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Assessment and Distribution of Metal Pollutants in Fadama Soils along River Ngadda and Alau Dam in Maiduguri, Borno State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Elemental metal pollutants concentration levels and their distribution in soils obtained from farmlands along the bank of river Ngadda and Alau dam in Maiduguri, Borno State, North-East of Nigeria is presented. The study was aimed at determining the levels of contamination of soils with metal pollutants used for fadama farming along the bank of river Ngadda and Alau dam with the objectives of assessing the contamination levels of the soils with metal pollutants from the various farmlands at the various sampled sites of study, and the distribution of the various metal pollutant in the various sampled sites. Soil samples were collected from thirteen different sites on the farmlands along the bank of the river and the dam. The samples were analyzed using Instrumental Neutron Activation Analysis (INAA) and the result obtained indicate that the concentration level of some of the elements determined were above maximum allowable concentration (MAC) value while some below the (MAC) values for example the concentration range for Cr was (16 ± 2 – 47 ±3) ppm, Sb was (0.18 ± 0.04 – 14.2 ± 7) ppm, Zn was (21.8 ± 4 – 145 ± 7) ppm and the maximum

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values for these ranges exceed the (MAC) value recommended for Agricultural soils while the concentration ranges for As was (0.46 ± 0.12 – 1.0 ± 0.2)ppm, Co was (1.6 ± 0.3 – 5.3 ± 0.4) ppm, Vn was (14.6 ± 2.32 – 29 ± 2) ppm with the maximum value for these ranges being below the MAC values given by some countries. The elements obtained from samples collected from different study areas along the bank of river Ngadda and Alau dam were analyzed for similarity distribution of the study area using mathematical tool of cluster analysis technique employing hierarchical procedure and using WARD's method. The result obtained produce a dendrogram consisting of two clusters comprising of six and seven sites with percentage similarity of 96.5% and 90.8% respectively with one site as an outlier. It is recommended that since some of the trace metals namely Cr, Sb, and Zn assessed in the fadama soils indicates concentrations above the MAC values, they can posed negative health implications to consumers of food which were cultivated on soils from the study area, therefore there is the need to condition the soils before using it for farming so as to make it suitable for food crop farming.

Keywords: Heavy metal contamination; soil pollution; ward's-multivariate clustering; environmental degradation.

1. INTRODUCTION

The environment basically consists of land, water, and air and these three are always in constant interaction with each other. Pollution of the environment is the introduction by man or nature, either directly or indirectly of substances or energy form into the environment resulting in hazard to human health, harm to living resources and ecosystem, damage to amenities or interferences with other legitimate users of the environment EEC [1], Al-Juboury, [2] Lomniczi et al. [3], Khares and Singh [4]. Metal pollution of the environment refers to when the quantities of these elements in it are higher than the maximum allowable concentrations (MAC) value and this is potentially harmful to biological organisms at such a location. Heavy metals are the major pollutants of the environment because these metals are indestructible and most of them have toxic effects on living organism when permissible concentration levels are exceeded Mmolawa et al. [5] Heavy metal pollution of soil, sediment, and water is a global problem, frequently aggravated by rapid industrial development and urban expansion Li P et al. [6]. Recently, heavy metal concentration has received much attention with regard to accumulation in soils, uptake by plants and contamination of water Samali and Shinggu [7], Fakayode and Onianwa [8], Fakayode [9]. Reports presented by some researchers showed that industrial and domestic effluents constitute the largest sources of heavy metals and contribute to the steady increasing metallic contaminant in both aquatic and terrestrial environment in most part of the world Jibrin and Adewuyi [10]. It has been observed that many pollutants are continuously discharged into the soils through land waste disposal, input from the atmosphere, metals from vehicular exhaust emissions and irrigation by municipal waste water Uwah et al. [11]. Soil, water and sediments are the major sinks for heavy metals Adeniyi and Yusuf [12], Olowu et al. [13] therefore landfills and waste dumpsites which characterize urban settlements are among the major contributors in polluting land, and stream around them. Rain washout accompanied by leaching, channeled these metals substances either from one point to another or into the rivers and stream. The specific problem associated with heavy metals in the environment is their accumulation through food chain and persisted in nature Dimari et al. [14].

The proximity of the people to river Ngadda around which the study was carried out encourages dry season (fadama) farming. Also the long period of dry season usually experienced by that part of Nigeria makes irrigation farming very lucrative as it serves as a means of economic empowerment. The soil type of the study area is predominantly sandy loam mixed with alluvial as the area was believed to be part of Lake Chad many years ago after which the water gradually receded and the bank of the river used as fadama farmlands. It is therefore paramount to assess the composition and the distribution of metal toxicants in the soil used for fadama farming for the cultivation of vegetables sustained via irrigation with water from River Ngadda and Alau Dam. Therefore, this work determined the concentration levels of trace elements in soils obtained from farm lands along the bank of River Ngadda and Alau Dam.

2. MATERIALS AND METHODS

The study area lies between latitude 11° 48' N – 11° 52' and longitude 13° 06'E – 13° 14' at an altitude of 345m above sea level. This area has a long period of dry season and the vegetation is of grassland type with sudan type of climate. The annual rainfall is light with average value of 864mm (34inches) and the temperature ranges from (22 – 31)°C. River Ngadda originates from Rivers Yedzaram and Gadambole which met at a confluent at Sambisa both in Nigeria and flows as River Ngadda into Alau Dam and stretches down across Maiduguri Metropolis then empties into Lake Chad Bukar et al. [15]. The River Ngadda flows from Alau Dam down through the Maiduguri Municipal Council to Shukwari in Jere local government area of Borno State.

2.1 Sample Collection and Preparation

Soil samples were collected on thirteen different farmlands along the bank of river Ngadda and Alau dam at various farmland sites and labeled (So, S1, S3, S4, S5, S6, S8, S9, S10, S11, S12, S13, and S14). The sampling points were selected by targeting farmlands along the bank of river Ngadda and Alau Dam where vegetables farmlands were situated and the sampling was carried out during the dry season on cultivated farmlands. Surface scrapping of the soil were carried out at each point of collection so as to prevent accommodation of extraneous materials along with the samples collected and thereafter soils samples at depth (0 – 10 cm) were collected at five different points of each farmland sites, four near the edges of the plots and one at the centre of the plot to constitute a homogenate sampling point. Hand driven auger was used to collect the soil samples throughout the sampling process. The soil were put in a clean black polyethylene bags and well-labeled for identification before they were transported to the laboratory. The soil samples were then air dried at ambient temperature and thereafter oven dried at (70 – 80)℃. Agate mortar and pestle previously properly cleaned with dilute HCl were used to ground the soil samples and then sieved through a 200 µm stainless steel mesh wire. The soils were packed in sample bottles and taken to the laboratory at Centre for Energy Research and Training, Ahmadu Bello University Zaria for further preparation for neutron activation analysis.

2.2 Sample Preparation for Neutron Activation Analysis

Sample for irradiation was prepared using the protocol for geological samples thereafter the prepared samples were put in irradiation vials which was then capped and sealed. Standard

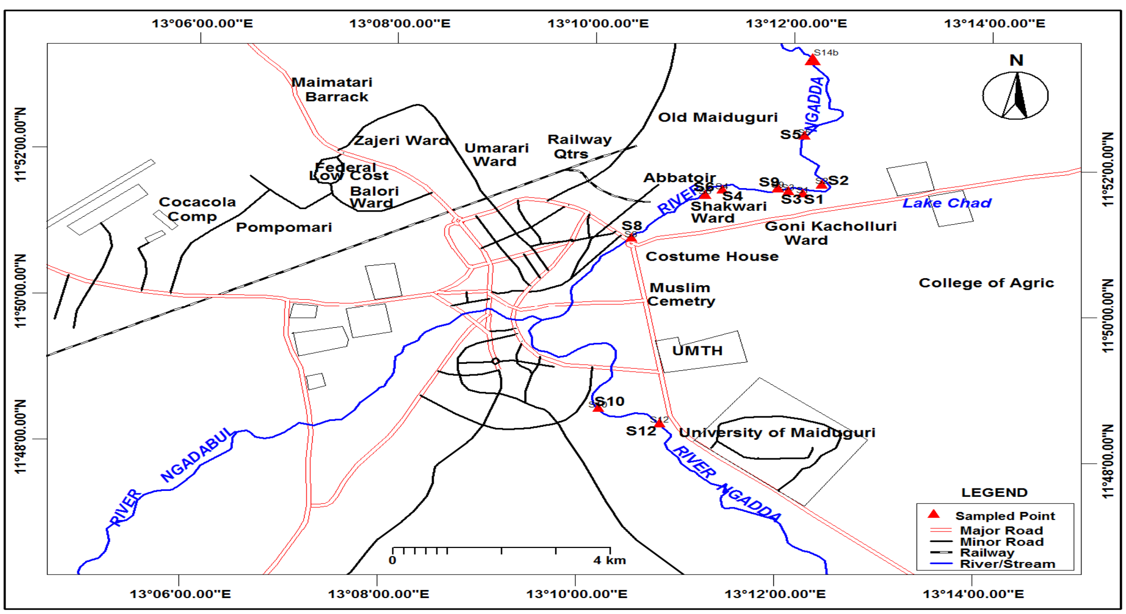

Fig. 1. Maiduguri township map showing the sampling points
Source: Adapted and modified from Maiduguri township map

Reference Material (SRM) NIST 1633b (coal fly ash) was used since it is a direct representative of the soil sample. The SRM of known quantity undergo the same preparation process as the samples and both of them irradiated simultaneously.

2.3 Sample Analysis

The standard and the unknown sample were placed in the same position and irradiated with the same flux and under the same necessary conditions. The induced intensities of both the standard and the unknown sample were measured. During, and after irradiation the irradiation, counting and decay parameters are related by equation (1).

$$\frac{A_{sam}}{A_{std}} = \frac{\phi\omega\epsilon I N_A\left(1-e^{-\lambda t_{irr}}\right)sam\left(e^{-\lambda t_d}\right)sam\left(1-e^{-\lambda t_c}\right)sam}{\phi\omega\epsilon I N_A\left(1-e^{-\lambda t_{irr}}\right)std\left(e^{-\lambda t_d}\right)std\left(1-e^{-\lambda t_c}\right)std} \quad (1)$$

where A_{sam} is activity of the unknown sample, A_{std} is activity of the standard. Since measurement were carried out under the same condition some of the parameters cancelled out allowing the ratio of the activity of the element in the unknown sample and the standard to become

$$\frac{A_{sam}}{A_{std}} = \frac{m_{sam}}{m_{std}}\frac{\left(e^{-\lambda t_d}\right)}{\left(e^{-\lambda t_d}\right)}\frac{sam}{std} \quad (2)$$

m_{sam} = mass of element in the sample, m_{std} = mass of element in standard, λ = decay constant for the isotope. For isotopes with short half lives, the irradiation, decay, and counting times are usually fixed the same for both unknown samples and standards so that the time dependent factors in the equation cancel out..Therefore equation (2) simplifies into

$$C_{sam} = C_{std}\,\frac{W_{std}}{w_{sam}}\frac{A_{sam}}{A_{std}} \quad (3)$$

where C_{sam} = concentration of the element in the unkown sample, C_{std} = concentration of the element in the standard, W_{sam} = weight of the sample, W_{std} = weight of standard.

3. RESULTS

The concentration values of the different elements determined in this work were subjected to statistical analysis using cluster technique and employing Ward's method so as to obtain the similarity in the distribution of the various elements in the various study sites along the bank of river Ngadda and Alau dam. The cluster analysis (CA) applied in this study is one of the multivariate techniques such as principal components analysis (PCA) which are popular methods of solving multi-parameter problem Kim et al. [16], Tang [17]; Wu et al. [18]. The Ward's method of clustering that is associated with similarity distribution of the elements arrange the elements in the sample as a matrix consisting of i number of sample and j number of elements in the sample to constitute an array of concentration values. The criteria for linking clusters are based on minimization of the error sum of squares (SS) Oladipo [19] given as

$$SS = \sum_{clusters\,(A)} \sum \left[L_{ij} - L_{ij(s)}\right]^2 \text{samples(i) elements(j)} \quad (4)$$

where Lij(A) = mean value of j for cluster say (A) to which i is assigned to. The WARD's method calculates the increase in SS by joining samples to clusters and merging of clusters. The working of the statistics is base on replacing concentration of the elements by standard score. The cluster analysis was carried to establish the similarity in the distribution of the elements in the samples obtained from the various sites in terms of the source(s) of the content of the samples from the different sites which were the elements. The resulting hierarchical treatment is displayed in form of a dendrogram is as shown in Fig. 2.

Fig. 2 is the dendrogram indicating the cluster analysis of soil samples data. It clearly shows that the sampled area was divided into two major groups according to similarity with an outlier at site three (S3) and for clarity the groups have been designated as cluster I and II. The cluster groups represent the similarity in sources and or content of the variables in the samples that were grouped together.

The first cluster which constitutes sampled sites S1, S4, S5, S10, S11, and S14 suggests that the content of the samples from these sites i.e the elements in the samples have common or similar origin of source of accumulation and it can be observed from the dendrogram that the similarity of the distribution of the contents of the sites was about 96.5%, the second cluster consists of sampled sites S2, S6, S8, S9, S12, S13, and S0 with similarity of the distribution of the contents of the sites at about 90.86% in their sources and/or content. The outlier which does not belong to either groups could be associated with low value of the elemental concentration of Al in S3 this is because outliers show disproportionate effect in multivariate analysis and do not tend to cluster at some levels with their sub-groups Yarzab et al. [20] cited by Ewa [21] thus outliers normally indicate deviation from the content of a subgroup due to source differences. The disproportionality that lead to the occurrence of an outlier from among the sites studied arise from the fact that usually significant difference in the content of a feeder source make the different sites to be assigned to the respective clusters accordingly since high concentration content of a source in specific environment will deliver proportionate to the target site where accumulation occur.

To obtain the structural composition of the soil data dendrogram, normalized concentration values of the elements was plotted as shown in Fig. 3.

It can be observed from Fig. 3 that the elements responsible for the deviation of the two clusters (cluster I and cluster II) were Lu, Mn and U for cluster I and Eu from cluster II. This deviation of the different elements which were due to the content of the samples from the two clusters were either due to increase or decrease in the content of the samples from the mean values in the specified sites i.e. high concentrations for values above the mean value or low concentrations for values below the mean value. The increase or decrease in values of these elements in the soil could be due to different factors such as natural weathering processes , windstorm, erosion or human activities such as application of fertilizer, or landfill process which either enhance the accumulation of a particular element(s) or reduce deposition of such element at a particular site; for example wind storms can transport some of elements in particulate form from one area to the other since the study area is closed to desert environment, effect of erosion from rain water during rainy season can wash and transport some elements from one site to another, storms from the municipal can be channeled to farmlands near the river bank which may eventually end up in the stream, farming activities such as continuous application of chemical fertilizers that contain some of these elements can introduce some elements which were part of the constituents of the fertilizer, landfill processes with solid waste from the Metropolis for land reclamation which may contained heavy metals.

The concentrations of some of the elements determined in this research work was compared with the Maximum Allowable Concentrations (MAC) values given by some countries in different years and at different places as indicated in Figs. 4a – 4f.

4. DISCUSSION

The result obtained which indicate the similarity in the distribution of trace elements on different farmlands along the bank of river Nggada and Alau dam using cluster analysis of the soil samples data divided the study area into two clusters namely cluster I and cluster II with an outlier at site three to form a dendrogram as shown in Fig. 2. The dendrogram indicates the similarity in the distribution of the content of the samples obtained from the different sites. along the bank of River Ngadda and Alau Dam in terms of both the constituents of the soil samples and/or the sources of the constituents of samples that made up the groups. Cluster I showed a distribution similarity of 96.5% of the content of the samples collected in the study sites while cluster II showed a distribution similarity of 90.8% of the content of the samples in the study sites. It can also be observed from Fig. 2 that, the cluster I consist of sampled sites S1, S4, S5, S10, S11 and S14 which constitute sampled sites from both Alau Dam studied area sites consisting of (S10, S11 and S14) and sampled sites from Gongulon studied area sites consisting (S1, S4, S5). Cluster II consist of sampled sites S2, S6, S8, S9, S12 and S13 with those sites around Alau Dam area studied area constituting sampled sites S9, S12 and S13 while those sampled sites around Gongulon studied area consisting of sites S2, S6 and S8. This clustering of the similar farmland sample type in term of elemental contents and samples from different area into the same cluster or vice versa may be attributed to the fact that the metal pollutants sources were heterogeneous implying that content of sampled sites arise due combination of different processes or were brought about due to combination of so many factors and may be from more than one source which could include sources from places such as town storm from different parts of the municipal, erosion from surface soil far away or along the roadsides that crosses the different bridges at various points of the town, windstorm originating from distant desert environment that transport particulates carrying metal pollutants which may have attached to ittdifferent element and moved from one place to another and application of chemical fertilizer which may introduce some elements into the soil.

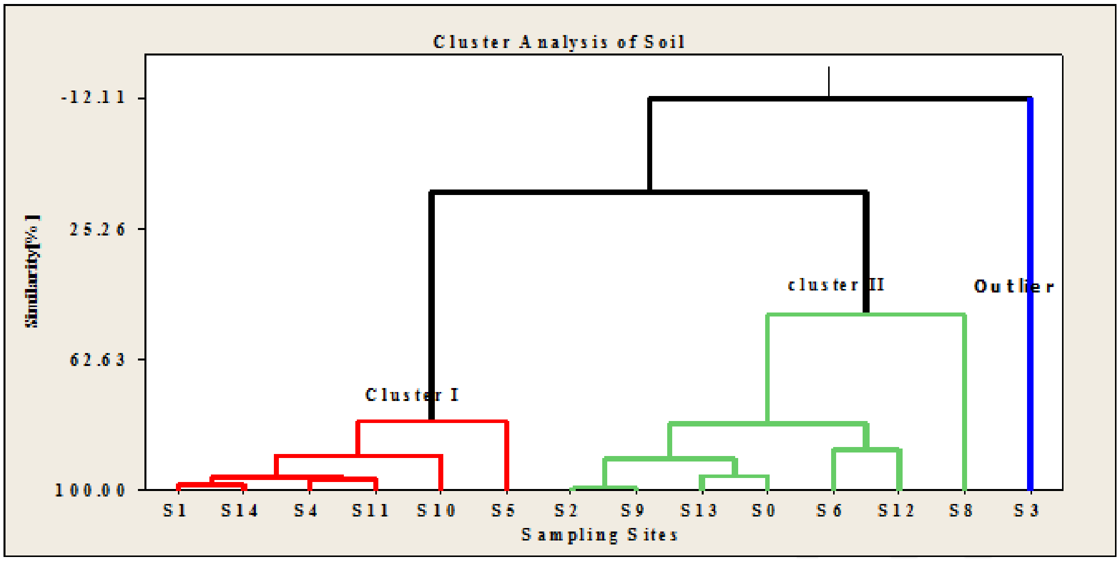

Fig. 2. Dendrogram for cluster analysis of soil samples data

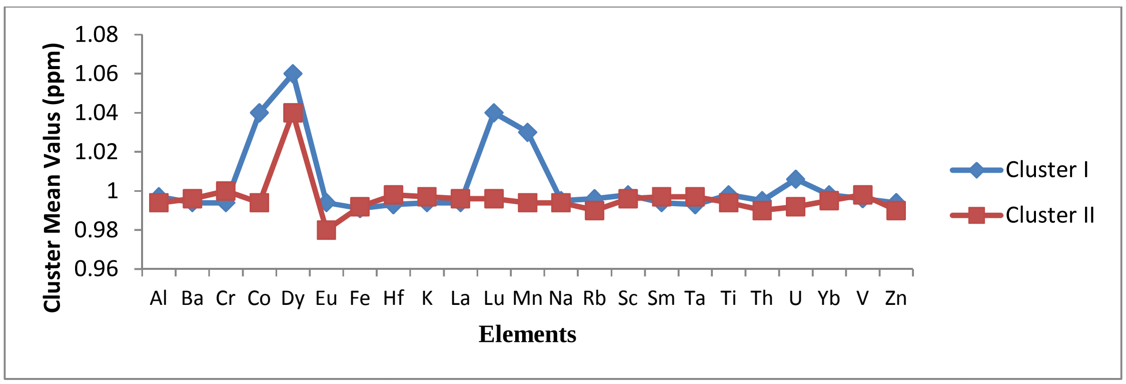

Fig. 3. Normalized concentration profiles obtained from the cluster analysis of soil samples

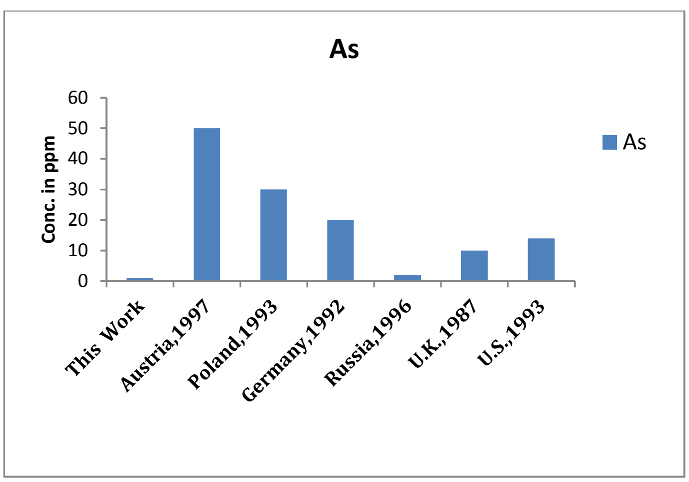

Fig. 4a. MAC values given by some countries and max value obtained in this work

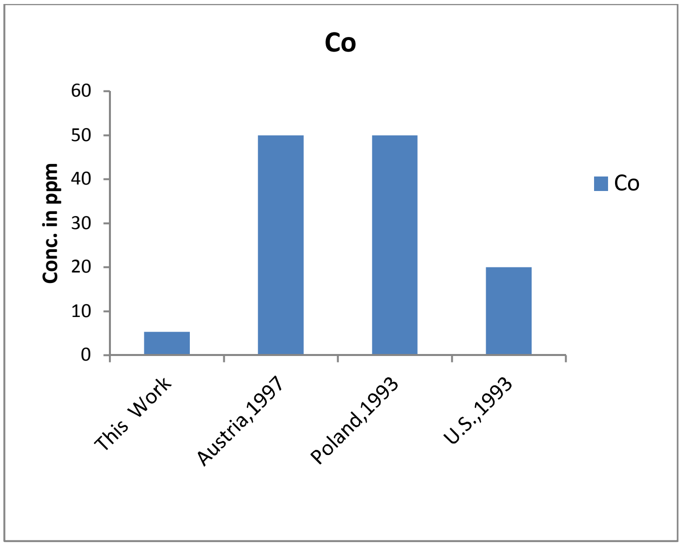

Fig. 4b. MAC values given by some countries and the max. value otained in this work

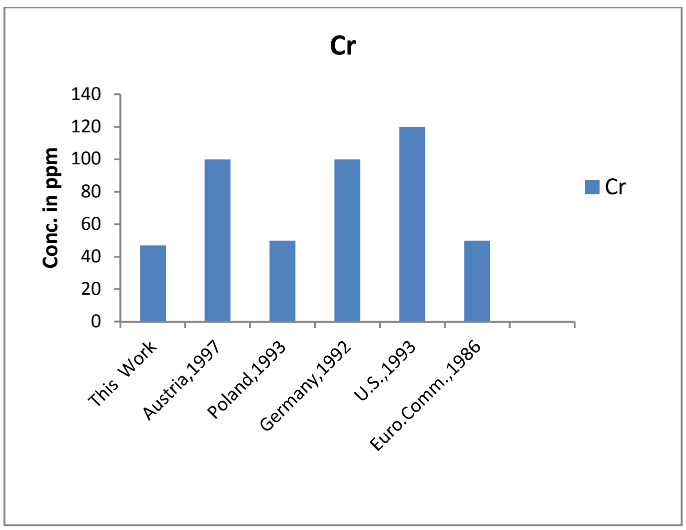

Fig 4c. MAC values given by some countries and the vax. value obtained in this work

It can be clearly seen from Figs. 4(a –e) that the maximum concentrations of Arsenic (1.0)ppm, Cobalt (5.3),ppm Vanadium (29.0)ppm determined in the various sites in this work were below the MAC values given by the other countries while the maximum concentration Chromium (47.0)ppm, Antimony (14.2)ppm, and Zinc (72.0ppm) determined from soil samples collected from different study sites in this work were above the MAC values given by some respective countries as indicated in Figs. 4a to 4f. The elemental investigation of As, Co, and Cr in soil samples obtained from Alau dam and Gongulon farmlands and analyzed using Atomic Absorption Spectrophotometer by Uwah et al. in [22] showed that the maximum values of metal pollutants in the two respective sites were As 3.42, 4.34) ppm; Co (9.65, 11.45) ppm, and Cr (65.50, 76.18) ppm and these values were more than the values obtained in this work. It is therefore required that for safe agricultural practice in the study area considered in this work, the farmlands that have their soil contents containing metal pollutants concentration above the MAC value should have their soils conditioned before using them for cultivation of food crop so that edible food crops that may absorbed some of these pollutants with nutrients and transferred to man through food chain can be avoided and its health implications which man can be susceptible to t due to consumption of such crops cultivated from such polluted soils.

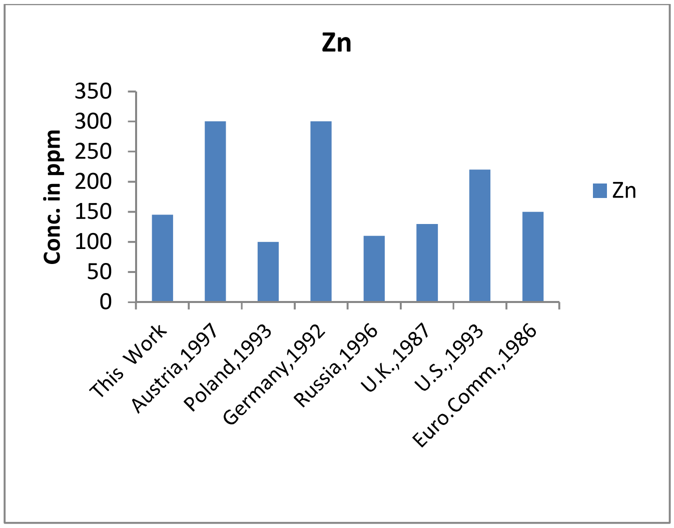

Fig. 4d. MAC values given by some countries and max. value obtained in this work

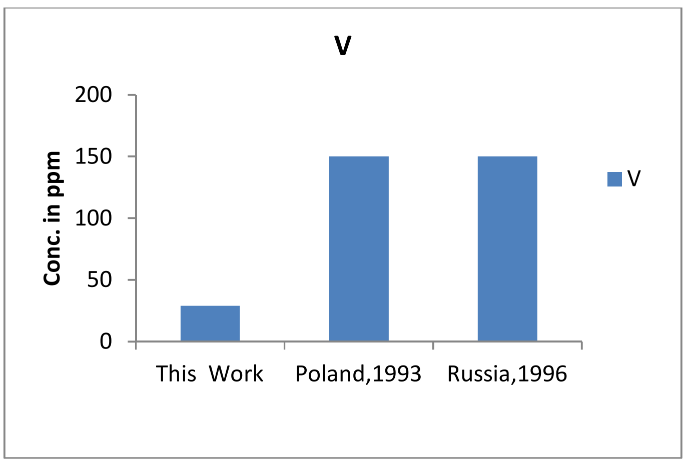

Fig 4e. MAC values given by some countries and the max. value obtained in this work

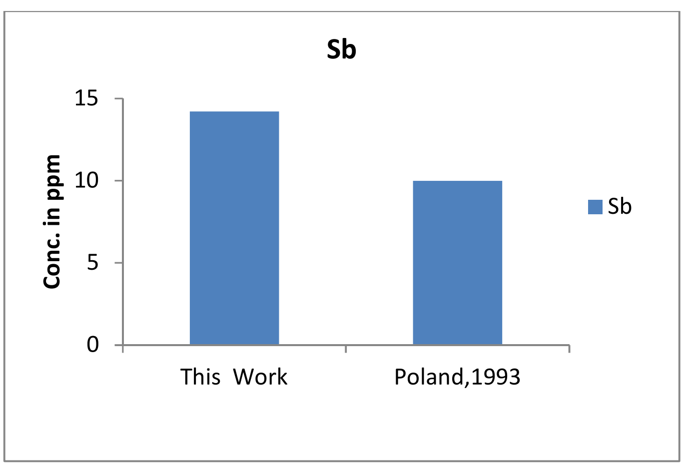

Fig. 4f. MAV value given by Poland and max. value obtained in this work

5. CONCLUSION

From the results obtained from this and presented, it can be clearly observed that the concentrations of some of the toxic trace elements analyzed and determined in this research were found to be above the MAC values given by some countries for soils to be used for agricultural purposes while others were within the range of the MAC values and some were below the limit given by some countries. However, even for soil samples that were having concentration below the MAC values since the soils were used for agricultural purposes it will be of great importance that such studies and investigations on such soils be carried out periodically so as to ascertain and monitor the levels of this metal toxicants and where the level of metal pollutants were above the MAC values there is the need to conditioned the soils so as to remedy the concentration of the pollutants before using the soils for agricultural purposes since the plants may absorb these metal toxicants and it will accumulate above threshold level thereby causing negative effect on the use of the soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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