PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

**Full-text Available Online at**
**https://www.ajol.info/index.php/jasem**
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J. Appl. Sci. Environ. Manage.
Vol. 28 (2) 311-324 February 2024

# Concentration and Health Risk of Heavy Metals in Herbs from Electronic Waste Disposal Site in Lagos State, Nigeria

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**ABSTRACT:** Considering that about 80 % of the world population uses herbs for the treatment of illnesses and the contamination that is prevalent at electronic waste (e-waste) disposal sites, this study evaluated the concentrations of heavy metals and health risks in the use and consumption of *Rhynchospora corymbosa, Pentodon pentandrus* and *Cyclosorus dentatus*, herbs commonly found in electronic waste disposal site in Lagos State, Nigeria using appropriate standard methods. The mean concentrations of the heavy metals in the plant were: 100.78±0.91, 0.16±0.02, 25.68±0.44, 258.94±1.62, and 8.51±0.04 mg/kg for Pb, Cd, Ni, Cu and Cr, respectively. *Pentodon pentandrus* had the highest Pb, Cu and Ni concentrations, *Cyclosorus dentatus* had the highest Cd concentration while *Rhynchospora corymbosa* recorded the highest concentration of Cr. The bio-accumulation factor of Cu in *Pentodon pentandrus* and in *Rhynchospora corymbosa* and of Cr in *Rhynchospora corymbosa* were higher than 1. The estimated daily intake of Pb and Ni in *Pentodon pentandrus*, *Cyclosorus dentatus* and *Rhynchospora corymbosa* exceeded the Provisional Maximum Tolerable Intake, indicating an intolerable risk to the consumers' health. The hazard index of each of the plants indicates that the cumulative health effects of the heavy metals would cause potential health hazards to the consumers. This useful information gives an accurate indication of the levels of contamination of the plants and the potential health risk effects of the consumption of these herbs from the dumpsite.

**DOI: https://dx.doi.org/10.4314/jasem.v28i2.3**

**Cite this paper as**: Orji, N. C. (2024). Concentration and Health Risk of Heavy Metals in Herbs from Electronic Waste Disposal Site in Lagos State, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (2) 311-324

**Dates:** Received: 07 December 2023; Revised: 21 January 2024; Accepted: 11 February 2024 Published: 28 February 2024

**Keywords**: Herbs; Electronic Waste Disposal Site; Heavy Metals; Health Risk Assessment

About 80 % of the world's population uses herbs for the treatment of their ill health, since the herbs are affordable, available and of natural origin (Ekor 2013). Different herbs are used extensively as antibiotic, bacteriostatic, fungi-static; glycosides, saponins and steroids (Burkill 2000); pain-killer during the treatment of fever, arthritis, rheumatism and headache (Fern, 2014); in the treatment of cough, diarrhoea, hypertension, sexually transmitted diseases (Meseret et al., 2020); conjunctivitis, promote lactation in nursing mothers (Fern, 2014); treat obesity (Ogbonnaya and Chinedum2013), breast and colon cancer (Kristine *et al.*, 2015), asthma (Ogunlesi *et al.*, 2010)*etc. Pentodon pentandrus*, is used to cure conjunctivitis, promotes lactation in nursing mothers and serves as pain-killer in the course of treating fever, arthritis, rheumatism and headache (Fern 2014). In our society today, where pains and fever from malaria, typhoid fever and stress are predominant, *Pentodon pentandrus*, may then be used to treat the pain. The extract from *Cyclosorus dentatus* serves *as* antibiotic, bacteriostatic, fungi-static; glycosides, saponins and steroids (Burkill 2000). More so, farmers use green manure to improve crop yield and soil texture with great increase in the activities and development of soil flora and fauna (Li *et al*., 2020). Maitra *et al*., (2018) added that using green manure and compost manure have proven to be better than chemicals fertilizers as they enhance the fertility, physico-chemical and biological properties of the soil. Green manure also boosts nutrients supply to crops and protects the soil and plants from erosion (Maitra *et al*., 2018). Burkill

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(1985) reported that the leaves of *Rhynchospora corymbosa can be* ploughed into the soil as green manure in rice farms or used in making compost manure to enable famers increase the productivity of their cash and food crops; thereby improving both the soil structure and the soil biota. *Talinum fruticosum* is a medicinal plant used to treat cardiovascular diseases, obesity, diabetes mellitus (Ogbonnaya & Chinedum 2013); to prevent breast and colon cancer (Kristine *et al.,* 2015); while the extracts from its roots and leaves are used to treat anemia, asthma, high blood pressure and fresh cut (Ogunlesi *et al.,* 2010). Just like any plant, medicinal plants grow naturally on different soil environments, such as disposal sites, that favor their survival. Disposal sites are places where wastes generated from homes, offices, factories, industries, markets, schools, etc., are discarded. An electronic waste (e-waste) disposal site is a dumpsite where obsolete electronics, which cannot be repaired and reused by those who cannot afford the modern ones, are discarded. These e-wastes originated from obsolete electronics are mostly shipped from developed countries into developing countries such as Nigeria (Olowu 2012) for those who could only afford the cheaper fairly used electronics. They contain heavy metals and brominated flame retarders (BFR) which pose health hazards when released into the environment (Babayemi *et al.*, 2019; Needhidasan *et al.*, 2014). At the e-waste disposal site, scavengers use different methods to recover valuable parts of the electronic waste. These methods, which include open burnings, acid baths, baking circuit boards and toxic dumping; cause the pollution of the land, air and water due to the release of heavy metals and brominated flame retarders (BFR) into the environment (Heacock *et al.*, 2018). Heavy metals deposited on the soil are trans-located to the leaves of plants via the roots while the aerial deposits of fly ash on the leaves diffuse into the leaves through the stoma. These heavy metals are absorbed and trans-located to other plant tissues. According to Hu *et al.*, (2013), the presence of these heavy metals in plants reduces the quality and productivity of cash crops, food crops and herbal plants. More so, they are carcinogenic and highly toxic to humans and animals; and cause hazardous effects on the hosts after the consumption of contaminated plants (Hu *et al.*, 2013; Shuchi and Avani 2014; Odeyemi *et al.*, 2011).

Humans, animals and plants are exposed to severe health dangers due to these contaminants. The health of any herb growing on a particular soil environment depends largely on the health of the soil accommodating the herb and can be monitored using bioaccumulation factor (BAF). The consumption of contaminated herbs from e-waste disposal sites with high concentrations of heavy metals can cause health hazards to consumers (Odoh and Ajiboye 2019; Durodola *et al.*, 2019; Mirosławski and Paukszto 2018; Abbas *et al.,* 2017). The potential health risk of herbs/plants on human health after the consumption of contaminated plants can be assessed by the hazard quotient and hazard index. Hence, the objective of this paper is to evaluate the concentrations of heavy metals and health risks in the use and consumption *of Rhynchospora corymbosa*, *Pentodon pentandrus* and *Cyclosorus dentatus* herbs commonly found in the electronic waste disposal site in Lagos State, Nigeria

## MATERIALS AND METHODS

*Sampling:* About twenty-five (25) samples of each of the three medicinal plant species: *Rhynchospora corymbosa* (L.) Britton; *Pentodon pentandrus* (Schun and Thun) and *Cyclosorus dentatus* (forsk Ching); were collected randomly at the electronic waste disposal site located at Alaba International Market, Ojoo local Government Area, Lagos State at 6$^{O}$ 27′ 14″ N, 3$^{O}$ 11′ 25″ E. Image 1 shows Ojoo Local Government Area indicating the study area (Alaba International market).

The disposal site was divided into five quadrants and five plant samples of each plant species were collected randomly within each quadrant. The randomly collected samples of each plant species were merged to form the representative sample of each plant species from the disposal site. All samples were stored in paper bags, to prevent fungi growth and labelled appropriately. Soil samples were collected along with the plant samples from each of the five quadrants using a trowel. A total of 20 soil samples were collected. These were placed in their respective labelled black polyethene bags and were later merged to get the representative sample.

Control soil and plant, *Talinum fruticosum,* was sampled from a farmland far from traffic road at Ago Palace way Okota in Lagos State at 6$^{O}$ 30′ 25″ N, 3$^{O}$ 17′ 43″ E, where there was no sort of pollution. *Talinum fruticosum* is a medicinal plant like the *Rhynchospora corymbosa*, *Pentodon pentandrus and Cyclosorus dentatus*. The three medicinal plants were not found at the control site, hence an alternative medicinal plant, *Talinum fruticosum,* was used. As at the time of sampling, the farmland was under about a year fallow. It was divided into four quadrants; 2 soil samples and 5 plant samples were collected from each quadrant to give a total of 8 soil samples and 20 plant sample.

*Sample Preparation:* The four plant samples were first washed under a fast-flowing tap to remove adhered soil and dust. The leaves were separated from the stem, drained, dried in an oven using stainless trays at 60 $^0$C to avoid possible loss of some volatile metallic compounds and to make grinding and sieving easy. Thereafter, the dry samples were pulverized using agate mortar and pestle that were previously soaked in 10 % Trioxonitrate (V) acid solution to avoid metal contamination and rinsed with deionized distilled water. The samples were then sieved using 2 mm sieve and stored in air-tight black polyethylene bags for 2 days before the commencement of analysis.

The soil samples were spread on a new transparent water-proof placed on a drying table in a drying room and air dried for two weeks. To prevent metal contamination, the samples were pulverized using agate mortar and pestle that were previously soaked in 10 % Trioxonitrate (V) acid solution and rinsed with deionized distilled water. Then, they were sieved using 2 mm sieve and stored appropriately.

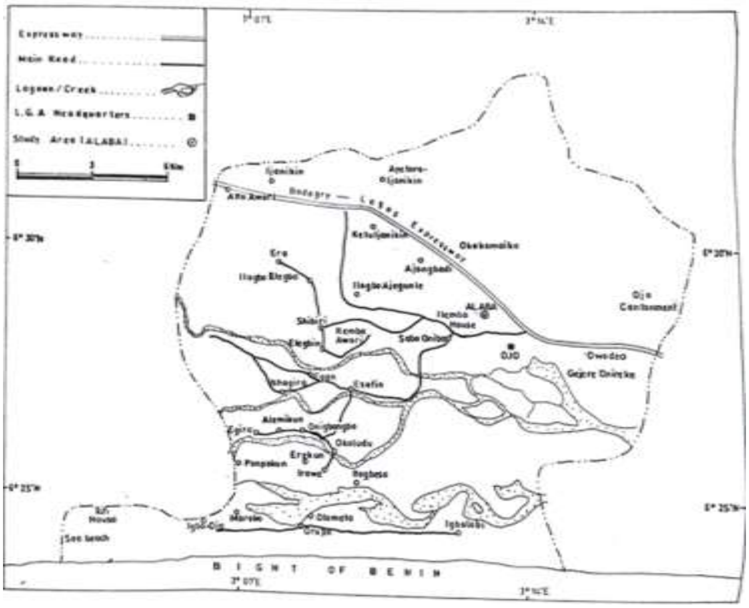

**Fig. 1** Map of Ojoo Local Government Area showing the study area (Alaba) in Lagos State

*Sample Digestion:* A modified method of Van Wychen and Laurens (2015) was used to dry-ash the plant sample. About 1 g of oven-dried 2 mm sieved plant sample was weighed into crucibles in duplicates and placed in an oven whose temperature was gradually increased from room temperature to 350 °C. The dry digestion was carried out for about 4 hrs. After complete digestion, the crucible was removed from the muffle furnace and allowed to cool to room temperature in the desiccators. About 10 ml of Aqua-regia was added into the crucible to dissolve the ash. Then, the crucible was heated on a hot plate to reduce the volume of the solution to half of original volume. The solution was allowed to cool, filtered and made up to mark using 25 ml standard flask. The digests were stored in plastic container and placed in the refrigerator. The method of Orji *et al.,* (2018) was adopted for the wet digestion of soil samples. About 2 g of the pulverized soil samples were weighed into previously washed centrifuge tubes and about 10 ml of 2 M Trioxonitrate (V) added into the centrifuge tube and prepared in duplicates. The centrifuge tubes were placed in a beaker containing boiling water and were opened and shook at 20 min intervals. The heating was carried out for about 2 hours in the water bath and thereafter the solution filtered using a filter paper (Whatman No.1 filter paper). The filter paper was rinsed with deionized distilled water while the filtrate/digest was made up to mark with deionized distilled water in 25 ml standard flask. The digests were stored in well-labeled plastic containers and analyzed for metals using a Flame Atomic Absorption Spectrophotometer (AAS).

*Trace metals Analysis:* Nickel (Ni) and Chromium (Cr) concentration levels in samples were determined using Buck scientific (Model 210) Atomic Absorption Spectrophotometer using Air- acetylene flame at 232.0 nm and 357.9 nm respectively. While Cadmium (Cd), Copper (Cu), and Lead (Pb) were determined using Perkin Elmer Analyst 200 Atomic Absorption spectrophotometer at 228.80 nm for Cd, 324.75 nm for Cu and 283.3 nm for Pb using Air –Acetylene flame.

*Method of data analysis:* Analysis of variance (ANOVA) was used to determine if the mean concentrations of the heavy metals in the soil and plants from the e-waste disposal site were statistically significant ($p < 0.05$). The variations in the mean of the duplicate concentrations of each of the heavy metals (Pb, Cd, Cu, Cr and Ni) contained in *Talinum fruticosum, Rhynchospora corymbosa, Pentodon pentandrus Cyclosorus dentatus,* soil from e-waste site, soil from control, Background level of DPR and the WHO permissible allowable concentrations of heavy metals in plants were compared with each other using multiple comparison in ANOVA. The descriptive analysis was used to ascertain the minimal, maximum and standard deviation of the concentration of the heavy metals from the mean value of the duplicate concentrations obtained.

*Bio-accumulation factor:* The bio-accumulation factor was determined using equation 1 below.

$$\text{BF} = \frac{\text{Concentration of metal in plant}}{\text{Concentration of metal in soil}} \qquad (1)$$

*Estimated daily intake (EDI):* The estimated daily intake of heavy metals via herbal consumption increases the accumulation of heavy metals in the human body which in turn determines the level of toxicity of the metals (Abbas et al., 2017). The estimated daily intake (EDI) of heavy metals from herbal plants is obtained as a function of the concentration of each heavy metal in the herbal plant, the daily intake of the herbal and the mean body weight of the consumer (Kowalska 2021; Gaya and Ikechukwu2016; Okeke and Okeke, 2015). EDI is stated as shown in equation 2:

$$\text{EDI} = \frac{C_{HM} x H_{IR}}{B_{wa}} \qquad (2)$$

Where: EDI = Daily Intake of heavy metals from herbal plants (mg $kg^{-1}$ $day^{-1}$); $C_{HM}$ = concentration of heavy metal in the herbal plant (mg $kg^{-1}$); $H_{IR}$ = ingestion rate of herbal plant (g $person^{-1}$ $day^{-1}$) (0.02 g/person/day for all the medicinal plants (Meseret *et al.*, 2020); $B_{wa}$ = mean body weight (kg)

*The hazard quotient:* The non-carcinogenic risk of heavy metals exposure to humans from long-term via consumption of vegetables, medicinal plants, and fruits are evaluated via the use of hazard quotient. If HQ <1, this means that no potential health effects are expected from exposure, while HQ >1 signifies that there are potential health risks due to exposure (Meseret *et al.*, 2020). The hazard quotient (HQ) was calculated as the ratio of the daily intake of heavy metals to the Oral reference dose for non-carcinogenic risk, as expressed in equation 3.

$$\text{HQ} = \frac{DI}{R_{fd}} \qquad (3)$$

Where: HQ = Non-cancer hazard quotient (HQ); EDI= Estimated Daily intake (mg/kg/day); $R_{fd}$ = Oral reference dose ($R_{fd}$) for the heavy metals (mg/kg/day)

The oral reference dose is the highest amount of a metal that can safely be consumed daily by the human population without any appreciable risk of deleterious effects during a lifetime, with SI unit, mg/kg/day (US EPA 1993). $R_{fd}$ is the oral reference dose for non-carcinogenic risk of heavy metals. The oral reference dose of metals of interest are: Pb = 0.0035 mg/kg/day; Cd = 0.001 mg/kg/day; Cu = 0.040 mg/kg/day; Cr = 0.003 mg/kg/day (Meseret *et al.,* 2020) and Ni = 0.020 mg/kg/day (Gebreyohannes and Gebrekidan 2018) as stated by Integrated Risk Information System of United States Environmental Protection Agency (IRIS 2016).

*Hazard index (HI):* The exposure to two or more heavy metals by consuming contaminated plants may cause a collective health effect. Hazard index is used to assess the risk to human health by the collective effect of more than one heavy metal through the consumption of a given contaminated plant. It is the sum of more than one hazard quotient for multiple toxicants in the contaminated plant sample as given in equation 4 (US EPA (1989).

$$HI = \sum_{n=1}^{i} HQ \qquad (4)$$

# RESULTS

*Lead concentration:* In this study, the highest mean concentration of Pb was 504.23±0.18 mg/kg from the contaminated soil while the least was recorded in the control plant, *Talinum fruticosum* with a concentration of 0.12±0.01 mg/kg. The order of Pb concentration in the plant samples was *Pentodon pentandrus* > *Cyclosorus dentatus*> *Rhynchospora corymbosa*> *Talinum fruticosum* as shown in fig 1. The mean concentration of Pb in *Pentodon pentandrus,* 220.30±0.21 mg/kg, was significantly higher than the Pb concentrations in *Cyclosorus dentatus* ($p< .001$), *Rhynchospora corymbosa* ($p< .001$) and in the control plant, *Talinum fruticosum* ($p< .001$). More so, *Rhynchospora corymbosa* had Pb concentration that was significantly lower than *Cyclosorus dentatus* ($p< .001$) but higher than that in *Talinum fruticosum, whose concentration,* 0.12±0.01 mg/kg, was significantly the lowest in the analysis with $p< .001$. The permissible concentration of Pb allowed in vegetables by WHO was exceeded in all the analyzed plant samples except in the control plant, *Talinum fruticosum,* which showed no significant difference ($p= .327$). The mean Pb concentration in the contaminated soil was significantly higher (p< .001) than those in all the plant samples as shown in Fig 1. It was also significantly higher than the Pb concentrations from the control soil with p< .001and exceeded the background Pb concentration set by DPR in Nigeria with p< .001, as indicated in Fig 2.

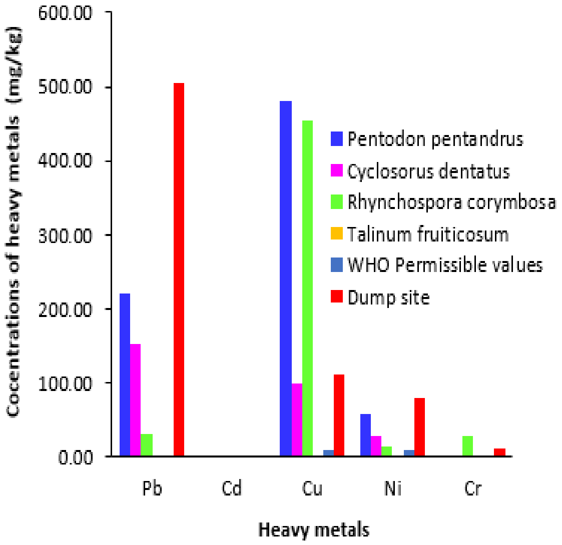

**Fig 1.** Concentrations of heavy metals in plants from e-waste disposal site compared with the permissible concentrations set by WHO

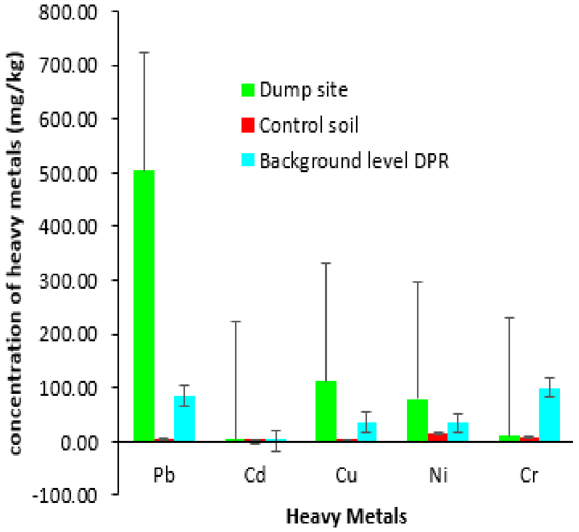

**Fig 2.** Concentrations of heavy metals in soil compared with the set standard and control

*Cadmium concentration:* The Cadmium concentrations in the plants and soil are shown in Fig 1. The highest mean concentration of Cadmium, 3.43±0.12mg/kg, was found in the soil sample, whereas, *Cyclosorus dentatus* had the highest Cadmium mean concentration in plants. This was followed by the concentration in *Rhynchospora corymbosa*, 0.17±0.09 mg/kg. The concentrations of Cadmium in *Pentodon pentandrus and Talinum fruticosum* were below the detection limit of the AAS used for the analysis. The analysis therefore indicates that the concentration of Cadmium in *Pentodon pentandrus* was significantly lower than the concentrations in *Cyclosorus dentatus* (p= .025), Dumpsite soil (p< .001) and control soil (p= .042). However, there were no significant difference between its Cadmium concentration and that in *Talinum fruticosum* (p= 1.00) *and Rhynchospora corymbosa* (p= .425) but remained within the allowable concentrations in plants set by WHO (p= 1.00) as shown in Fig 1.The ANOVA test indicated that there were no significant differences between the mean concentrations of Cadmium in *Rhynchospora corymbosa* and those in *Pentodon pentandrus* (p= .425), *Cyclosorus dentatus* (p= .395), *Talinum fruticosum* (p=.425), and that allowed by WHO in vegetables (p= .561). However, the mean Cadmium concentration in *Cyclosorus dentatus* was significantly higher than the WHO allowable Cadmium concentration (p = .035). The mean Cd concentration in the control soil, 0.34±0.04 mg/kg, was significantly higher than that in the control plant, *Talinum fruticosum,* with a p-value of 0.040 but still below the background concentration set by Department of Petroleum Resources (DPR). The mean Cd concentration of the dump site soil, 3.43±0.12 mg/kg, was significantly higher (p< .001) that the allowable concentration permitted by DPR, 0.80 mg/kg as shown in figure 2 and as such the dump site is contaminated with Cadmium.

*Copper concentration:* From the study, the mean Cu concentration in *Pentodon pentandrus,* 480.14±0.20 mg/kg, was the highest concentration followed by *Rhynchospora corymbosa*, 454.43±0.13 mg/kg, and thirdly by that in the dumpsite soil 111.64±0.08 mg/kg. Among the contaminated plants, the concentration of Cu in *Cyclosorus dentatus*, was the lowest as shown in figure 1 while the control plant, *Talinum fruticosum,* showed the lowest among the foliar part of plants analyzed. In addition, the permitted concentration of Copper in plants set by WHO was exceeded by all the contaminated plants whereas, the control plant had a significantly lower concentration (p< .001) than that set by WHO. There was no significant difference between the concentrations of Copper in the soil and plant samples collected from the control site (p= 1.00). More so, the mean concentration of Cu in the control soil was significantly lower than the background concentration set by DPR of Nigeria with p< .001. However, from fig 2, the mean Cu concentration in the soil from the dumpsite was significantly higher than the concentration in the control soil with p< .001 and that set by DPR (p< .001).

*Nickel concentration*

The highest mean concentration of Nickel in this study was found in dumpsite soil, 78.77±0.08 mg/kg, while the least concentration, 0.44±0.52 mg/kg, was observed in the control plant, *Talinum fruticosum*. The order of the Ni concentration in this study is: disposal site soil >*Pentodon pentandrus*>*Cyclosorus dentatus*>Control soil>*Rhynchospora corymbosa*> *Talinum fruticosum.* For the plant samples, *Pentodon pentandrus,* 58.63±0.18 mg/kg, had the highest mean concentration whereas, *Talinum fruticosum,* 0.44±0.52 mg/kg had the lowest mean concentration as shown in figure 1. Statistically, the mean concentration of Ni in *Pentodon pentandrus* was significantly the highest among the plant samples analyzed (p< .001). Although it was significantly lower than that from the dumpsite soil with p < .001. The mean concentration of Ni in the control plant sample, *Talinum fruticosum,* was significantly lower than the concentration in the contaminated plant samples (p<.001). The permissible concentration of Ni in the herbs was exceeded in *Pentodon pentandrus, Cyclosorus dentatus and Rhynchospora corymbos,* as their concentrations were significantly higher than that permitted by WHO (p< 0.01). However, at p<0.05 level of confidence *Pentodon pentandrus* and *Cyclosorus dentatus* exceeded the set allowable concentration while there was no significant difference between the concentration set by WHO and that in *Rhynchospora corymbos.* In figure 2, the concentration of Ni in the soil from the contaminated disposal site was significantly higher (p< .001) than the background concentration set by DPR, as shown by the error bars. More so, Ni concentration in the control soil was significantly lower than that in the dumpsite with p< .001.

*Concentration of chromium:* The concentration of Chromium in the plants from the contaminated site ranged from 1.56 mg/kg of *Cyclosorus dentatus* to 29.17 mg/kg of *Rhynchospora corymbosa* as shown in Figure 1. The concentration of Chromium in *Rhynchospora corymbosa,* 29.17±0.24 mg/kg, was significantly the highest (p<0.05) among the samples analyzed. Chromium concentration in *Pentodon pentandrus,* 3.32±0.10 mg/kg, was significantly higher (p< 0.05) than the concentration in *Cyclosorus dentatus* (p= .017) and the *Talinum fruticosum* (p=.001), the control plant. The concentration of Chromium in *Cyclosorus dentatus* was significantly the lowest among the plants from the dumpsite with P< 0.05 but have no significant difference with that in *Talinum fruticosum,* from the control site. Statistically, there was no significant difference between the Chromium concentration in *Cyclosorus dentatus* and that set by WHO (p=.999 at 95 % confidence level); this also applied to *Talinum fruticosum*, with p= .230 at 95 % confidence level. Nevertheless, the allowable concentrations of Chromium in plants set by WHO were exceeded in *Pentodon pentandrus* and *Rhynchospora corymbosa.* The concentration of Chromium in the soil from the dumpsite was statistically higher than those in the plants from the same dumpsite except *Rhynchospora corymbosa* which was significantly higher, with p<.001, as shown in fig 1. However, the Cr concentration in the soil from the dumpsite was significantly lower (p<.001) than the allowable concentration set by DPR but was significantly higher than the concentration in soil from the control site as shown in figure 2, with p< .001. The mean concentration of Chromium in the soil from control soil, 7.70±0.10 mg/kg, was significantly higher (p<0.001) than the concentration in *Talinum fruticosum,* 0.33±0.01 mg/kg.

Generally, the five heavy metals under consideration critically reached and exceeded the concentration level for uncontaminated plants with the exception of Cd which lies within the normal range in plants. From figure 1, *Pentodon pentandrus* had the highest mean concentration of Pb (220.30±0.21 mg/kg), Cu (480.14±0.20 mg/kg) and Ni (58.63±0.18 mg/kg) and lowest concentration of Cd (ND). *Cyclosorus dentatus* had the highest concentration of Cd (0.34±0.01 mg/kg) while *Rhynchospora corymbosa* had the highest concentration of Cr (29.17±0.24 mg/kg). Also, it was observed that the highest mean concentration of Cu in the leaves of plant samples (480.14±0.20 mg/kg) was higher than that contained in soil (111.64±0.08 mg/kg). *Pentodon pentandrus and Rhynchospora corymbosa* had higher concentrations of Cu than the soil. Meanwhile, the Pb, Cd and Ni mean concentrations in the soil of the dumpsite; 504.23±0.18, 3.43±0.12 and 78.77±0.08mg/kg respectively, were significantly higher than those in all the plants analyzed, p<.001. Figure 2 shows the concentrations of heavy metals in the dumpsite and that permitted in farmlands in Nigeria as detailed by DPR. From the figure, the Lead, Cadmium, Copper and Nickel concentrations in the contaminated soil sample exceeded the background level in farmlands with the exception of Chromium which was below the permitted limits. Likewise, the concentrations of these heavy metals in the control soil were significantly lower (p<.001) than those from the contaminated soil. The significant different in the mean concentrations of the heavy metals in the soil and plant from the e-waste disposal site was glaring as indicated by the error bars in Fig 3. There was extreme significant different between the mean concentration of Cu and those of Pb, Cd, Ni, and Cr, in the analyzed samples. Additionally, the mean concentration of Pb in the samples was significantly higher than mean concentrations of Cd, Ni and Cr in the samples. However, there was no significant different between the mean concentrations of Cd, Ni and Cr in the samples.

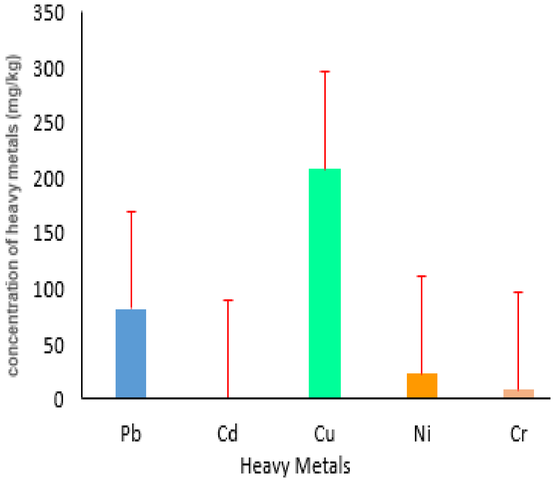

**Fig 3.** Showing the Mean concentration of the heavy metals in the contaminated soil and plants

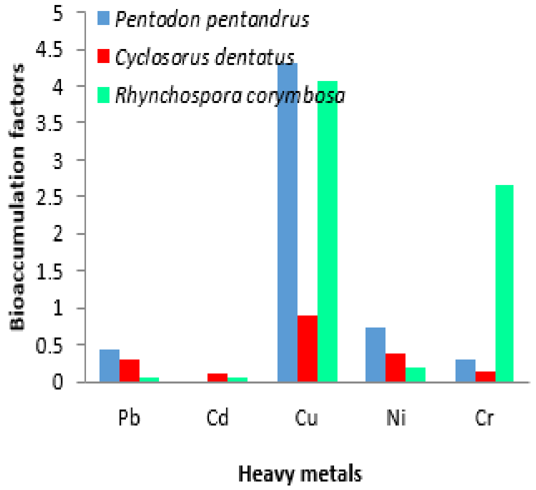

**Fig 4.** Bio-accumulation factor of heavy metals in plants

*Bio-accumulation factor:* The bio-accumulation factor of the heavy metals of interest in the plants is displayed in Fig 4. From the figure, this present investigation revealed that the BAF of Cu in *Pentodon pentandrus and Rhynchospora corymbosa* were greater than 1 and likewise the BAF of Cr in only *Rhynchospora corymbosa*.

*Estimated daily intake (EDI):* The estimated daily intake (EDI) of the metals in the plants is displayed in Fig 5. From the figure, the EDI of Pb and Ni in *Pentodon pentandrus*, *Cyclosorus dentatus and Rhynchospora corymbosa* exceeded the provisional maximum tolerable intake (PMTDI) of 0.0017 mg/kg for Pb, 0.0008 for Cd; 0.5000 mg/kg for Cu; 0.0010 for Ni and 0.2500 for Cr set by the joint FAO/WHO committee (FAO/WHO 2012). However, the estimated daily intakes of Cd, Cu and Cr in all the herbs were lower than the PMTDI while the EDI of Pb, Ni, Cd, Cu and Cr in the control plant, *Talinum fruticosum*, were below the PMTDI.

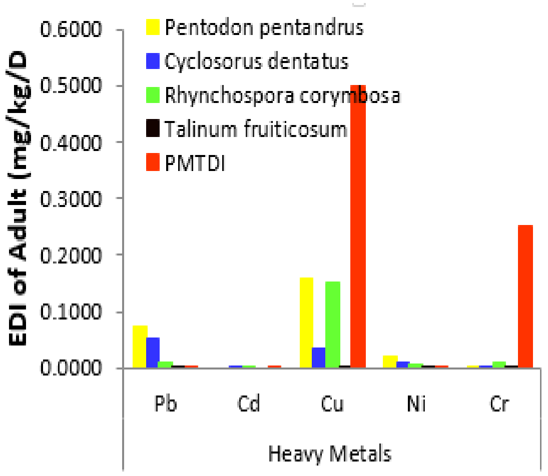

**Fig 5.** The Estimated Daily Intake of heavy metals in adult compared with the PMTDI

*Hazard quotient, HQ:* The HQ of Pb in the sample ranged from 0.011 to 20.981 as shown in table 1 with an order of *Pentodon pentandrus > Cyclosorus dentatus> Rhynchospora corymbosa >Talinum fruticosum.*

From the table, the HQs of Pb in the three samples, *Pentodon pentandrus, Cyclosorus dentatus* and *Rhynchospora corymbosa*, from the e-waste disposal site were > 1 while the HQ of Pb in *Talinum fruticosum* was < 1. However, the HQs of Cd and Ni in all the plants analyzed were less than 1. More so, the HQs of Cr were less than 1 in all the plants except in *Rhynchospora corymbosa* with HQ > 1. From the table, the HQs of Cu in *Pentodon pentandrus* and *Rhynchospora corymbosa* were > 1 while those of *Cyclosorus dentatus* and the control plant, *Talinum fruticosum*, were < 1.

*Hazard index:* The Hazard Index, the collective health effects of the different heavy metals due to the use of the contaminated herbs from the e-waste disposal site, is shown in table 1. The values obtained from the analysis ranged from 0.068 for *Talinum fruticosum* to 26.328 for *Pentodon pentandrus.* The descending order of the HI is *Pentodon pentandrus > Cyclosorus dentatus > Rhynchospora corymbosa >Talinum fruticosum.* The percentage representation of the HI in each of the analyzed plant sample is shown in Fig 6. Meanwhile, the order of the average contributory effect of the heavy metals was Pb> Cu> Cr > Ni > Cd, with a range of 0 % for Cd to 73 % for Pb.

**Table 1:** The Hazard quotient (HQ) and health risk index (HI) of heavy metals in plants

| Samples | HQ | | | | | HI |
|---|---|---|---|---|---|---|
| | Heavy Metals | | | | | |
| | Pb | Cd | Cu | Ni | Cr | |
| *Pentodon pentandrus* | 20.981 | 0 | 4.001 | 0.977 | 0.369 | 26.328 |
| *Cyclosorus dentatus* | 14.505 | 0.113 | 0.833 | 0.498 | 0.173 | 16.122 |
| *Rhynchospora corymbosa* | 2.94 | 0.055 | 3.787 | 0.23 | 3.241 | 10.253 |
| *Talinum fruticosum* | 0.011 | 0 | 0.0132 | 0.007 | 0.037 | 0.068 |

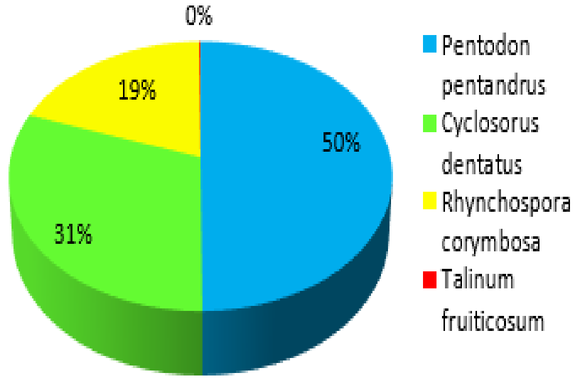

**Fig 6.** Percentage representation of the HI of the different plant samples

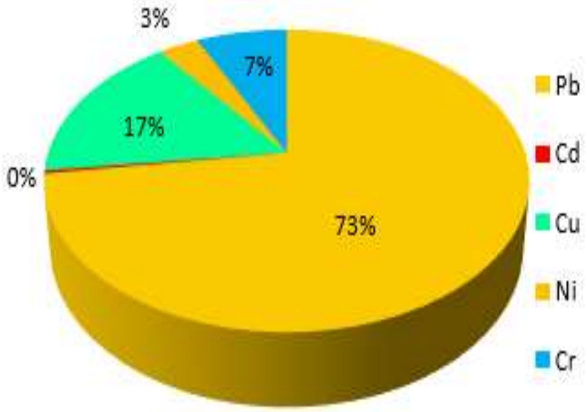

**Fig 7.** Average percentage contribution of the heavy metals to the Hazard Index

Therefore, Pb had the highest average contributory effect of 73 % to the average HI of the contaminated plant samples from the e-waste disposal site, followed by Cu with 17 %, thirdly by Cr, contributing averagely by 7 % as shown in Fig 7. The average percentage contributory effect of Ni was only 3 % whilst Cd had the least average contributory HI of 0 %.

The additive effect of the five heavy metals analyzed in *Pentodon pentandrus* yielded the highest HI of 50 %, followed by *Cyclosorus dentatus* with 31%, while the HI of the heavy metals in *Rhynchospora corymbosa* added up to only 19% of the total HI whilst the control plant, *Talinum fruticosum*, had 0%. The HI of each of the plants from thee-waste disposal site was greater than 1.

## DISCUSSION

*Lead Concentration:* The result indicates that the plants from the dump site were contaminated with Pb. Hence the use of *Pentodon pentandrus*, from the dumpsite: to promote lactation in nursing mothers; as pain-killer while treating fever, arthritis, rheumatism and headache; and to cure conjunctivitis (Fern 2014) may lead to a health hazard. Also, using *Cyclosorus dentatus* obtained from the disposal site as an antibiotic, bacteriostatic, fungi-static; glycosides, saponins and steroids (Burkill 2000) may lead to health hazards from Pb contamination. Ploughing the leaves of *Rhynchospora corymbosa* into the soil as green manure in rice farms or in making compost manure (Burkill 1985) will introduce high concentrations of Pb into the soil which will be trans-located to the rice plants. Thereafter, leading to high exposures to Pb through the consumption of the rice. The high concentrations of Pb in the contaminated samples could be as a result of indiscriminate burning of printed circuit boards, Cathode ray tubes, light bulbs, batteries and electric wires (Li *et al.*, 2020; Pant *et al.*, 2012) at the dump site, which led to the release of Pb into the environment and deposits on soil and plants. This could lead to damaging effect to the kidney, nervous, blood & reproductive systems and can affect the development of children's brain (Ghimire and Ariya 2020; Lenz *et al*, 2019; Olubanjo *et al.*, 2015; Khaliq *et al.*, 2014; Grant *et al.*, 2013) when the foliar parts of these plants are consumed or their extracts used as medicine.

Furthermore, comparing the analysis in this present study with other work that analyzed herbs and other edible leaves from different site, it was found that the highest mean concentration of Pb, 220.30 mg/kg, from this study, was extremely higher than, 5.680 mg/kg of Pb obtained in herbs commonly used in Poland (Kowalska 2021); 6.42 mg/kg of Pb found in aquatic plant species near an electronic waste open dumpsite in Thailand (Parkpoom *et al.*, 2022); 178 mg/kg of Pb found in leafy Vegetables at the vicinity of Warri refining and petrochemical company in Delta State (Patrick-Iwuanyanwu and Nwokeji 2018); 50.11 mg/kg of Pb found in analyzed medicinal plants (Luo et al., 2021); 0.41 mg/kg of Pb found in vegetables from contaminated soils from a typical mining city in Central China (Kowalska 2021); 0.14 mg/kg found in herbal plants sold in a major urban market in Southwest, Nigeria (Olusola *et al*., 2021);3.92 mg/kg of Pb found in traditional herbal preparations in Northeast Ethiopia (Meseret *et al*., 2020).

*Cadmium concentration:* The high mean concentrations of Cd in dumpsite soil could be as result of the dismantling and open burning of electronic components that contain Cadmium. These components include: printed circuit boards, semiconductor chips, printer's drum with toner, cathode ray tubes, batteries, SMD chip resistors (Lenz 2019; Khaliq et al., 2014; Grant et al., 2013). High exposures to concentrations of Cadmium could affects the renal bone (Frazzoli *et al.,* 2010), neonatal weight and length (Xu et al., 2015), shortens placental length, and may be involved in ageing (Lin *et al.,* 2013). It may also cause the irritation of the respiratory system; cause kidney disease (Lenz *et al.,* 2019; Khaliq *et al*., 2014; Grant *et al.*, 2013); mitochondrion damage, chemical modifications of DNA and histones (Frazzoli *et al.*, 2010) and different types of cancer (Lin *et al.,* 2013; Giuseppe et al., 2020). Extreme exposure to Cd causes itai-itai disease, characterized by the malfunctioning of the renal tubular which is connected to softening of the bones (osteomalacia) and atrophic kidney (Jayantaw *et al*., 2017). The result of Cd concentrations, 0.34 mg/kg, in the present study was lower than those presented in the literature; Parkpoom *et al.,* (2020) reported 2.170 mg/kg, Kowalska (2021) presented 3.55 mg/kg and Luo *et al.,* (2021) reported 6.20 mg/kg of Cd. Meanwhile, the Cd concentration of 0.230 mg/kg by Patrick-Iwuanyanwu and Nwokeji (2018) and 0.15 mg/kg by Wang *et al.,* (2021) were lower than the Cd concentration of the present study.

*Copper concentration:* These high concentrations of Cu observed in the results indicate Cu contamination which could be from the unfriendly and unhealthy environmental practices by the e-waste scavengers at the dumpsite such as burning of cables, wires and printed circuit boards. These parts of the e-waste are known to be made of Copper (Engwa *et al*., 2019; Olubanjo *et al.*, 2015; Grant *et al.,* 2013). High Copper concentrations in soil could cause reduction of the height and fresh weight of plants and subsequently results to low yield and quality of crops (Wei-Yang and Fu-Chiun 2019; Chiou and Hsu, 2019) and could cause the death of plants since plants scarcely survive in soils rich in Copper (Orji *et al.*, 2018). Ingestion of Copper via the consumption of the foliar parts of: *Pentodon pentandrus*, to promote lactation and as pain-killer (Burkill 2000)*; Cyclosorus dentatus, as* antibiotic and bacteristatic (Burkill 1985) and *Rhynchospora corymbosa* as green manure in farm (Burkill 1985); from the dumpsite could cause health hazards. Headaches, dizziness and irritation in the eye, nose and mouth are examples of such health hazards (Grant *et al.,* 2013). Long term accumulation of Copper causes liver, kidney or central nervous system toxicity (Taylor *et al.,* 2020). At high concentrations, Cu is linked with hepatic disorder, neurodegenerative especially when Cu homeostasis is disrupted (Gaetke *et al*., 2014). Ferenci and Ott (2019) reported that the Hepatic ATP7B protein controls Copper content in the entire body by mediating its excretion into bile or irreversible incorporation into ceruloplasmin. Hence, the dysfunction of the ATP7B protein leads to inability to excrete copper, resulting to its accumulation in the liver and extra hepatic tissues, causing Wilson's disease, which could be fatal when overlooked but curable when diagnosed (Ferenci and Ott 2019). The concentration of Cu, 480.14 mg/kg, in the present study was higher than 4.05 mg/kg (Wang et al., 2021); 34.01 mg/kg (Luo *et al*., 2021), 14.55 mg/kg (Olusola *et al.*, 2021) and 12.3 mg/kg (Meseret *et al.*, 2020) from other studies.

*Nickel concentration:* The results, implies that the consumption of the leaves of these plants as herbs and green-feed for animals may likely cause health hazards due to exposure to and accumulation of high concentrations of nickel in the samples analysed. The high concentration of Ni in the soil from the disposal site signifies that the site is polluted and streams from the unhealthy activities that go on at the disposal site. The Nickel concentrations obtained in other studies 0.05 mg/kg (Olusola et al., 2021); 2.53 mg/kg (Patrick-Iwuanyanwu and Nwokeji 2018), were lower than the concentration of Ni 58.63 mg/kg in this study. Generally, Nickel metal and its compounds are used in applications such as batteries of cell phones, stainless Steel and alloys for surface treatments of electronics, underlying coating when plating electronics with gold *and as* corrosion inhibitor (Xu *et al.*, 2015; Buxton *et al.,* 2019). The high concentrations of Ni in soil and plant from the e-waste site could be as a result of open burning of Nickel-Cadmium batteries and cathode ray tubes (Grant *et al.*, 2013) and printed circuit boards (Needhidasan *et al.,* 2014), since Nickel is used in the production of these parts of the electronic. Inhalation of high levels of Nickel can cause: allergy; cardiovascular and kidney diseases (Ferenci and Ott, 2019; Gaetke *et al.*, 2014); dermatitis of the fingers, hands and forearms (Taylor *et al.*, 2020; Buxton *et al.*, 2019); respiratory distress such as lung fibrosis, lung and nasal cancer (Olusola *et al*., 2021; Genchi *et al.*, 2020; Rodríguez & Mandalunis 2018); bronchial asthma (Kuntawee *et al.*, 2020) especially during dismantling of e-waste at the disposal site. Non-cancer respiratory, gastrointestinal (Giuseppe *et al*., 2020; Buxton *et al.,* 2019) and reproductive effects (Buxton *et al.*, 2019) may result at high exposures.

*Concentration of chromium:* From the result, *Pentodon pentandrus* and *Rhynchospora corymbosa* have been polluted with chromium, thus should neither be used as herbs to increase lactation in nursing mother nor ploughed into the soil during farming process, respectively. Chromium is used in the production of data tapes, disk, as anti-corrosion coatings and as pigments in many electrical and electronic products (Han *et al.*, 2019; Song and Li 2014; Grant *et al.*, 2013). The thermal combustion of these electronic components in the open air would lead to the release of Chromium into the environment. Exposures to Chromium through inhalation and ingestion of contaminated plants and food could cause: damage to DNA (Grant *et al*., 2013), dizziness, damage to nasal mucosa, stomach ulcer, convulsion and kidney damage (Hossini *et al*., 2016). Exposure by contact during dismantling can cause dermatitis with symptoms such as dryness, cracked and swelling skin; allergic and eczematous skin reactions (Zhang *et al.*, 2011) and other skin inflammations (Hossini *et al.*, 2016). Chromium (VI) can cause respiratory tract irritation (Kuntawee *et al.,* 2020), running nose, asthmatic conditions (bronchitis), and shortness of breath (Grant *et al.,* 2013; ATSDR 2012), liver damage, weakened immune systems, and nasal, sinus or lung cancer (Kuntawee *et al.*, 2020; ATSDR 2012). The highest Cr concentration, 29.17 mg/kg in this study was higher that the concentrations of 6.42 mg/kg (Parkpoom *et al*., 2022); 2.33 mg/kg (Patrick-Iwuanyanwu and Nwokeji 2018); 0.52 mg/kg (Buxton et al., 2019); 0.22 kg/mg (Wang *et al*., 2021) and 10.7 mg/kg (Meseret *et al*., 2020).

*Bio-accumulation factor:* The result shows that Cu had been trans-located from the soil into the leaves of *Pentodon pentandrus and Rhynchospora corymbs* while Cr was translocated from the soil into the leaves of *Rhynchospora corymbosa*. These show that *Pentodon pentandrus and Rhynchospora corymbosa* can serve as accumulators of Cu while only *Rhynchospora corymbosa* can be used as an accumulator of Cr. Hence these plants, *Pentodon pentandrus and Rhynchospora corymbosa* can be used to phyto-remediate Cu contaminated soils while *Rhynchospora corymbosa* can be used during the phytoremediation of soil contaminated with Cr.

*Estimated daily intake (EDI):* The results of the estimated daily intake (EDI) of Pb and Ni in *Pentodon pentandrus, Cyclosorus dentatus and Rhynchospora corymbosa,* indicate risks to the human health that is intolerable while the estimated daily intakes of Cd, Cu and Cr in all the herbs indicate tolerable risk to the health of the consumers.

*Hazard quotient, HQ:* The HQs of Pb in the three samples: *Pentodon pentandrus, Cyclosorus dentatus* and *Rhynchospora corymbosa*, from the e-waste disposal site, indicate that potential health effects will occur from the consumption and use of these plants as herbs and the risk is unacceptable. However, the HQ of Pb in *Talinum fruticosum shows* that no potential health effect is expected from the use of this plant. The HQs of Cd and Ni in all the plants analyzed point out that exposure to Cd and Ni were at levels not sufficient to cause any potential health effect after the consumption of these herbs. More so, the HQs of Cr indicate that Cr will cause a potential health effect from the use of *Rhynchospora corymbosa.* In addition, the HQ of Cu in all the plants tells that the use of the foliar parts of *Pentodon pentandrus* and *Rhynchospora corymbosa* as medicinal herbs has a potential health risk effect from exposure to Cu in these plants.

*Hazard index:* The results indicate that the cumulative health effects of the heavy metals after using each of the contaminated herbal samples would cause potential health hazard to the consumer at a level that is not acceptable.

The results of the average percentage contributory effects, implies that the health effect from Pb would be expressed more than the other heavy metals.

*Conclusion:* The present herbal investigation revealed that the five heavy metals under consideration critically reached and exceeded the concentration level for uncontaminated plants with the exception of Cd. *Pentodon pentandrus, Cyclosorus dentatus and Rhynchospora corymbosa* from the e-waste dumpsite, should not be used as herbs for the treatment of the eye in-case of conjunctivitis and as pain-killer by human nor grazed by animal. Therefore, there is a need to monitor the concentration and health risk of heavy metals in herbs from this e-waste disposal site regularly to prevent heavy metals contamination via consumption and use of the herbs.

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