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Research Article

BEHAVIOUR OF CADMIUM AND LEAD CONCENTRATION FROM IRRIGATION WATER IN SOILS AT FIVE URBAN IRRIGATION SITES IN GHANA

Richard Amfo-Otu

[1]Department of Environment and Natural Resources Management, Presbyterian University College, Ghana – Akropong, Ghana

**kbotu2001@yahoo.com*

ABSTRACT : The research looks at cadmium (Cd) and lead (Pb) levels in the water being used for urban irrigation for vegetable production and the levels in the soil from three sites in Accra and two sites in Kumasi. Effects of soil characteristics like pH, clay content, organic matter and exchangeable bases on batch adsorption experiment were studied at the laboratory using different concentrations of Cd and Pb. Extractable Cd and Pb from the soil were carried out to determine the bioavailable Cd and Pb in the soil using synthetic organic ligand. The Cd and Pb levels in the water samples used for irrigation by the farmers were all within recommended irrigation water levels (0.01ppm for Cd and 5ppm for Pb) except two sites where the Cd level was 0.2 and 0.02ppm. All the five soil samples showed high adsorption for Cd than Pb for the six hours equilibration time. The effects of soil properties on the adsorption were not so clear. The adsorption decreased in almost all the soils with time but percentage of adsorption increased with increasing irrigation water concentration of Pb and Cd. The available Pb increased with time for all the soil samples but Cd showed this with Marine drive soil for samples treated with 5ppm Pb of Cd. Desorption was noticed when distilled water was used for all the soils and also occurred for 1ppm in some of the soils at one point for Pb.

Key words: Lead, Cadmium, Irrigation, Bioavailable, Adsorption, Desorption

INTRODUCTION

In Ghana, urban agriculture is dated to the colonial time. Currently, most of the urban dwellers practise backyard farming for family use or irrigated farming for commercial purposes [11]. Most of the lands used by the farmers are marginal like road sides, valleys; wetlands, dumpsites etc. As access to good quality water for irrigation is difficult, farmers resort to the use of water from drains, polluted streams, hand-dug wells with only few using piped born water [1]. There is strong public outcry of possible contamination of such crops from these areas due to the use of water of low quality.

Cadmium and lead accumulate in soil and become accessible to crops. The crops produced in these areas are consumed by the public; therefore it is important to establish the heavy metal (Cd and Pb) concentrations that may be available to these crops for absorption through irrigation water. This will help in adopting measuring for reducing the health hazards associated with indirect ingestion of high amount of lead and cadmium and promote good health. The most common irrigation method being used almost in all the study areas is overhead irrigation by using watering can. Only a few farmers use sprinkler system while most use watering cans with capacity of 15 litres. Previous studies [8, 4] showed that farmers closer to water sources tend to over-irrigate beyond absolute crop water requirements.

This research therefore focused on the level of contamination of the water sources for irrigation at the urban areas with heavy metals like lead (Pb) and cadmium (Cd) which are of greater environmental concerns. The research also looks at the sorption of lead and cadmium by the soils from formulated irrigation water, their availability in the soil after irrigating with formulated irrigation water and the effects of some soil properties like pH, total exchangeable bases, organic matter content and the texture on sorption and mobility of metals in the soil.

MATERIALS AND METHODS

Soil and water samples were collected from three urban irrigation sites selected in Accra namely, Dzorwulu, Marine Drive and Korle-Bu and two sites in Kumasi namely, College of Engineering KNUST and Georgia Hotel.

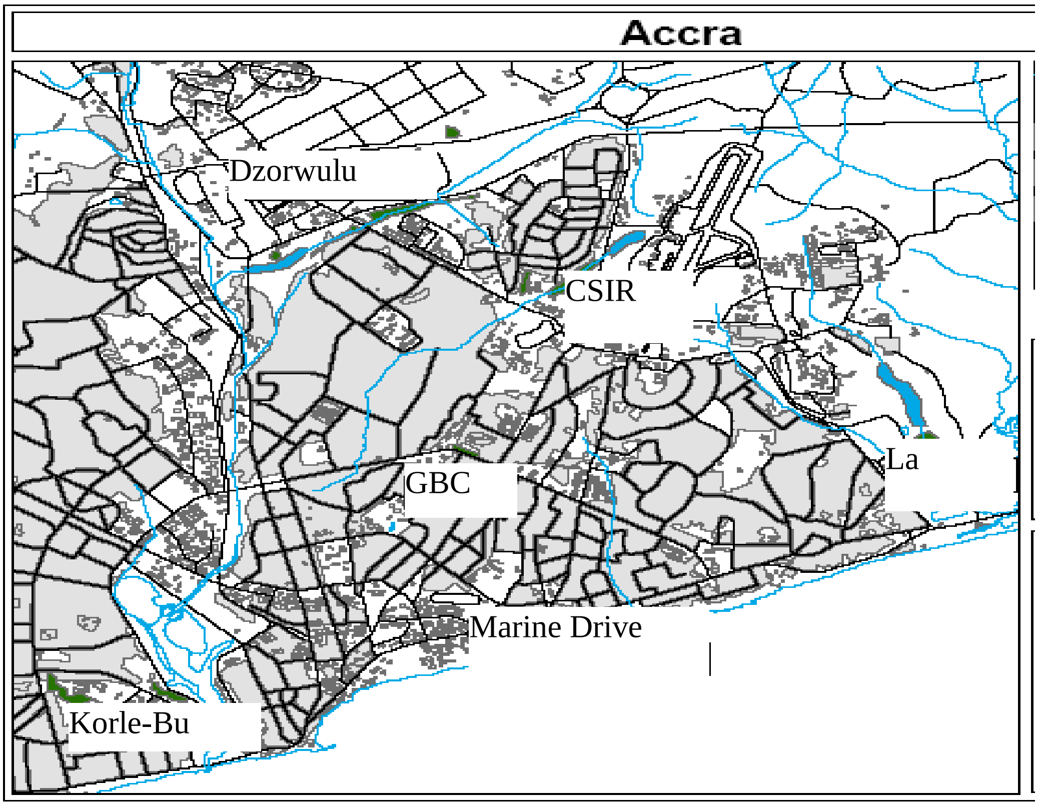

Fig. 1: Layout showing the major urban irrigation sites in Accra, adopted from IWMI

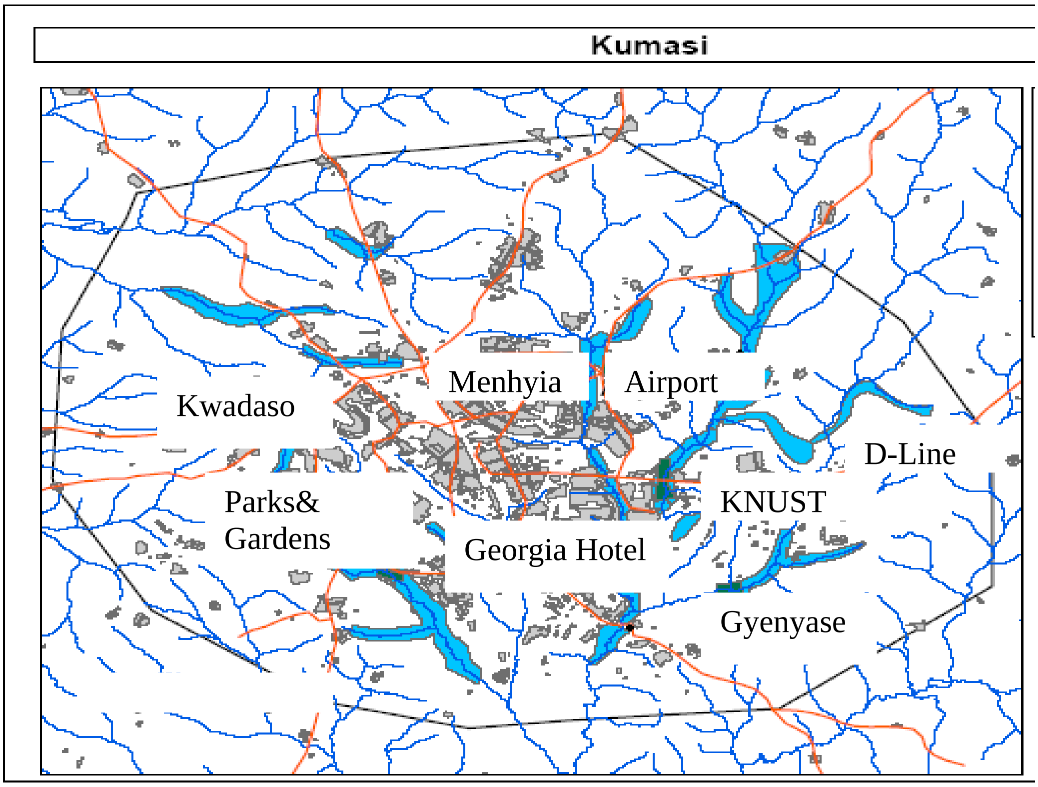

Fig. 2: Layout showing the Major urban irrigation sites in Kumasi, adopted from IWMI

Water samples used for irrigation by the farmers were collected from all the sites into separate sterilised bottles, kept in ice chests and sent to the laboratory to analyse for pH, lead and cadmium. Samples were filtered with 42mm pore filter paper, preserved with 2ml of concentrated HNO_3 and kept in polyethylene bottles for analysis using atomic adsorption spectrophotometer (AAS).

Soil samples were taken from 0-20cm deep from the surface of the ground and kept in polyethylene bags, sealed and labelled. Samples were taken from abandoned seedbed, newly planted bed, newly harvested bed, bed with almost matured vegetables and unplanted borders of the farmland.

A duplicate cleaned 50ml plastic containers were filled with water samples for the pH determination using Cyberscan 1000 pH meter, which was calibrated with 7.00 and 4.01 buffers. The electrodes were rinsed with distilled water after each sample measurement.

For soil pH measurements, a duplicate of 25g of each soil sample was weighed and 25ml of distilled water was added to obtain a saturated paste of 1:1 ratio. The mixture was stirred for some time and allowed to stand for about 30minutes after which a calibrated Cyberscan 1000 pH meter (calibrated with 7.00 and 4.01 buffers) was used to measure the pH of the soil samples.

A 50g air-dried soil mass was taken from each sample, weighed and (passed through a 2mm sieve) transferred into a milkshake cup after which 50ml of 4% sodium hexameta-phosphate (calgon) and 96% sodium carbonate was added along with 100ml of distilled water. This was mixed, stirred with a rod and allowed to settle for 30 minutes and the soil suspension was stirred for 15 minutes with the multimix machine. The suspension was transferred from the cup to 1000ml sedimentation cylinder by sieving and washing with distilled water to separate the sand from the clay and the silt. The hydrometer was placed in the suspension and distilled water was added to make up to the 1000ml mark. The hydrometer was then removed from the suspension and the cylinder was corked and shaken several times until all the soil was in suspension. The cylinder was placed on a flat surface while the time was noted. The suspension was allowed to stand for 5hrs after which readings of the hydrometer and temperature of the suspension were taken and calculation for the various soil separates were done.

A 0.2g-1.0g soil of each sample was placed into bottles and used for the analysis using Walkley and Black method. Potassium dichromate of volume 7.5ml and 1N concentration was added followed by 15ml of concentrated sulphuric acid. The mixture was shaken and allowed to stay for 30min after which 100ml distilled water was added to it. This was followed by the addition of 5ml orthophosphoric acid and titrated against ferrous sulphate using diphenylamine as the indicator and the titre values were recorded and percentage organic matter was calculated.

The total Cadmium and Lead concentration was determined by using the EPA method 3050 of digestion of soil for atomic absorption spectrophotometer (AAS) analysis of the metal content. A 0.5g portion of soil was weighed into a beaker followed by addition of 10.0 ml of 1: l HNO_3: H_2O. The solution was heated to 95 ^{0}C for 5 min, followed by sequential addition of 5.0 ml of concentrated HNO_3, 1.0ml of 30% H_2O_2, and 5.0 ml of concentrated HCl. The resulting solution was filtered and diluted with deionised water to a final volume of 50.0 ml. The filtrate was kept in spinning tubes for analysis using AAS.

The sorption experiment was done using batch system approach. A stock solution of 50ppm of lead and cadmium was prepared from the nitrate salts of the metals by dissolving 0.14g and 0.08g of cadmium and lead respectively in 1000ml of distilled water. By dilution method, 1ppm, 2pppm and 5ppm of lead and cadmium were prepared from the stock solution. Using a ratio of 1: 2 of soil: $Cd(NO_3)_2$ and $Pb(NO_3)_2$ salt solution, 10g of each soil sample was weighed into spinning bottles and 20ml of the salt solution was added. This was shaken from one hour to six hours (1-6h). The solution was filtered with number 42 filter paper. The filtrate was kept for lead and cadmium concentration analysis using AAS.

The extractable Cd and Pb were carried out using batch extraction method [10]. Soil samples from the fields and soils treated with formulated irrigation water of 5ppm Cadmium and Lead concentration were used for extraction of cadmium and lead. Extraction of soil Cd and Pb with 0.05M EDTA solution was carried using soil to EDTA ratio of 1: 4. This was done by shaking it on Multi Shaker for 5, 30, 60 and 120minutes at 176 oscillations per minute. The sample was filtered through 42mm filter paper and the filtrate was kept in centrifuge polyethylene containers for the determination of the extracted Cd and Pb using flame atomic absorption spectrophotometer (FAAS).

RESULTS

The pH of the soil and water samples collected from the field ranged between 6.65 - 7.72 and 5.24 – 7.60 respectively.

Table 1: Characteristics of soil samples from the fields

Soil Samples	TEB meq/100g)	% Org. matter	% Clay	Soil pH	Total Cd mg/kg	Total Pb mg/kg
Marine drive	20.65	1.96	12.05	7.10	1.8	28.0
Korle-Bu	34.45	1.89	22.03	7.70	2.6	17.5
Dzorwulu	38.25	1.84	18.01	7.31	3.2	61.0
Georgia hotel	14.29	1.89	11.29	7.12	2.4	15.5
College of Eng.	8.32	1.77	4.02	7.11	1.7	15.0

The concentration of Cd and Pb in the water samples being used for irrigation at the various sites ranged between 0.0025-0.2ppm and 0.0450-0.4425ppm respectively. The organic matter content of the soil samples ranged between 1.77-1.96% for sandy loam to loamy sand soils. The total exchangeable bases for the soil samples ranged between 8.32-38.25meq/100g. The total Cd and Pb in the soil samples ranged between 1.7-3.2mg/kg for the Cd and 15-61mg/kg for the Pb before laboratory treatment as shown in table 1 above.

Irrigation water of Cd and Pb concentrations of 0, 1, 2 and 5mg/l, used on the soils showed different adsorption and desorption for each metal with respect to time as shown in the Fig. 3 and 4 below.

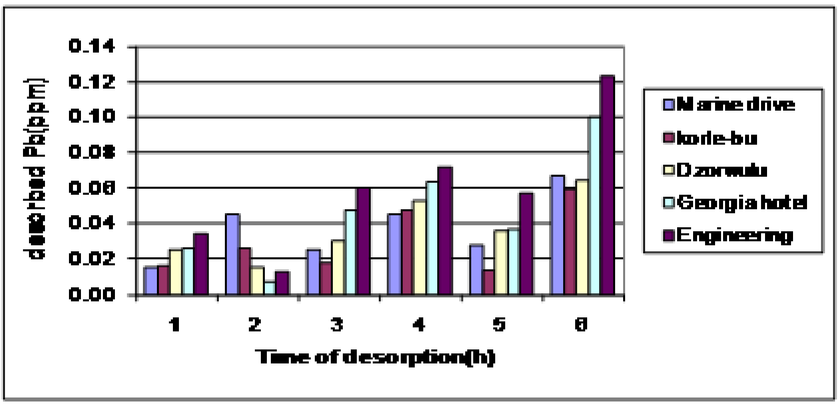

Fig. 3: Desorption of Pb from the soil samples treated with distilled water

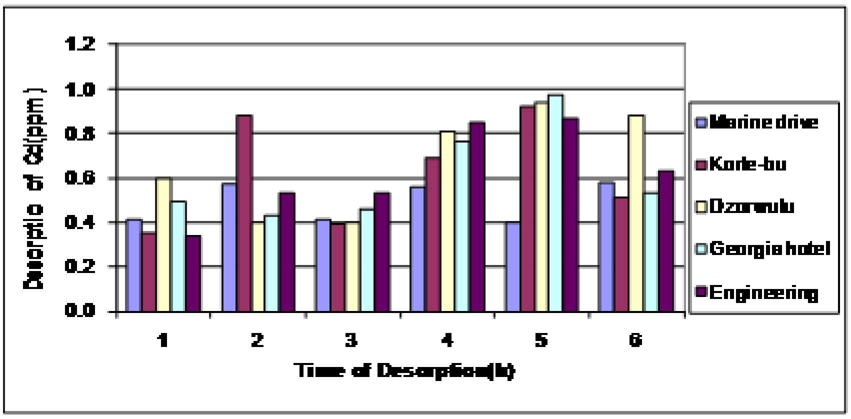

Fig. 4: Desorption of Cd from the soils irrigated with distilled water

The adsorption increased with increased initial concentration of Cd and Pb in the irrigation water with respect to time. The maximum adsorption was observed for the 5ppm concentrations as shown in the Fig. 5 below

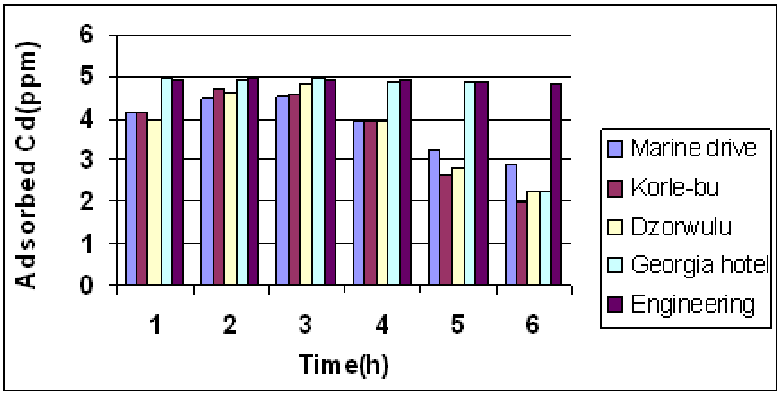

Fig. 5: Sorption of Cd by the various soils

The extractable Cd and Pb with Ethylene Diamine Tetra-acitec Acid (EDTA) from the soil samples from the irrigation sites were less than the extractable Cd and Pb from the 5ppm treated soils. This gives the available metals for plants absorption from soil solution as shown in Figures 6, 7 and 8 below.

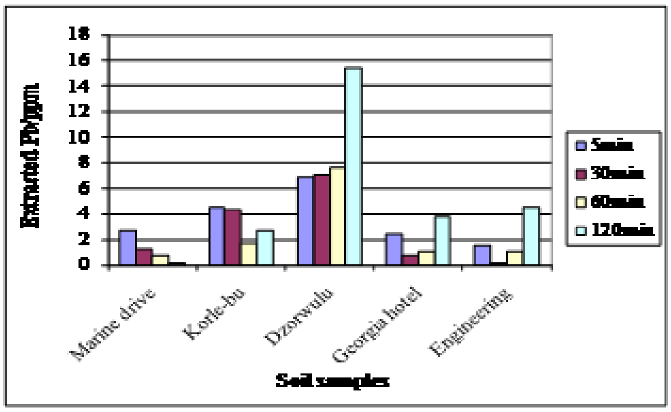

Fig. 6: Extractable Pb from the soil samples from the sites

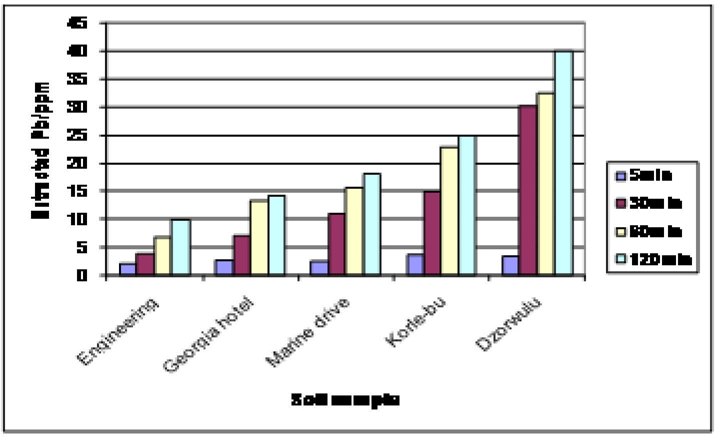

Fig. 7: Extractable Pb from the soils treated with 5ppm Pb

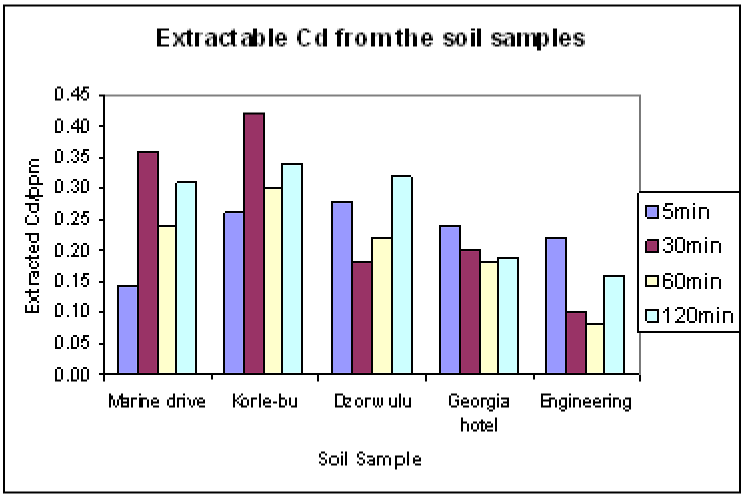

Fig. 8: Extractable Cd from the soil samples from the field

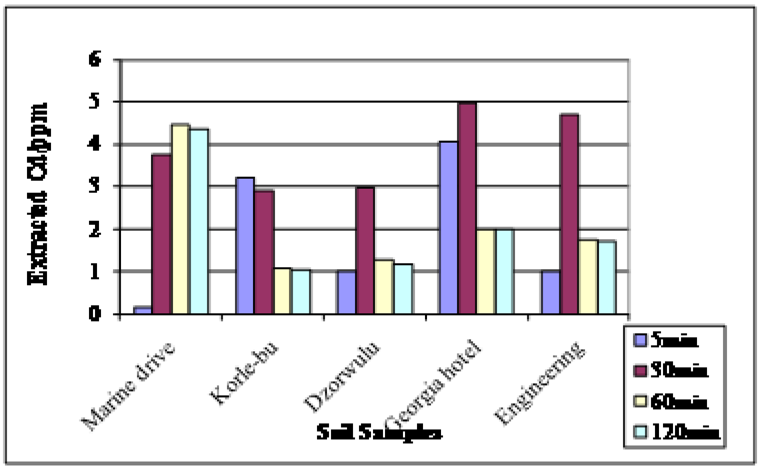

Fig. 9: Extracted Cd from soil samples treated with 5ppm Cd

DISCUSSION

The pH values for the soil samples showed that the soils were almost neutral. The pH values for the water samples generally were found to be acceptable for irrigation according to Food and Agriculture Organisation (FAO) guidelines of 6.5 – 8.4 except the shallow hand-dug well from “College of Engineering, KNUST” site, which had 5.24 indicating being acidic. According to FAO guidelines, Cd in irrigation water should not be more than 0.01ppm but water sample from fire hydrant at Marine drive which had Cd of 0.2ppm and 0.02 for the stream at College of Engineering, KNUST being higher than the recommended level. The Pb content was within FAO recommended value of 5ppm, and therefore safe for irrigation.

The soil particle size distributions were; clay 4.02-22.07%, sand 50.74-79.22% and silt 16.76-36.74%. Soil from College of Engineering, KNUST had the highest percentage of sand and the least clay content. The soil from Korle-Bu had the highest percentage clay and the least percentage sand. The organic matter content of the soil samples ranged between 1.77-1.96% for sandy loam to loamy sand soils were acceptable for agricultural purposes. This could be due to the application of fertilizers and manure for soil improvement.

The total exchangeable base for the Dzorwulu soil sample was high (38.25meq/100g), therefore competition for adsorption sites will be high between Pb, Cd and Ca^{2+}. The lower the exchangeable cations the lower the ability to hold cations therefore the Georgia Hotel and College of Engineering.

KNUST soil samples which had 7.67 and 8.32meq/100g respectively will have lower ability to hold cations. Harter (1979) [7] indicated that Ca in solution has a greater effect on Pb adsorption. Cavallaro and McBride (1978) [3] found that adsorption of Cu and Cd decreased due to competition with Ca for adsorption sites. Soils with cation exchange capacity between 4-10meq/100g are classified to be Kaolinitic, 20-40meq/100g illitic [12], therefore most of the soils may contain Koalinitic and illitic as the soil minerals.

The total Cd and Pb in the soil samples ranged between 1.7-3.2mg/kg and 15-61mg/kg respectively. Dzorwulu soil had the highest Pb and Cd whilst soil at College of Engineering, KNUST had the least Cd content. The soil under cultivation (Planted Soil) showed higher values of Pb at all the sites and this may be due to the application of soil fertility improvement chemicals. Generally, it has been considered safe to use garden produce grown in soils with total lead levels less than 300mg/kg [13]. Therefore the Dzorwulu soils having high Pb levels (51.56 and 61.00ppm) can be considered safe for vegetable production.

Cadmium adsorption was almost the same for all the soil samples for the first five hours and decreased in the sixth hour except the soil from College of Engineering, KNUST. The behaviour of the soil from College of Engineering, KNUST may be due to strong bond of attraction formed between the Cd and the soil organic materials and other soil compounds as well as low exchangeable cations in the soil.

Adsorption of Cd and Pb by the soils from the formulated irrigation water of concentrations of 0, 1, 2 and 5mg/l showed to be different for each metal with respect to time. The sorption behaviour observed was similar for the 2mg/l and 5mg/l concentrations. When distilled water was used to irrigate the soils, desorption of Cd and Pb into the water was observed. This implied the release of Cd and Pb to be available for plants uptake. Comparing the desorption of Cd and Pb from the soils, Cd was relatively more desorbed than Pb which confirms the fact that Pb forms more stable complexes and therefore is less available than Cd which forms surface complexes that are more mobile and hence more available.

The extractable Cd and Pb from the soil samples from the irrigation sites were less than the extractable Cd and Pb from the 5ppm treated soils. Silveira and Sommers (1977)[14] and Latterell *et al*. (1978)[9] find out that, salt extractable metals represent the potentially mobile portion of the total concentration of metals in soils. The soil with high Cd and Pb contents had the highest extractable Cd and Pb, implying that the available Cd and Pb in the soil is a function of the initial concentration of the metals in the soil. Available Cd in the soil samples from Marine Drive and Korle-Bu was highest within 30 minutes and reduced after 1 hour. This increasing and decreasing trend may be due to interference or competition by Ca^{2+} in the soil with Cadmium (Cd) complexation with EDTA as observed by [7].

CONCLUSION

In conclusion, the sorption behaviours of the soils were similar for Cd and Pb even though the soil properties differed. The Pb levels in the water samples from the various fields were in the FAO recommended range for irrigation water and are safe to be used. Cadmium levels in all the water samples from the fields were in the FAO recommended range except a hand-dug well from College of Engineering KNUST. The effect of the soil properties like clay, and total exchangeable bases was observed in the sorption of Pb and Cd for almost all the soil samples. The adsorption of the metals decreased as time increased implying that the rate of adsorption was decreasing whiles their availability in solution increased. The irrigation water with the highest (5ppm) Cd and Pb concentrations had the highest adsorption at the third hour with 99.6% and 96.8% for Cd and Pb respectively. The available Cd and Pb in solution after several hours of irrigation ranged from 0.04% to 60.2% for Cd and 3.2% to 60.2% for Pb from 1 to 6hours. The EDTA extractable Pb was 0.5 to 107 times higher for the treated soil samples than the original planted soil samples from the various fields. The Cd was 1 to 19 times higher than the original soil samples from planted fields.

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