



# Phytoextraction of Heavy Metals and Risk Associated with Vegetables Grown from Soil Irrigated with Refinery Wastewater

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## ABSTRACT

With the increase in anthropogenic activities, Heavy metal contamination of vegetables is inevitable as such it has become a course for concern due to food safety issues and potential health risk. This research is aimed at evaluating the phytoextraction efficiency of some vegetables and the potential health risk resulting from the consumption of vegetables that are grown in agricultural soil irrigated with Refinery wastewater. Wastewater was collected from the effluent point of Kaduna Refining and Petrochemical Company from October 2016 to February 2018 and analyzed for the presence of heavy metals ( $\text{Cd}^{+2}$ ,  $\text{Hg}^{+2}$ ,  $\text{Ag}^{+2}$  and  $\text{Pb}^{+2}$ ,  $\text{Cr}^{+3}$ ) before use for irrigation. Soil samples were collected from a farm located in Rigasa, Igabi Local Government of Kaduna State. The soil samples were digested and analyzed for heavy metal ( $\text{Cd}^{+2}$ ,  $\text{Hg}^{+2}$ ,  $\text{Ag}^{+2}$  and  $\text{Pb}^{+2}$ ,  $\text{Cr}^{+3}$ ) and physicochemical parameter before and after the wastewater is used for irrigation and treatment process. The seeds of the vegetables were planted in the botanical garden of the Biological Sciences Department of Kaduna State University and were constantly irrigated by a refinery wastewater throughout the period of the research. After germination the plants were harvested and separated into root/rhizome and shoot, digested and analyzed heavy metals using Atomic Absorption Spectrometer. Bioconcentration factor, Biotranslocation factor, Daily intake of metal (DIM) and Health risk index (HRI) were calculated. The result obtained showed high accumulation trend in the vegetable for Cd and Hg in *Solanum melongena*, *Cucumis sativa*, *Phaseolus vulgaris*, *Spinacia Oleracea*, *Allium cepa*, *Lactuca sativa*, *Daucus carota*, *Lycopersicon esculentum*, *Piper nigrum* above recommended standard. The high DIM and HRI value by all the vegetables that are above FAO/WHO recommended a limit for the heavy metals. These researches thereby discourage the use of refinery wastewater in irrigation farming of vegetables. It also recommends the need to stop all vegetable farming activities within the bank of Romi stream since refinery wastewater is constantly been released into the stream.

## 1. INTRODUCTION

Industrial and sewage wastewater are continuously disposed of in open drains whose water is used for irrigation [1,2]. These wastewaters contains huge amount of heavy metals e.g. iron (Fe), manganese (Mn), lead (Pb), copper (Cu), zinc (Zn), chromium (Cr), cobalt (Co), nickel (Ni), and cadmium (Cd) along with organic matter and nutrients. Crops irrigated by wastewaters store and secrete these heavy metals through various parts. These heavy metals cause serious health effects when consumed through foods [1,6]. Many clean-up technologies exist for the treatment of contaminated soils, but only a few are applicable to heavy metal contaminated soils. The use of plants and associated

microorganisms to contain, inactivate, remove or degrade harmful environmental contaminants and to revitalize contaminated sites is gaining more and more attention [3]. Plants and leafy vegetables have a high capacity to bioaccumulate these heavy metals when grown in soil irrigated by wastewater [4,5,6] Irrigation can impact potential yield by affecting morphological and physiological traits. Irrigation of crops by wastewater for a long period of time causes increased concentration of heavy metals in plants and vegetables through bioaccumulation [7,8]. Heavy metals accumulate in all parts of vegetables with only a few e.g. Zn, Ni, Cu that are essential for body function at low concentration, Zn at high concentrations causes abnormal functions of reproductive activities [8,9,10,11]. Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, as well as vitamins, minerals and also a source of micro and macro elements. Heavy metals are one of a range of important types of contaminants that can be found on the surface and in the tissue of fresh vegetables

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[12,13]. A number of elements, such Pb, Cd, Ni, Co, Cr, Cu and Selenium (Se) can be harmful to plants and humans even at quite low concentrations [14,15,16].

Soil pollution is caused by misuse of the soil, such as poor agricultural practices, disposal of industrial and urban wastes, etc. The soil is also polluted through the application of chemical fertilizers (like phosphate and Zn fertilizers), and herbicides [17,18,19]. Heavy metal accumulation in soils is of concern in agricultural production due to the adverse effects on food quality, crop growth, and environmental health. Plant species have varying capacities of removing and bioaccumulating heavy metals. Researches have shown that some plant species selectively bioaccumulate heavy metals [21,22,23]. Vegetables, especially leafy vegetables, bioaccumulate higher amounts of heavy metals [23]. Roots and leaves of herbaceous plants retain a higher concentration of heavy metal than stems and fruits [12]. There are limited studies on heavy metal content at different growth stages of vegetables, available studies focused on the status of metal content inedible parts of vegetables [15]. A review of the literature also showed the scarcity of data on the comparison of metal content on different leafy vegetable species in Hawul [15]. Potentially harmful metal contents in soils may come not only from the bedrock itself, but also from anthropogenic sources like solid or liquid waste deposits, agricultural inputs, and the fallout of industrial and urban emissions [24]. Excessive accumulation in agricultural soils may result not only in soil contamination but has also had consequences on food quality and safety. So, it is essential to monitor food quality, given that plant uptake is one of the main pathways through which heavy metals (HMs) enter the food chain [25]. Vegetables are very important because they contain essential components of protein, vitamins, iron, calcium and other nutrients [26,27]. However, their nutritional value and consumer acceptance as food must be taken into consideration, because vegetables can contain both essential and non-essential elements over a wide range of concentrations [28,29]. It is well established that the daily intake of heavy metal contaminated vegetables may pose a risk to human health. This is because heavy metals can bioaccumulate in living organisms and at elevated levels, they can be toxic. It has been reported that prolonged consumption of unsafe concentrations of heavy metals through foodstuffs may lead to the chronic accumulation of metals in the kidney and liver of humans, causing disruption of numerous biochemical processes, leading to cardiovascular, nervous, kidney, and bone diseases [31,32,33]. Absorption and accumulation of heavy metals in vegetables and fruits are influenced by many factors, such as their solubility, soil pH, plant species; soil type, the concentration of heavy metals in soil, composition, and intensity of atmospheric deposition, including precipitations, the phase of plant vegetation [21,34]. To all of these, can be added other sources generated by agricultural technologies such as irrigation with wastewater, the administration of organic and mineral fertilizers with a load of heavy metals, or application of pesticides, which contain in their structure as chemical elements [35]. Urban, industrial, household activities and traffic contribute significantly to increasing the load degree of heavy metals containing particles of inferior atmosphere [34]. The intake of heavy metals can lead to altering of humans and animals state of health. Thus, the carcinogenic effects generated by the continuous consumption of fruits and vegetables loaded with heavy metals such as Cd, Pb or even Cu and Zn are known. There are already published works related to the incidence of gastrointestinal cancer, cancer of the pancreas, urinary bladder or prostate [1,28]. In Romania, there are three areas (Coșta Mică-Sibiu County, Zlatna – Alba County and Baia Mare – Maramures County) that are strongly polluted with heavy metals,

caused by nonferrous ores extraction and metallurgical processing. The concentrations of heavy metals in the soils around these localities are higher than the maximum allowable limits. As a result, the plants, including vegetables, bioaccumulated high quantities of such chemical elements [14, 15]. Human exposures to heavy metals may occur through inhalation of air or ingestion of food and water. Heavy metals concentration in the environment varies markedly depending on their concentrations in soil and vicinity to sources of emission [36,37]. Heavy metal accumulation in soil and plants is of increasing concern because of the potential human health risk. Food chain contamination is one of the most important pathways for the entry of these toxic elements into the human body. Phytoremediation, also known as green technology, which consists of the use of plants including trees, grasses, herbs and aquatic plants to extract, sequester, and detoxify heavy metals, is a novel approach that has shown considerable promise as a cost-effective and an environmentally friendly technology and has received much attention in recent years [40,41,42]. In this technique, the natural capacity of plants is used to extract some elements and compounds from soil and translocate them between fruits, flowers, leaves, stems, and roots relating to the biological stage in which the elements and compounds are involved [43,44]. Phytoremediation of heavy metals is divided into three categories: phytoextraction, which shows the ability of plants to extract heavy metals from soil by accumulating the metal in aerial parts of plant [45,46,47]; phytostabilization, which is the use of plants to stabilize the soil surface by maintaining the metals in the roots [48,49]; and rhizofiltration, which is the use of plant roots to adsorb metals from water and aqueous waste streams [50,51]. This research thereby determine the phytoextraction efficiency and the risk associated with vegetables grown from soil irrigated with wastewater from refinery since this wastewater is used for vegetable farming at the bank of Romi stream and River Kaduna when it finally makes it way into this stream and river respectively.

## 2. MATERIAL AND METHODS

### 2.1. Water Sampling and Analysis

Wastewater was collected from effluent point discharge of Kaduna Refining and Petrochemical Company from October 2016 to February 2018 and transported to the laboratory for analysis of heavy metals ( $\text{Cd}^{+2}$ ,  $\text{Hg}^{+2}$ ,  $\text{Ag}^{+2}$  and  $\text{Pb}^{+2}$ ,  $\text{Cr}^{+3}$ ) before used for irrigation.

### 2.2. Soil Collection and Analysis

Soil samples were collected from a farm located in Rigasa, Igabi Local Government of Kaduna State. The samples were collected from this location because it is an area of minimal anthropogenic activities such as industrial, artisanal or water body for irrigation that can lead to heavy metal pollution. Surface soil (0-20 cm) samples were collected using a stainless steel grab sampler. The sampler was inspected for possible cross-contamination and cleaned with ambient water for individual sample collection. The soil was sampled from the central part of the grab sampler by avoiding contact with the inside materials of the sampler and transferred to a pre-cleaned plastic container [52]. The surface soil samples were collected in pre-cleaned zipper polythene bags, which were kept in airtight large plastic containers [53]. Soil samples were air-dried, grounded into fine powder and passed through 2-mm mesh sieve and stored at ambient temperature prior to analysis. The soil samples were digested and analyzed for heavy metal ( $\text{Cd}^{+2}$ ,  $\text{Hg}^{+2}$ ,  $\text{Ag}^{+2}$  and  $\text{Pb}^{+2}$ ,  $\text{Cr}^{+3}$ ) and physicochemical parameter using the method employed by Yoon *et al.* [55] before and after the wastewater is used for irrigation and treatment process.

## 2.2. Plants Collection and Identification

The seed of the vegetables (Table 2) used for this research was purchase in Bakin-Dogo market located in Kaduna south local government, Kaduna, Nigeria.

**Table 1:** Plants used for Phytoextraction.

SN	Scientific Name	Common Name
1	<i>Allium cepa</i>	Onion
2	<i>Cucumis sativa</i>	Cucumber
3	<i>Lactuca sativa</i>	Lettuce
4	<i>Daucas carota</i>	Carrot
5	<i>Lycopersican esculentum</i>	Tomato
6	<i>Spinacia Oleracea</i>	Spinach
7	<i>Solanum melongena</i>	Garden egg
8	<i>Pipper nigrum</i>	Pepper
9	<i>Phasaelus vulgaris</i>	Green beans

**Table 2:** Biotranslocation Factor of Vegetables Irrigated with Refinery Wastewater.

SN	Plant Sample	Cd	Hg	Ag	Pb	Cr
1	<i>Allium cepa</i>	1.3	1.1	0.1	0.4	0.3
2	<i>Cucumis sativa</i>	3.8	1.5	0.6	2.3	1.2
3	<i>Lactuca sativa</i>	2.5	0.1	0.1	0.1	1.3
4	<i>Daucas carota</i>	2.2	0.1	0.1	0.2	0.5
5	<i>Lycopersican esculentum</i>	1.3	0.2	0.6	0.8	0.4
6	<i>Spinacia Oleracea</i>	1.7	1.4	0.7	0.3	0.2
7	<i>Solanum melongena</i>	4.8	2.0	2.4	1.6	2.1
8	<i>Pipper nigrum</i>	1.6	1.5	1.3	1.8	2.0
9	<i>Phasaelus vulgaris</i>	3.3	1.8	2.1	2.5	1.9

## 2.4. Experimental Setup

The purchase seeds were planted in the botanical garden of the Biological Sciences Department of Kaduna State University and constantly irrigated by refinery wastewater throughout the period of the research. After germination, the plants were harvested and separated into root/rhizome and shoot, the root/rhizome and shoot. The separated plant parts were digested and heavy metals analysis was carried out using AAS. Bioconcentration factor and Bio translocation factor were thus calculated using the method of Ugya et al. [55], Daily intake of metal (DIM) and Health risk index (HRI) was calculated according to Khan et al. (2013) [58].

## 3. RESULT AND DISCUSSION

The bioaccumulation and translocation abilities of the plant species varies by species of plant and irrigation source. It was reported that the accumulation of metal by a plant depends on factors such as physicochemical parameters of soil (Table 6), the plant species involved, climatic condition and speciation of metal [57,58,59]. The heavy metals content of the soil generally changes with irrigation of the soil with refinery wastewater and this had led to the accumulation of the heavy metal in the edible part of the vegetables which is detrimental to human health [60,61]. The accumulation trend in the vegetable for Cd and Hg is *Solanum melongena* > *Cucumis sativa* > *Phasaelus vulgaris* > *Spinacia Oleracea* > *Allium cepa* > *Lactuca sativa* > *Daucas carota* > *Lycopersican esculentum* > *Pipper nigrum* although the studies

show a significant difference in the BTF and BCF of Cd and Hg when the vegetables were irrigated Refinery water. The result show higher BTF and BCF by *Solanum melongena*, followed by *Cucumis sativa* and *Phasaelus vulgaris* signifying that these three vegetables are best in phytoextraction of Cd Hg than the other vegetables [63,64,65]. The result also show higher BTF and BCF by *Phasaelus vulgaris* followed by *Cucumis sativa* and *Solanum melongena* signifying that these three vegetables are best in phytoextraction of Ag, Pb, and Cr than the other vegetables [65,66,67]. The studied data showed that the heavy metals content varies among different vegetables. The variations in heavy metals concentrations in vegetables may be ascribed to the differences in their morphology and physiology for heavy metals uptake, exclusion, accumulation and retention [68,69,70]. The result obtained also show high DIM and HRI value by all the vegetables that are above FAO/WHO recommended a limit for the heavy metals (Tables 4 and 5). The estimation of the risk to human health from the presence of heavy metals in food, particularly in vegetables, according to the European Food Safety Authority (EFSA) is between 0.3 mg/kg b.w. per day for heavy metals from the lowest Non-Observed Adverse Effect Level (NOAEL) identified in a (National Toxicology Program) NTP chronic oral toxicity study in rats [71]. The presence of these metals into the food chain may either in the long run or short span affect human health and creates toxicity which can result in nausea, vomiting, abdominal pains, anorexia, constipation, insomnia, anemia, irritability, mood disturbances, coordination loss and neurological effect [71,72,64]. In the consumption habits of local residents, the leafy vegetable consumption accounted for 70% of total consumption of vegetables, while other vegetables amount to 30% [73,70]. Chronic low-level intake of toxic metal elements has a negative effect on human health, and the detrimental impact becomes apparent after several years of exposure [74,75].

**Table 3:** Mean Bioconcentration Factor of Vegetables Irrigated with Refinery Wastewater.

SN	Plant Sample	Cd	Hg	Ag	Pb	Cr
1	<i>Allium cepa</i>	0.5	0.6	0.7	0.7	0.5
2	<i>Cucumis sativa</i>	2.0	1.9	1.9	1.8	2.1
3	<i>Lactuca sativa</i>	0.5	0.2	0.5	0.3	0.2
4	<i>Daucas carota</i>	0.7	0.3	0.3	0.3	0.9
5	<i>Lycopersican esculentum</i>	0.4	0.7	1.1	1.1	1.3
6	<i>Spinacia Oleracea</i>	1.6	1.8	1.7	0.6	0.5
7	<i>Solanum melongena</i>	2.0	2.7	1.8	1.6	1.5
8	<i>Pipper nigrum</i>	1.7	1.7	1.5	2.0	1.3
9	<i>Phasaelus vulgaris</i>	1.8	2.0	2.3	2.7	2.6

**Table 4:** Mean Health risk index (HRI) arising out of consumption of vegetables irrigated with Refinery Wastewater.

SN	Plant Sample	Cd	Hg	Ag	Pb	Cr
1	<i>Allium cepa</i>	1.4	0.5	0.6	1.5	0.6
2	<i>Cucumis sativa</i>	0.6	0.6	0.5	0.5	1.5
3	<i>Lactuca sativa</i>	0.5	0.7	0.8	0.7	0.5
4	<i>Daucas carota</i>	0.7	0.6	0.6	0.8	0.9
5	<i>Lycopersican esculentum</i>	1.5	0.9	0.6	0.5	1.4
6	<i>Spinacia Oleracea</i>	0.7	0.8	0.7	0.9	0.8
7	<i>Solanum melongena</i>	0.5	1.1	1.5	0.6	0.6
8	<i>Pipper nigrum</i>	0.6	0.5	0.8	0.6	1.5
9	<i>Phasaelus vulgaris</i>	0.6	0.5	0.9	0.5	0.6

**Table 5:** Daily Intake of Heavy Metals (DIM) (mg/kg bw/day) arising out of consumption of vegetables irrigated with Refinery Wastewater.

SN	Plant Sample	Cd	Hg	Ag	Pb	Cr
1	<i>Allium cepa</i>	1.5	0.8	0.6	0.7	1.4
2	<i>Cucumis sativa</i>	0.7	0.5	0.6	0.8	0.6
3	<i>Lactuca sativa</i>	0.5	0.5	0.7	0.7	0.8
4	<i>Daucas carota</i>	0.6	0.7	0.5	0.8	0.7
5	<i>Lycopersican esculentum</i>	0.5	0.5	0.7	0.6	1.4
6	<i>Spinacia Oleracea</i>	0.5	0.7	0.6	0.6	0.9
7	<i>Solanum melongena</i>	1.4	0.7	0.6	0.6	0.6
8	<i>Pipper nigrum</i>	0.7	0.4	0.6	0.8	0.8
9	<i>Phasaelus vulgaris</i>	0.6	0.6	0.7	0.8	0.9

**Table 6:** Physico-chemical Parameter of Soil Sample.

SN	Physico-chemical Parameter	Quality/Concentration Before Treatment	Quality/Concentration After Treatment
1	Soil Type	Sandy loamy	Sandy loamy
2	Total Nitrogen	350.98 mg/kg	150.13 mg/kg
3	Phosphorus	5.78	2.13
4	PH	5.31	6.91
5	Electrical Conductivity	6.75 Ms/cm	2.04 Ms/cm
6	Organic Carbon	1.08%	1%

#### 4. CONCLUSION

Since heavy metals tend to have an identical tendency to be phytoaccumulation, with Bioconcentration higher than biotranslocation [77], these research have also shown the ability of *Solanum melongena*, *Cucumis sativa*, *Phasaelus vulgaris*, *Spinacia Oleracea*, *Allium cepa*, *Lactuca sativa*, *Daucas carota*, *Lycopersican esculentum*, *Pipper nigrum* to phytoaccumulate significant amounts of these toxic metals. Many researchers such as Ugya et al. [55], Ugya et al. [77] have shown the presence of these heavy metals in Kaduna Refining and Petrochemical Company wastewater and Romi stream which causes cross-contamination of the food chain [77]. The ability of *Solanum melongena*, *Cucumis sativa*, *Phasaelus vulgaris*, *Spinacia Oleracea*, *Allium cepa*, *Lactuca sativa*, *Daucas carota*, *Lycopersican esculentum*, *Pipper nigrum* to bioremediate this water pollution is a promising technology which will easily serve as an alternative method of remediation compared to another convectional method. These researches validate the consumption of these vegetables as not totally safe since it could biomagnify in the food chain. These researches thereby discourage the use of refinery wastewater in irrigation farming of vegetables. It also recommends the need to stop all vegetable farming activities within the bank of Romi stream since refinery wastewater is constantly been released into the stream.

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