Journal of Research in Forestry, Wildlife & Environment Vol. 14(3) September, 2022
E-mail: *jrfwe2019@gmail.com; jfewr@yahoo.com*
http://www.ajol.info/index.php/jrfwe
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ISBN: 2141 – 1778
Akintola et al.,2022

HEAVY METALS UPTAKE OF *Ricinus communis* L. GROWN IN SOIL IRRIGATED WITH INDUSTRIALWASTE WATER

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ABSTRACT

This study assessed the potential of Ricinus communis for heavy metals uptake in soils irrigated with industrial waste water to reduce their toxicity impact on the environment. Pot experiments consisting 2 kg of top soil irrigated with different proportion of borehole water and industrial waste water (100% borehole water, 75% borehole water+25 % industrial waste water, 50% borehole water + 50% industrial waste water, 25% borehole water+75% industrial waste water and100% industrial waste water were replicated five times in a completely randomized design in this study. Physicochemical properties of the soils, borehole and industrial waste water; before the experiment as well the concentrations in soils and seedlings (roots and shoots) after the experiment were determined using standard instrumentation methods.Growth parameters, bioaccumulation and translocations factors at the end of twelve weeks after transplanting were used to assess the potential of the plants for heavy metal uptake. Significant seedling heights (11.02-18.22cm), leaf area (92.11-137.19 cm^2), stem diameter (0.90-2.11mm) and leaf production (12.84-26.10) were observed in Ricinus communis at P≤0.05 The concentrations of heavy metals in the growing media after the experiment were Fe (89.87 - 95.81 mg/kg), Zn (28.98 – 35.69mg/kg), Cu (22.51- 27.99mg/kg), Pb (16.21 – 20.95mg/kg), Co (6.01 – 8.99 mg/kg) and Cr (3.01 – 5.01mg/kg). The trend of Fe>Cu>Zn>Pb>Co> Cr uptake was observed in different parts of the seedlings. Respective bioaccumulation factor values of 0.20-0.88 classified the plants as accumulator while translocation factor values of 1.09 -1.82 for heavy metals, classified Ricinus communis as high efficiency phytoextractor plant. This study has shown the efficacy of Ricinus communis to uptake heavy metals and transfers it into its tissue parts.

K**ey words:** Accumulation, heavy metals, industrialization, phytoextractor, urban forestry

Correct Citation of this Publication
Akintola O. O., Abodunrin E. K., Falana A. R., Adeniran, T. and Ofordu C. S. (2022). Heavy metals uptake of *Ricinus communis* L. grown in soil irrigated with industrial waste water. *Journal of Research in Forestry, Wildlife & Environment*, 14(3): 1 – 9.

INTRODUCTION

The use of plants and/or associated microorganisms to remove contaminated or rendered harmful material harmless has been shown to be effective for different kinds of contaminants such as heavy metals, radio nuclides and broad range of organic pollutants (Merkl, 2005; Pinto *et al.*, 2018, Schwab and Banks, 1999; Wang *et al*, 2019). However, heavy metals pollution in natural ecosystem is one of the environmental issues that have become a global problem. With the industrial development, the concentrations of heavy metals have increased and their bioaccumulation cause toxicity in biological systems such as humans, animals, microorganisms and plants. Accumulation of heavy metals can reduce soil quality, reduce crop yield and the quality of agricultural products, and thus give negative impacts to the health of human, animals, and the ecosystem (Nagajyoti *et al.*, 2010). Some metals such as manganese, copper, zinc and nickel are important and beneficial to plants, and animals, but at high concentrations can become toxic and pose an environmental threat (Nodelkoska, 2000). Wang and Chen (2000) reported that heavy metals are of considerable environmental concern due to their toxicity, wide sources, non-biodegradable properties, and accumulative behaviours. Heavy metals contaminations are released by various anthropogenic activities into the environment, such as manufacturing processing of industries, domestic refuse and waste materials particularly sawdust sludge, sewage sludge, textile industry sludge and slaughter house sludge. Studies have shown that wastes from dumpsites release harmful leachates containing heavy metal into local water bodies; this in turn can lead to environmental hazards (Akintola, 2014, Rajkumar *et al.*, 2009). Industrial wastewater (IWW) contains a number of toxic chemicals including heavy metals (Wong, 2003). These toxic chemicals from the waste water can infiltrate into the soil through surface runoff and bioaccumulate in plants (Wong *et al.* 2002).Plants grown on a land contaminated with municipal, domestic or a land polluted with municipal, domestic industrial wastes can absorb heavy metals inform of mobile ions present in the soil through their roots or their foliar absorption (Singh and Jain,2003).Higher concentration of these metals may cause metabolic disorders and growth inhibition for most of the plant species, often leading to death (Pehlivan *et al.* 2009; Tiwari*et al.*, 2008; Wong *et al*., 2007). Their negative impact on soil micro flora, ground cover and plant growth has been well documented (Roy et al. 2005). Since these heavy metals/toxic elements cannot undergo chemical degradation but need to be transformed into non- toxic compounds or removed physically (Gaur and Adholeya, 2004). Recent concerns regarding the environmental contamination have initiated the development of appropriate technologies to assess the presence and mobility of metals in soil, water, and wastewater, thus a need for cleaning up for a safe and conducive environment (Bhargava *et al.*, 2012; Shtangeeva *et al.*, 2004).Therefore, there is a need for remediation of waste lands to refurbish soil fertility and productivity. *Ricinus communis* L. (Euphorbiaceae family) commonly known as castor bean has been potentially recognized for phytoremediation (Akintola*et al*, 2019; Haung*et al.* 201; Olivares *et al.*, 2013Rajkumar and Freitas 2008; Vara Prasad and De Oliveira Freitas,2003.). It has also been reported as a high salt tolerance salinity and drought tolerance (Bauddh and Singh 2012; Li *et al.* 2011). The plant according to Berman *et al*. (2011) and De Lima da Silva *et al.* (2006) has multiple uses in industrial, medical, and cosmetic products and is excellent crop rotation in modern agriculture. The plant attracts biofuel and biodiesel industries because of its high seed oil content. These attributes according to Boda *et al* (2017) make the plant an excellent to be used for restoration of waste disposal sites and bioenergy production. This study thus aimed at investigating the uptake of heavy metals by *Ricinus communis L* from soils irrigated with industrial waste water for remediation of waste lands to refurbish soil fertility and productivity through urban Forestry.

MATERIALS AND METHOD

Study Location

The experiment was carried out in the screen house of Forestry Technology Department, Federal College of Forestry Ibadan, Oyo State. The area lies between Latitude (7^{o}26'N - 7^{o}28'N) and Longitude (3^{o}51'E- 3^{o}54'E). The climate of the area is tropical. The annual rainfall ranges from 1400mm – 1500mm and average relative humidity of about 65%, the average temperature is 31.8^{0}C. The area is dominated by two seasons: the dry season and rainy season. The rainy season usually begins from November to March, while the rainy season starts from April to October (FRIN Meteorological Station, 2020).

Sample preparation and Experimental design

Ricinus communis seeds were collected from Igangan in Ibarapa L.G.A, Oyo state. Industrial waste water was collected from Oluyole Industrial Estate, Ring Road, Ibadan. The soil samples were collected from farmland around the same area. The topsoil collected was thoroughly sieved and filled into polythene pots. Seeds of *Ricinus communis* were sown into germination box. Pots were filled with 2 kg of top soil. After two weeks of sowing; the sprouted and healthy *Ricinus communis* were transplanted into the already filled pots. They were watered daily with the following treatments from borehole water (BW and industrial waste water (IWW):T1 (100% BW), T2 (75% BW+25 % IWW), T3 (50% BW+ 50% IWW), T4 (25% BW+75% WW) and T5 (100% IWW).Plastic containers were put at the base of the pots for collection of vertical seepage of wastewater for irrigation.

All treatments were replicated seven times in a completely randomized design. Inter-culture operation such as weeding and watering was done every day. The experiment lasted for 12 weeks after transplanting (WAT). The parameters such as stem diameter, seedling height, leaf area and Leaf production were assessed throughout the period of the experiment.

Sample Analysis

Top soil was analyzed for physiochemical and heavy metal. The pH of the soil samples was determined using electrode pH meter (PCE-228) in water-soil solution (1:1), while the organic carbon contents of the soils were determined using Walkley and Black (1934) method and then multiplied by 1.724 to calculate soil organic matter content. Total nitrogen and available phosphorus were determined by micro-kjeldhal digestion-distillation methods (Bramner, 1965) and electrophotometer method (Bray and Kurtz, 1945). Heavy metal analysis of the boreholeand industrial waste water was done using atomic absorption spectrophotometer (AAS) instrumentation technique. Roots and shoots of the studied tree species as well as soils from each of the treatments after the experiment were analysed for heavy metals concentrations using atomic absorption spectrophotometer (AAS) instrumentation technique.

Data Analysis

Data were analyzed using descriptive statistics, one-way analysis of variance (ANOVA) to determine the effectiveness of treatment and least significant difference (LSD) tests were performed to determine the statistical significance of the difference between means of treatments. Bioaccumulation factor (BAF) and Translocation factor (TF) were used to assess to potential of *Ricinus communis* for removal of contaminants from the soil using the formular given by Yadav *et al.*, (2009) as shown in Equation 1 and 2.

$BAF = HMCP/HMCS$ …… (1)

Where:
BAF - Bioaccumulation factor
HMCI - heavy metal concentration in plant
HMCS - heavy metal concentration in soil

$TF = HMCS/HMCR$…… (2)

Where:
BAF – Translocation factor
HMCI - heavy metal concentration in shoot
HMCS - heavy metal concentration in root

RESULTS

Soil Characteristics

The pH of the soil used in this study is slightly acidic with value of 6.72 (Table 4.1). Particle sizes of the topsoil were sand (85%), clay (10%) and silt (5%). Organic matter content of the soil is 3.87 % while the respective total nitrogen and available phosphorus in the soils are 0.87% and 23.71 mg/kg. The respective concentrations of Na, K, Mg and Ca in the soils were 1.70Cmol/kg, 0.04Cmol/kg, .0.47Cmol/kg and 0.93Cmol/kg while those of the determined heavy metals in the soils were Fe (112.86 mg/kg), Zn (48.29mg/kg), Cu (37.81mg/kg), Pb (22.21mg/kg), Co (10.75mg/kg) and Cr (8.11mg/kg).

Heavy metals Concentration in Borehole water and Industrial waste water

The concentration of heavy metals in borehole water were Fe (0.21mg/kg), Zn (1.02mg/kg), Cu (0.12mg/kg), Pb (2.11mg/kg), Co (0.02 mg/kg) and Cr (0.05 mg/kg) while that of the industrial waste water were Fe (4.02 mg/kg), Zn (3.55mg/kg), Cu (1.57mg/kg), Pb (6.11mg/kg), Co (0.89 mg/kg) and Cr (0.42 mg/kg) as presented in Table 2. Heavy metals concentrations in industrial waste water were higher than those from the borehole water indicating the effect of toxic materials used in the industry on the waste water.

Table 1: Physicochemical parameter and heavy metal content in the top soil

Parameter	Values in Topsoil	Recommended values) in soil (Kabata -Pendias, 2000 and Adriano, 2001; FAO,2003
pH	6.72	
Calcium (Ca)	1.70cmol/kg	
Potassium (K)	0.04cmol/kg	
Sodium (Na)	0.47cmol/kg	
Magnesium (Mg)	0.93cmol/kg	
Clay	5%	
Silt	10%	
Sand	85%	
Phosphorus	23.71mg/kg	
Organic matter Content (OMC)	4.91%	
Total Nitrogen (TN)	1.87%	
Iron (Fe)	112.86mg/kg	
Zinc (Zn)	48.29mg/kg	300
Copper (Cu)	37..81 mg/kg	100
Lead (Pb)	22.11 mg/kg	100
Cobalt (Co)	10.75 mg/kg	50
Chromium (Cr)	8.11 mg/kg	50

Table2. Heavy metals Concentration in Borehole water and Industrial waste water

HeavyMetals (mg/kg)	Borehole water (BW)	Industrial waste water (IWW)	Recommended value (WHO, 2006)
Fe	0.21	4.02	0.3
Zn	1.02	3.55	2
Cu	0.12	1.57	0.2
Pb	2.11	6.11	5
Co	0.02	0.89	0.05
Cr	0.05	0.42	0.1

Growth performance of *Ricinus communis* grown in industrial waste water

Table 3 showed the effect of industrial waste water on the growth performance of *Ricinus communis* seedlings. The seedlings grown in soil irrigated with100% IWW had highest growth performance at 12 weeks after transplanting for seedling heights (18.22 cm), leaf area (137.19cm^2). Stem diameter (2.11mm) and leaf production (26.10) while those grown in soil irrigated with 100% borehole water had lowest growth performance in seedling heights (11.02 cm), leaf area (92.11cm^2), Stem diameter (0.90mm) and leaf production (12.84).

Table 3: Mean values of growth performance of *Ricinus communis* at 12 WAT

Treatment	Seedling height cm	Leaf Area cm^2	Stem Diameter mm	Leaf production
100% BW	11.02^d	92.11^e	0.90^c	12.84^e
75% BW+25 % IWW	13.81^c	111.01^d	0.99^c	18.10^d
50% BW+ 50% IWW	15.55^b	119.23^c	1.56^b	21.03^c
25% BW+75% IWW	17.01^a	129.22^b	1.89^a	24.22^b
100% IWW	18.22^a	137.19^a	2.11^a	26.10^a

BW= Borehole water; IWW- Industrial waste water; WAT- weeks after Transplanting

Values with different letters within the same columns are significantly different from each other’s at P≤0.05

Heavy metals concentration in soils after the experiment

Table 4 presented the concentrations of determined heavy metals in soils from each of the treatment after the experiment. The concentrations of the heavy metals from all the treatments were Fe (89.87 - 95.81 mg/kg), Zn (28.98 – 35.69mg/kg), Cu (22.51- 27.99mg/kg), Pb (16.21 – 20.95mg/kg), Co (6.01 – 8.99 mg/kg) and Cr (3.01 – 5.01mg/kg) were lower when compared to their concentration in soils before the experiment Fe (112.86 mg/kg), Zn (48.29mg/kg), Cu (37.81mg/kg), Pb (22.21mg/kg), Co (10.75mg/kg) and Cr (8.11mg/kg) as presented in Table 3.

Table 4. Heavy metals concentration in soils after the experiment

Treatment	Heavy metals in mg/kg					
	Fe	Zn	Cu	Pb	Co	Cr
100% BW	89.87^{c}	28.98^{c}	22.51^{c}	16.21^{c}	6.01^{c}	3.01^{bc}
75% BW + 25 % IWW	90.11^{c}	29.10^{c}	22.98^{c}	16.47^{c}	6.23^{c}	3.57^{b}
50% BW+ 50% IWW	91.07^{c}	30.56^{c}	23.13^{c}	17.35^{c}	6.49^{c}	3.65^{b}
25% BW +75% IWW	93.01^{b}	32.91^{b}	25.67^{b}	18.11^{b}	7.67^{b}	4.71^{a}
100% IWW	95.81^{a}	35.69^{a}	27.99^{a}	20.95^{a}	8.99^{a}	5.01^{a}

BW= Borehole water; IWW- Industrial waste water

Values with different letters within the same columns are significantly different from each other's at $P \le 0.05$

Table 5. Heavy metal concentrations in *Riccinus communis* seedling' parts

Treatments	Plant's part	Heavy metal concentrations in mg/kg					
		Fe	Zn	Cu	Pb	Co	Cr
100% BW	shoot	15.10	9.11	10.00	2.20	1.12	1.47
	Root	13.00	6.90	7.13	1.61	1.00	1.30
75% BW + 25 % IWW	shoot	15.61	9.99	10.20	2.45	1.13	1.50
	Root	13.14	7.04	7.29	1.55	1.12	1.31
50% BW + 50 % IWW	shoot	16.00	10.01	10.22	2.56	1.17	1.71
	Root	13.01	7.20	7.38	1.45	1.14	1.41
25% BW + 75 % IWW	shoot	17.00	10.41	10.51	2.60	1.25	1.95
	Root	12.97	7.05	7.11	1.43	1.15	1.60
100% IWW	shoot	17.20	10.37	11.01	2.70	1.30	1.90
	Root	13.36	7.54	7.00	1.41	1.15	1.71

BW= Borehole water; IWW- Industrial waste water

Heavy Metal Concentration in the *Ricinus communis* seedling' parts

Heavy metal concentrations in *Ricinus communis'* parts after the experiment are presented in Table 5. The results showed that there is variation in heavy metal concentrations in the shoot and roots of the plants. The heavy metal concentrations in shoots of the plants after the experiment from all the treatments were Fe (15.10 – 17.20mg/kg); Zn (9.11 - 10.37mg/kg); Cu(10.00 -11.01mg/kg); Pb (2.20 -2.70mg/kg); Co (1.12 - 1.30mg/kg) and Cr (1.47 -1.71mg/kg) while their concentrations in roots were Fe (13.00 – 13.36mg/kg); Zn (9.11 - 10.37mg/kg); Cu(10.00 -11.01mg/kg); Pb (2.20 -2.70mg/kg); Co (1.12 - 1.30mg/kg) and Cr (1.47 - 1.71mg/kg).

Remediation potential of *Ricinus communis* for heavy metals

The potential of *Ricinus communis* seedlings to accumulate and translocation heavy metals into their various parts was assessed using bioaccumulation factor (BAF) and translocation factor (TF) presented in Table 6 and 7 respectively. The higher values of BAF were observed from Cr (0.72-0.88), Zn (0.50-58) and Cu (0.64- 0.88) from *Ricinus communis* seedlings while the lowers values of BAF were observed in Fe (0.32-0.36), Pb (0.20-0.24) and Co (0.27-0.36) as shown in Table 6.

Table 6: Value of Bioaccumulation factor of *Ricinus communis*

Treatment	Heavy metals in mg/kg					
	Fe	**Zn**	**Cu**	**Pb**	**Co**	**Cr**
100% BW	0.32	0.55	0.76	0.24	0.35	0.88
75% BW + 25 % IWW	0.32	0.58	0.76	0.24	0.36	0.79
50% BW+ 50% IWW	0.32	0.56	0.76	0.23	0.36	0.85
25% BW +75% IWW	0.32	0.53	0.68	0.22	0.31	0.75
100% IWW	0.36	0.50	0.64	0.20	0.27	0.72

BW= Borehole water; IWW- Industrial waste water

The values of translocation factor (TF) for the heavy metals are presented in Table 7. The values of TF for the heavy metals ranged from 1.09 to1.82. The values of TF are greater than one indicating high potential of the plants for transferring heavy metals from the roots into their shoots.

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Table 7: Value of Translocation Factor (TF) of *Ricinus communis*

Treatment	Heavy metals in mg/kg					
	Fe	**Zn**	**Cu**	**Pb**	**Co**	**Cr**
100% BW	1.16	1.32	1.40	1.34	1.12	1.13
75% BW + 25 % IWW	1.18	1.43	1.40	1.58	1.01	1.15
50% BW+ 50% IWW	1.23	1.39	1.38	1.76	1.02	1.21
25% BW +75% IWW	1.30	1.48	1,48	1.82	1.09	1.22
100% IWW	1.29	1.38	1.57	1.29	1.13	1.11

BW= Borehole water; IWW- Industrial waste water

DISCUSSION

According to the textural triangle (Whiting et al., 2011), the texture of the topsoil can be classified as loamy sand. The concentrations of the heavy metals in the soils are within the recommended value given by Kabata-Pendias (2011), Adriano (2001) and FAO (2003). Heavy metal concentrations in the soils are in the oder of Fe> Cu> Zn> Pb> Co> Cr. . Heavy metals concentrations in industrail waste water were higher than the recommended values given by WHO (2006) for irrigation water. The concentration of heavy metals in the borehole water were lower than the recommended values.The high values observed in the growth parameters of *Ricinus communis* seedlings could be attributed to the soil being rich in organic matter whichis the source of most of the nitrogen and phosphoruswhich enhances soil fertility and promote plant growth(Ideriah *et al*., 2010).

Plants needs not only macronutrients such as N, P, K, S, Ca, and Mg but also essential micronutrients such as Fe, Zn, Mn, Ni and Cu. Metals such as Pb, Co and Cr can also be of benefits to plants but when they are in excess they can be toxic to plants.Plants have developed highly explicit techniquess to take up, translocate, and store these nutrients in their tissue parts (Lasat, 2002). The observed reduction in the concentrations of the studied metals in soils after the experiment may be attributed to the metal uptake by potting media before planting and after harvest might indicate the uptake of this metal by *Ricinus communis* seedlings. Bioavailability depends on metal solubility in soil solution. According to Rosselli et al., (2003), the bioavailability and mobility of heavy metals to plants depends on their solubility in soil solution. The uptake of these metals by the studied plants may be due to the readily available of the heavy metals in soluble form (industrial waste water). Thus, *Ricinus communis* seedlings are able to uptake the metals into their roots and transfer them into the shoot. This also agreed with the reports of Liu *et al.*, (2015) and Yargholi *et al.*, (2008); that the removal of heavy metals in soils depend on the ability of the plants to absorb the metals and transfers it into their shoots thus preserving the soils and sustaining the environment. The higher concentrations of heavy metals observed in shoots of *Ricinus communis* seedlings than the roots agreed with the findings of Akintola et al

(2021a). This was attributed that plant species, time of harvest, soil types, bioavailability, mobility and solubility of heavy metal concentrations in the soils. The values of BAF and TF in plants greater than one according to Yoon *et al*. (2006) have the potential to be used as phytoremediation. Bioaccumulation factor values observed from Fe, Cu, Zn, Pb,Co and Cr in *Ricinus communis* classified the plants as accumulators (Akintola t al., 2021b; Padmavathiamma and Li, 2007, Madanan *et al*, 2021;Yadav*et al.*, 2009). Plants with TF values > 1 are classified as high-efficiency, plants with TF< 1 are classified as low-efficiency plants for metal translocation from the roots to shoots(Madanan*et al*, 2021;Yadav*et al.*, 2009).The values of TF (>1) for the studied heavy metals, classified *Ricinu*s *communis* as high efficiency (phytoextractor) plants. Thus, the plants have the ability to uptake the metals from the soils to the roots and transfer them into their shoots.

CONCLUSION

This study assessed the potential of *Riccinus communis* to uptake heavy metals from the soil irrigated with industrial waste water. Results of study indicated no toxic effects of the heavy metals on growth parameters of *Ricinus communis* seedlings. Reductions in the heavy metals' concentration in soils after the experiment indicate the uptake of the metals by the plants. Bioaccumulation and Translocation factors of the heavy metals classified *Ricinu*s *communis* as accumulator and high efficiency phytoextractor plants. This study has shown the efficacy of *Ricinu*s *communis* to uptake heavy metals and transfers it into its tissue parts.

REFERENCES

Adriano, D.C (2001) Trace elements in terrestrial environments: Biogeochemistry; Bioavailability and Risks of Metals. 2nd ed. Springer-Verlag New York, Berlin Heidelberg.

Akintola, O.O, Abiola, I.O, Abodunrin, E.K, Olokeogun, O.S, Ekaun, A.A, Ademigbuji, A.T and Babatunde, K.O (2021a) Potential of Ricinuscommunis L. For Removal of Heavy Metal in Contaminated Soil. *Journal of Applied Science and Environmental Management* 25 (2), 373-378

Akintola, O.O.,Arojojoye, J.T., Ojo, M.O. and Ibode. R.T. (2021b). Remediation Potential of *Jatropha integerrima* (Jacq) in Lead Contaminated Soil. Pacific Journal of Science and Technology. 22(2): 227-23

Akintola, O.O. 2014. Geotechnical and Hydrogeological Assessment of Lapite waste Dumpsite in Ibadan, Southwestern Nigeria. Unpublished Ph.D. thesis. University Ibadan Nigeria. 237p.

Akintola, O.O, Aderounmu, A.F, Abiola, I.O. and Bodede, A.I. (2019).Remediation potential of Baobab (*Adansonia digitata* L.) Seedlings grown in sewage sludge contaminated by Heavy Metals. *Journal of Applied Science and Environmental Management*, 23 (9), 1691-1697

Bauddh, K. And Singh, R. P. (2012). Growth, tolerance efficiency and phytoremediation potential of *Ricinus communis* (L.) and Brassica juncea (L.) in salinity and drought affected cadmium contaminated soil. *Ecotoxicology and Environmental safety, 85*, 13-22.

Berman, P., Nizri, S and Wiesman, Z. (2011). Castor oil biodiesel and its blends as alternative fuel. *biomass and bioenergy, 35*(7), 2861-2866.

Bhargava, A., Carmona, F. F., Bhargava, M. and Srivastava, S. (2012). Approaches for enhanced phytoextraction of heavy metals. *Journal of environmental management, 105*, 103-120.

Boda, R. K., Majeti, N. V. P and Suthari, S. (2017). *Ricinus communis* L. (castor bean) as a potential candidate for revegetating industrial waste contaminated sites in peri-urban Greater Hyderabad: remarks on seed oil. *Environmental Science and Pollution Research, 24*(24), 19955-19964.

Bramner, J. M (1965). Nitrogen Availability. In: C.A. Black (Ed.). Method of soil analysis Part II. Longman Publishers: pp. 249.

Bray, R.H and Kurtz, L.T (1945). Determination of Total Organic and Available Forms of Phosphorous Soils. Agronomy Journal, 43: 434-438De Lima da Silva et al. (2006)

FAO. (2003). Wastewater Treatment and Use in Agriculture. FAO Irrigation and Drainage Paper No.47. Food and Agriculture Organization of United Nations, Rome

FRIN Meteorological Station (2020). Information on the climate condition on the study area Forestry Research Institute of Nigeria, Ibadan.

Gaur, A. and Adholeya, A. (2004). Prospects of *arbuscular mycorrhizal* fungi in phytoremediation of heavy metal contaminated soils. *Current Science*, 528-534.

Huang, J. W and Cunningham, S. D. (1996.) Lead phytoextraction: species variation in lead uptake and translocation, New Phytologist, 134 (1):75–84

Ideriah, T.J.K, Harry, F.O, Stanley, H.O and Igbara, J.K (2010) Heavy metal contamination of soils and vegetation around solid waste dumps in Port Harcourt, Nigeria. *Journal of Appllied Science and Environmental Management* 14 (1),101-109.

Kabata-Pendia, A (2011) Elements in Soils and Plants. 4 ed. Taylor and Francis Group, LLC CRC Press. Boca Raton, P 505 Florida, USA

Lasat, M.M (2002). Phytoextraction of toxic metals: A review of biological mechanisms. Journal of Environmental Quality, 31: 109-120

Li, Y., Zhou, W., Hu, B., Min, M., Chen, P., andRuan, R. R. (2011). Integration of algae cultivation as biodiesel production feedstock with municipal wastewater treatment: strains screening and significance evaluation of environmental factors. *Bioresource technology*, *102*(23), 10861-10867.

Liu, D., Song,L., Ejazul, I., Jun-ren, C., Jia-sen,W., Zheng-qian ,Y., Dan-li, P, Wen-bo, Y and Kou-ping ,L (2015) Lead accumulation and tolerance of Moso bamboo (Phyllostachyspubescens) seedlings: applications of phytoremediation. *Journal of Biomedicinal and Biotechnolology* 16(2), 123–130

Madanan, M. T., Shah, I. K., Varghese, G. K. And Kaushal, R. K. (2021). Application of Aztec Marigold (*Tagete serecta* L.) for phytoremediation of heavy metal polluted lateritic soil. *Environmental Chemistry and Ecotoxicology*, *3*, 17-22.

Merkl, N., Schultze-Kraft, R. and Infante, C. (2005). Assessment of tropical grasses and legumes for phytoremediation of petroleum-contaminated soils. *Water, air, and soil pollution*, *165*(1), 195-209.

Nagajyoti, P. C., Lee, K. D and Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental chemistry letters*, *8*(3), 199-216.

Nodelkoska, T. V. and Doran, P. M. (2000). Characteristics of heavy metal by plant species with potential for phytoremediation and phyto mining. Minerals Engineering, 5:549-56.

Olivares, A. R., Carrillo-González, R., González-Chávez, M. D. C. A. and Hernández, R. M. S. (2013). Potential of castor bean (*Ricinus communis* L.) for phytoremediation of mine tailings and oil production. *Journal of environmental management*, *114*, 316-323.

Padmavathiamma, P.K and Li, L.Y (2007) Phytoremediation technology: Hyper-accumulation metals in plants. *Water, Air andSoil Pollution*, 184 (1–4),105–126.

Pehlivan, E., Özkan, A. M., Dinç, S and Parlayici, Ş. (2009). Adsorption of Cu2+ and Pb2+ ion on dolomite powder. *Journal of Hazardous Materials*, *167*(1-3), 1044-1049.

Pinto, A. P., Varennes, A. D., Dias, C. M. B. and Lopes, M. E. (2018). Microbial-assisted phytoremediation: a convenient use of plant and microbes to clean up soils. In *Phytoremediation* (pp. 21-87). Springer, Cham.

Vara Prasad, M. N.and De Oliveira Freitas, H. M. (2003). Metal hyperaccumulation in plants: biodiversity prospecting for phytoremediation technology. *Electronic journal of biotechnology*, *6*(3), 285-321.

Rajkumar, M., and Freitas, H. (2008). Influence of metal resistant-plant growth-promoting bacteria on the growth of *Ricinus communis* in soil contaminated with heavy metals. *Chemosphere*, *71*(5), 834-842.

Rajkumar, M., Ae, N and Freitas, H. (2009). Endophytic bacteria and their potential to enhance heavy metal phytoextraction. *Chemosphere*, *77*(2), 153-160.

Rosselli, W., Keller, C. And Boschi, K. (2003). Phytoextraction capacity of trees growing on a metal contaminated soil. *Plant and soil*, *256*(2), 265-272.

Roy, S., Labelle, S., Mehta, P., Mihoc, A., Fortin, N., Masson, C. And Greer, C. W. (2005). Phytoremediation of heavy metal and PAH-contaminated brownfield sites. *Plant and soil*, *272*(1/2), 277-290.

Schwab, P and Banks, K. (1999). Phytoremediation of Petroleum-Contaminated Soils. *Bioremediation of contaminated soils*, *37*, 783-795.

Shtangeeva, I., Luiho, J. V., Kahelin, H., and Gobran, G. R. (2004). Improvement of phytoremediation effects with help of different fertilizer. *Soil science and plant nutrition*, *50*(6), 885-889.

Singh, O. V. and Jain, R. K. (2003). Phytoremediation of toxic aromatic pollutants from soil. *Applied microbiology and biotechnology*, *63*(2), 128-135.

Tiwari, K. K., Dwivedi, S., Mishra, S., Srivastava, S., Tripathi, R. D., Singh, N. K and Chakraborty, S. (2008). Phytoremediation efficiency of *Portulaca tuberosarox* and *Portulaca oleracea* L. naturally growing in an industrial effluent irrigated area in Vadodra, Gujrat, India. *Environmental monitoring and assessment*, *147*(1), 15-22.

Walkley, A and Black, I.A (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 37, 29–38

Wang, B., Xie, H. L., Ren, H. Y., Li, X., Chen, L., and Wu, B. C. (2019). Application of AHP, TOPSIS, and TFNs to plant selection for phytoremediation of petroleum-contaminated soils in shale gas and oil fields. *Journal of cleaner production*, *233*, 13-22.

Whiting, J. C., and Bybee, B. (2011). *Ecology and Management of Bats on the INL Site*. GSS-ESER-156.

WHO. (2006):Guidelines for drinking water quality [electronic resource]: incorporating first addendum. Vol. 1, Recommendations-3rd ed., Electronic version Web. 595p.

Wong, S. C., Li, X. D., Zhang, G., Qi, S. H. and Min, Y. S. (2002). Heavy metals in agricultural soils of the Pearl River Delta, South China. *Environmental pollution*, *119*(1), 33-44

Wong, C. S. C., Li, X. D., Zhang, G., Qi, S. H., and Peng, X. Z. (2003). Atmospheric deposition of heavy metals in the Pearl River Delta, China. *Atmospheric Environment*, *37*(6), 767-776.

Wong, C. S., Wu, S. C., Duzgoren-Aydin, N. S., Aydin, A., and Wong, M. H. (2007). Trace metal contamination of sediments in an e-waste processing village in China. *Environmental Pollution*, *145*(2), 434-442.

Yadav, S.K, Juwarkar, A.A, Kumar, G.P, Thawale, P.R, Singh. S.K and Chakrabarti, T (2009) Bioaccumulation and phyto-translocation of arsenic, chromium and zinc by *Jatrophacurcas* L.: impact of dairy sludge and biofertilizer. *Bioresource Technology*, 100:4616–4622

Yargholi, B., Azimi, A.A., Baghvand, A., Liaghat, A. M., Fardi, G.A. (2008) Investigation of cadmium absorption and accumulation in different parts of some vegetables. American Eurasian *Journal of Agricultural and Environmental Science*, 3, 357–364.

Yoon, J. M., Aken, B. V.and Schnoor, J. L. (2006). Leaching of contaminated leaves following uptake and phytoremediation of RDX, HMX, and TNT by poplar. *International Journal of Phytoremediation*, 8(1), 81-9