigators showed that increasing the temperature of the absorbing fluid generally increase the rate of absorption; however, temperature has a greater effect on reaction II than on reaction I (Treybal, 1981).

### Sodium hydroxide concentration (pH)

The pH of the scrubbing liquor is often an important process parameter. Low-pH liquor is required for ammonia scrubbing, neutral or high pH is needed for acid gas scrubbing (Wang et al., 2004). Dry solid, commercial grade caustic soda that contains 98.8% NaOH, available as regular flake, is used in this study. On analysis, concentration of the caustic soda showed a statistically significant relation with rate of absorption (Figures 7 and 8).

### Pollutant gas ($CO_2$) velocity

Increasing the gas velocity beyond needed does not support the absorption process rather it tends to cool the solvent temperature (Pflug et al., 1957). Elevating the gas and hence air velocity could create resistance to liquid fall- the phenomena called loading, if increased still could lead to flooding thus it has to be variable of interest in the design of the mass transfer equipment (Thomsen, 2002). This study has also demonstrated a statistically significant difference between gas velocity and rate of absorption (Figure 9).

Cosidering factor interactions, the four factors of absorbtion were analysed by using Design-Expert version 7.0.0 (Stat-Ease,Inc.2005) for developing a model equation that can be used in order to develop the laboratory scale finding to an application scale. The ANOVA for the data enterd proved the model to be significant (Table 3). In relation to this factor interactions were points of interst and the factors coded AD and BD showed significant effect where A refers to concentration, B refers to liquid flow rate, C refers to gas flow rate and D refers to temperature.

Further more, the *F- value* for the model is 4.27 which, in another check, implied the model to be significant. The A, D, AD, BD were the model terms that showed significant effect. A related parameter called "*Adeq Precision*" measures the signal to noise ratio. A ratio greater than 4 is desirable. Here ratio of 7.324 indicates an adequate signal. Therefore, this model can be used to navigate the design space.

### Sodium bicarbonate production

Despite the fact that $CO_2$ has climate change impact, it is

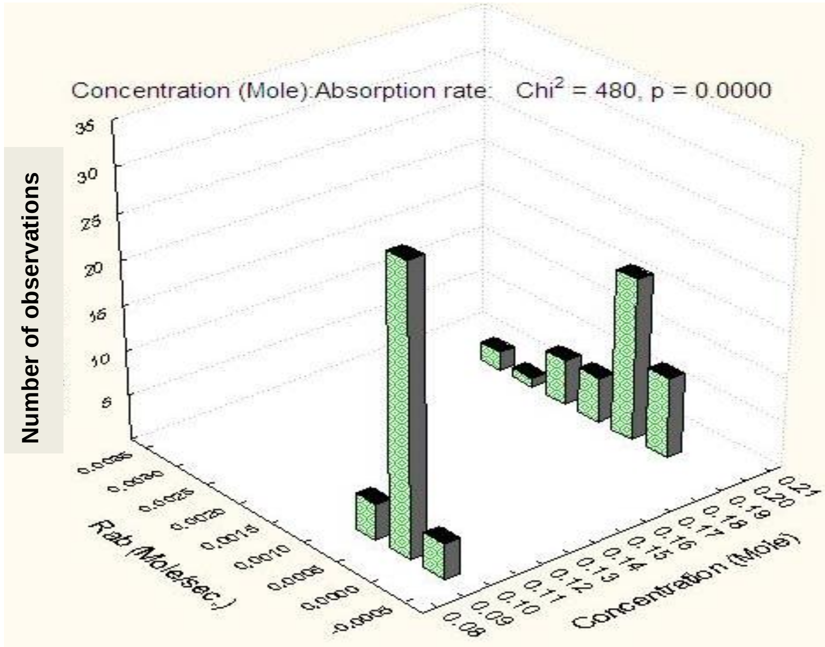


**Figure 8.** Bivariate histogram showing rate of absorption against NaOH concentration.

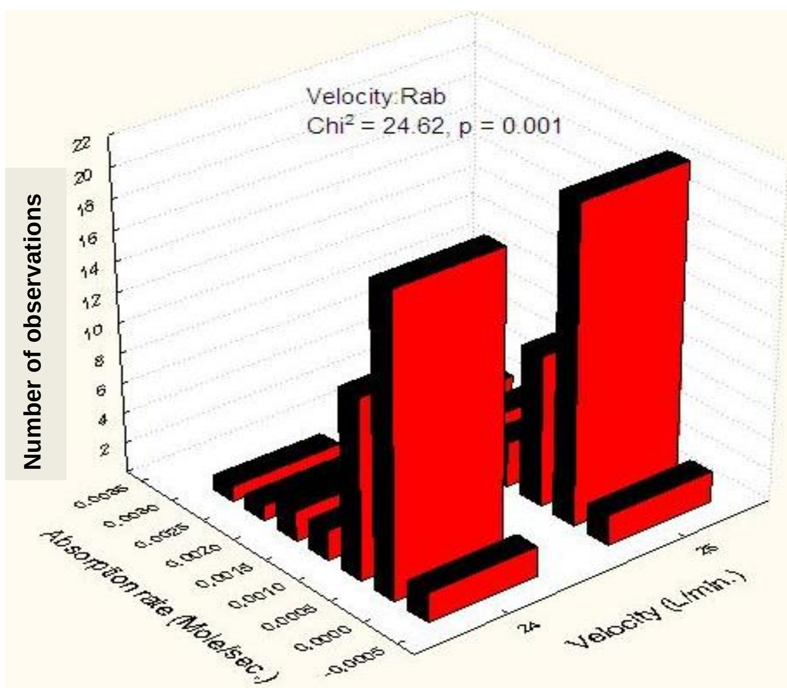


**Figure 9.** Bivariate histogram showing rate of absorption against gas velocity.

being produced even from use of fossil fuels for various application (Chapel et al., 1999); including beverages, hospital use and others (Table 4).

In the $CO_2$ capture and storage attempts, a number of investigations showed stripping of the separated $CO_2$ to store it at pressure somewhere underground. In this study, however, production of sodium bicarbonate is considered than stripping process, which is aimed at

**Table 3.** Analysis of variance for the selected factorial rate of absorption model.

| Source | Sum of squares | Degree of freedom | Mean square | F-value | P-value Prob>F | Remark |
|---|---|---|---|---|---|---|
| Model | 1.761E-005 | 15 | 1.174E-006 | 4.27 | <0.0001 | |
| A-concentration | 1.107E-005 | 1 | 1.107E-005 | 40.26 | <0.0001 | |
| B-liquid flow rate | 7.898E-007 | 1 | 7.898E-007 | 2.87 | 0.0950 | |
| C-gas flow rate | 1.006E-007 | 1 | 1.006E-007 | 0.37 | 0.5474 | Significant |
| D-temperature | 1.478E-006 | 1 | 1.478E-006 | 5.38 | 0.0236 | |
| AD | 1.854E-006 | 1 | 1.854E-006 | 6.74 | 0.0117 | |
| BD | 1.158E-006 | 1 | 1.158E-006 | 4.21 | 0.0442 | |

**Table 4.** Some examples of the use of $CO_2$ in the industry.

| Food industry | Process industry |
|---|---|
| Breweries | Enhanced Oil recovery (EOR) |
| Carbonated beverages | Precipitated Calcium Carbonate for paper |
| Quick freezing of meats and vegetables | Inert gas for welding |
| Flash drying of food | Casting |
| Grain fumigation | Methanol production |
| Photosynthesis enhancement | Neutralizing of alkalis in process water |
| Slaughterhouses | Inert gas blanketing |

large on managing the problem and at the same time to produce $CO_2$ based sodium bicarbonate (Ellison, 1984). Sodium bicarbonate is the chemical compound with the formula $NaHCO_3$. Sodium bicarbonate has much application and it is an industrial chemical. Among the various uses of this chemical cooking/leavening agent, neutralization of acids and bases, as a deodorizer, medical uses, cosmetic uses, as a cleaning agent and as a fabric softener in laundry can be mentioned.

The yield from absorption column is at left stand still for minimum of 2 h to separate the solid by precipitation. The moisture of the precipitate is evaporated using evaporating dish, oven and outdoor light at temperature below 70°C for a long time in order to avoid heat breaking of the $NaHCO_3$. Thus, this study, based on gravimetric analysis (Marı´a et al., 2004) produced up to 28% pure sodium bicarbonate where the rest constitute sodium carbonate and un-reacted caustic soda.

## Conclusion and recommendation

Cement production in the country increased from < 0.1 million tons per year in 1999/00 to 8 million currently and even in progress towards reaching 27 million by 2015 owing to massive construction. MCF emits more than 463,844 ton of $CO_2$/year on average currently and yet it accounts for only <3% of overall country emission from this particular sector. An end-of-pipe technology to reduce carbon emissions may be $CO_2$ removal. Probably, use of chemical solvent scrubbing could be the favoured method. In absorbing the pollutant gas, temperature did not have statistically significant effect unlike the concentration and pH. This study results partly help in planning an effective $CO_2$ removal method applying solvent scrubbing. Again, production of bicarbonate can be considered as an advantage of recovering this gas from such waste streams. However, further significant research should be done to complete the work by providing a concrete and useful framework plan with quantitative technical recommendations. Governments need to support such action in order for it to be approached at pilot scale. Further research including consideration of other option to manage such problem has to be done.

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