**Bioremediation of Heavy Metal Containing Effluent with *Cymbopogon Citratus* (Lemon Grass) in Hydroponics**

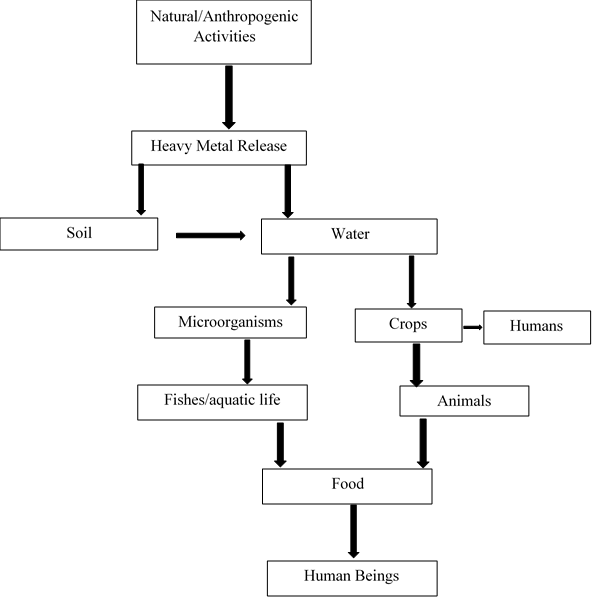
**ABSTRACT.**

Environmental pollution is no doubt a global problem. Heavy metals are pollutants of great concern. In this study, the heavy metal bioremediation potential of *Cymbopogon citratus* (lemon grass) was carried out. Four dilution concentrations of the effluent (100 %, TRT 1, 75% TRT 2, 50% TRT 3 and 25% TRT 4) were used hydroponically under greenhouse conditions to evaluate the uptake of chromium, copper cadmium and lead in a randomized block design. The uptake (P<0.05) of four heavy metals was studied and the concentration of chromium in effluent was reduced in the range of 65-98% across all the treatments, copper 6-69%, cadmium 12-46% and lead 42-83%. The bioaccumulation of chromium into the root of the plant was between 0.45-0.63 mg/kg and for the shoot 0.28-0.39 mg/kg, copper had 0.68-0.91 mg/kg for the root and 0.42 -0.57 mg/kg. Cadmium was concentrated about 0.14 -0.20 mg/kg for the root and 0.09-0.13 mg/kg. Lead was found within 0.34-0.43 mg/kg for the root and 0.18-0.26 mg/kg for the shoot. The Bio-concentration factor (BCF) of chromium, copper and lead were >1 and <1 for cadmium. Translocation factor (TF) for the four heavy metals were >1. There were significant reductions in some physico-chemical parameters (COD 79%), BOD (50%), Total solids (52%) and Electrical conductivity (10%). The results obtained from this study revealed that *Cymbopogon citratus* is a hyper accumulator plant and can be effective in the remediation of polluted systems with multiple heavy metals.

**KEYWORDS:** *Cymbopogon citratus*, Heavy metals, Physico-chemical parameters, Bioremediation, BCF, TF.

**INTRODUCTION**

The presence of heavy metals in wastewater is one of the major causes of water pollution (Kaur and Roy, 2020). Frequently, heavy metals get into the aquatic bodies through industrial effluents known as wastewater (Abdel-Razek *et al,* 2019). Heavy metals form a crucial constituent of inorganic pollutants (Khayatzadeh and Abbasi, 2010). The contamination of the water resulting from the presence of heavy metals has drawn a lot of concern publicly (Sobh *et al,* 2014). Subjection to heavy metals such as lead and cadmium is the major cause of hazard to human health (Zeitoun and Mehana, 2014). According to Verma and Dwivedi, (2013), toxic heavy metals make their way into the human bodies through the ingestion of contaminated food and water. Globally, heavy metals are considered the most principal pollutants disturbing both terrestrial and aquatic ecosystem by increasing geo-ecological imbalance and the alteration of the natural environment (Liu *et al,* 2003; Chabukdara and Nema, 2012).



**Figure 1. Heavy Metal Contamination Chain (Source: Self Diagrammatic Representation, 2025).**

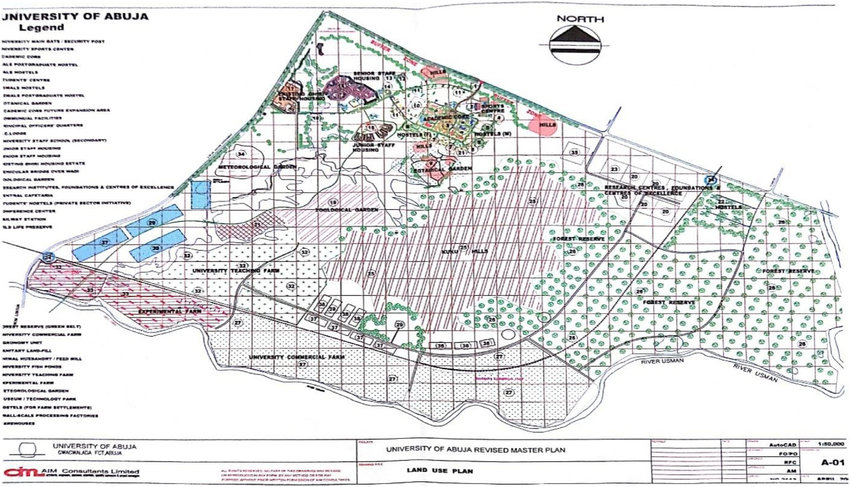
There is a great need for the restoration of water bodies and its resources that have been loaded with toxins such as the heavy metals (Bulgairu and Gravilescu, 2015). There comes a recent practice known as bioremediation that is employed in the eradication and possible recovery of heavy metals from contaminated ecosystems (Ayangbenro and Babalola, 2017). It is an arm of environmental biotechnology that involves the application of plants and other living organisms (e.g algae) in the decontamination of polluted environments by alleviating toxic waste (Sardrood *et al,* 2012; Singh *et al,* 2014).

Cymbopogon commonly known as lemon grass is a genus that belongs the poaceae family and exists as a highly significant essential oil producing plants that is made up of about one hundred and forty (140) species extensively disseminated around Asia, America and Africa in tropical regions and areas that have moderate temperature (Bhan *et al,* 2005; Anal, 2014; Shamsheer *et al,* 2020). It is a perennial plant that possesses partially branched roots developed above the earth surface belonging to the genus, Andropogon of the family of Poaceae known as Cymbopogon (Vaqar *et al*, 2007). Lemon grass according to Khilji and Sajid (2020) has been described as an herb with great economic value that is grown globally. Some of the attributes of lemon grass (*Cymbopogon citratus*) include; fast growth, large roots with great substiantiability and elevated biomass in comparism with other experimental grass species (Patra *et al,* 2020). Lemon grass possess economic significance and it is a globally grown herb with distinguishing characteristics which include; antioxidant, pharmaceutical application (anti-cancer agent), antimicrobic, remedy for heart related complications and pesticidal attributes (Kumar *et al,* 2008; Ogura *et al,* 2008; Figuerinha *et al,* 2010; Anand *et al,* 2011; Rajeswara *et al,* 2015). The polyphenol is an anti-oxidant contained in lemon grass which could be extracted and used for the treatment and avoidance of various ailments (Ogura *et al,* 2008). Terpenes, alkaloids and flavonoids are some of the compounds present in *Cymbopogon citratus* though the variety of compounds present is habitat dependent (Babarinde *et al,* 2016). It is of high notability that, the agrology of aromatic or redolent plants that are inedible including flowers in phytoremediation processes are not just advantageous but also practicable alternative in the prevention of toxicants in the food cycle (Lai *et al,* 2008a & 2008b). The biochar obtained from this plant after bioremediation has earlier been studied for its structural and chemical characteristics to help utilize its biomass for proper management (Sefatlhi et al, 2023). The threats that comes with the presence of heavy metal in the ecosystem doesn’t alter the oil production potentials of lemon grass because of its high tolerance to heavy metal toxicity (Patra *et al,* 2019) and also, the extracted oil is said not to contain the heavy metals that the said plants could have bio-accumulated (Zheljazkov *et al,* 2006). Lemon grass (*Cymbopogon citratus* DC stapf) has shown to exhibit high tolerance to heavy metal toxicity and can resist unfavorable ecological situations (Das and Maiti, 2009). Sobh *et al* (2014), has successfully carried out the study on the use of *Cymbopogon citratus* in the removal of Pb (II) ions from contaminated waters. Babrinde *et al* (2016), after their study came to the conclusion that, lemon grass has high potential for the sorption of metallic ions from polluted systems and presents an essential avenue for the uptake of heavy metals. Also, lemon grass has been utilized in the biosorption study of Cu (II), Ni (II) and Pb (II) (Zuo *et al,* 2012; Lee *et al,* 2014; Sobh *et al,* 2014). Khiliji and Sajid (2020), have also studied its phytoremediative potentials on Tannery waste. Its chromium bio-accumulation has also been investigated (Patra *et al,* 2020). Hydroponics as a word was coined out from two Greek words “hydro” which means water and “ponics” meaning workand was fundamentally launched by Dr. W.F. Gericke in the year 1936 with the aim of understanding the use of water and soluble nutrients in growing both decorative and consumable plants cultured in a liquid media (Upendri and Karunarathna, 2021). The hydroponic system is designed in such a way that the root mat is made to have direct contact with the wastewater via a root-biofilm network (Nayanathara and Bindu, 2017).

**MATERIALS AND METHODS**

**Study Area, Plant Sample and Effluent Collection.**

This study was undertaken in the university of Abuja main campus located in Abuja, Nigeria. The university of Abuja which is in Nigeria’s capital city lies between latitude 8o58’ north of the equator and longitude 7o10’ east of the Greenwich meridian.



**Figure 2. Map showing University of Abuja main campus. (Amarachukwu *et al*, 2020).**

Raw emulsion paint effluent sample was collected from a paint industry located at Madalla Zuba, Abuja, the Federal Capital of Nigeria. The Federal Capital (Abuja) is the capital city of the country, Nigeria and it is located at the Nigerian central with latitude 8o86’N to 8o95’N and longitude 7o18’E to 7o29’E with a population of about 1,406,239 (Nnodu *et al,* 2017).

*Cymbopogon citratus* (lemon grass) of uniform size was collected from a neighborhood in Gwagwaglada, FCT, Abuja, Nigeria. The plants were afterwards, left to acclimatize and established to their new environment for some time (Gupta *et al*, 2022). Plants with similar root length and shoot area were selected and after which, they were thoroughly washed under running tap water and then hydroponically propagated in a nutrient solution (Van Delden *et al*, 2020) for a period of about 14 days before being subjected to the effluent for the uptake study. 5 liters capacity pails were filled with different dilution factor (100%, 75%, 50% and 25%) of the effluent and were arranged in a complete randomized form under a greenhouse effect.

**Heavy Metal Determination and some Physico-Chemical Characteristics**

The heavy metal analysis for both effluent and plant sample was carried out using inductively coupled plasma modelled Agilent’s Microwave Plasma-Atomic Emission Spectrometer (MP-AES) model 4210. Total solid (TS) was carried out using Hach Laqua portable meter and UV Spectrophotometric method. Turbidity was determined using Hach 2100 portable turbidimeter. The analysis of COD followed Hach method 8000 and a 5 day BOD test method (APHA, 5210B) was conducted.

**Table 1. Experimental set up for the hydroponic growth of *Cymbopogon citratus*.**

|  |  |
| --- | --- |
| *Experimental Pots* | ***effluent Concentration/dilution*** |
| *Treatment 1 (TRT 1).* | 100% effluent |
| *Treatment 2 (TRT 2).* | 75% effluent dilution (25% effluent + 25% tap water). |
| *Treatment 3 (TRT 3).* | 50% effluent dilution (50% effluent + 50% tap water). |
| *Treatment 4 (TRT 4).* | 25% effluent dilution (25% effluent + 75% tap water). |

**Determination of Removal Efficiency (%) of the Test Plants**

Removal Efficiency was calculated using the following formula (APHA, 2012).

Removal Efficiency (%) = Ci - Ce x 100 …………………….. Equation I

Ci

Where;

Ci = initial concentration of the pollutant.

Ce = final concentration of the pollutant.

**Determination of the Bio-concentration Factor (BCF).**

The bio-concentration factor (BCF) was determined using the equation below by Cule et al (2006) and Yoon et al (2006).

BCF = b …………………………….. Equation II

a

Where; b = metal concentration in plants

a = metal concentration in the industrial wastewater

**Determination of Translocation Factor (TF)**

The translocation factor was calculated using the formula below (Kim and Kim., 1999).

Translocation Factor (TF) =Metal concentration in aerial parts x 100 Equation III

Metal concentration in roots

**Determination of Relative Growth Rate of the Test Plant.**

The formula below was used to calculate the relative growth rate (Aron, 1949).

Relative Growth Rate (RGR) = Ln W2 – Ln W1  ………… Equation IV

T2 – T1

Where;

W1 = initial weight of fresh biomass

W2 = final weight of the harvested biomass

T1 and T2 = the duration of the experiment in days.

**Statistical Analysis**

All values described were the means of the replicates. Microsoft excel was employed in the calculation of mean, standard error of mean, standard deviation and in the plotting of statistical graphs. Statistical Package for the Social Sciences (SPSS) version 25 for Windows was used. Descriptive statistics were employed. Kolmogorov-Smirnov-Test was used to check if the data were normally distributed. One-way Analysis of Variance (ANOVA) and Turkey Post Hoc Test were used to compare means between treatments and other parameters measured.

**RESULTS**

The study of the uptake of heavy metals (chromium, copper, cadmium and lead) from the paint effluent using *Cymbopogon citratus* was carried out for a period of 2 months under greenhouse hydroponic conditions using four (4) different dilution/treatments factor (100%, TRT 1, 75%, TRT 2, 50% TRT 3 and 25%, TRT 4).

**Uptake of Heavy Metals from Treatment 1 Paint Effluent by *Cymbopogon citratus*.**

In treatment 1 (TRT 1) the plant (*Cymbopogon citratus*) was inoculated with 100% of the effluent. The initial and final concentrations of chromium, copper, cadmium and lead after a period of 8 weeks (2 months) were recorded. Chromium concentration was reduced from 0.5 to 0.08 ppm. Copper was reduced from 0.3 to 0.2 ppm. Cadmium had initial concentration of 0.6 and final concentration of 0.3 ppm. For lead, the initial and final concentrations were 2.2 and 0.4 ppm respectively. The results obtained showed significant reductions in the concentrations of the heavy metals present in the paint effluent (Figure 3).

**Figure 3. Uptake of heavy metals from 100% paint effluent (TRT 1)**

**Uptake of Heavy Metals from Treatment 2 Paint Effluent by *Cymbopogon citratus*.**

Treatment 2 had 75% concentration of the effluent. Also, the uptake of four heavy metals was carried out for a period of 8 weeks. The initial and final concentrations of the analytes were examined with significant reductions in the concentrations of the heavy metals when compared with the initial concentrations. *Cymbopogon citratus* reduced the concentration of chromium from 0.44ppm to 0.09 ppm. Copper had initial and final concentrations of 0.31 and 0.21 ppm. Cadmium recorded 0.48ppm initial concentration and 0.34 ppm final concentration. The initial concentration lead was 1.67 ppm and the final level was seen at 0.37 ppm (Figure 4).

**Figure 4. Uptake of heavy metals from 75% paint effluent (TRT 2)**

**Uptake of Heavy Metals from Treatment 3 Paint Effluent by *Cymbopogon citratus***

This is the third treatment used in the heavy metal uptake study using the biomass of *Cymbopogon citratus*. The treatment 3 had 50% concentration of the paint effluent and the sorption study also lasted for a period of 8 weeks. Both the initial and final levels of the different heavy metals were analyzed. *Cymbopogon citratus* efficiently reduced the concentration of chromium from 0.25 ppm to 0.05 ppm, copper from 0.31 to 0.14 ppm. Cadmium level was reduced from 0.32 ppm to 0.28 ppm while the concentration of lead was reduced from 1.12 ppm to 0.68 ppm (Figure 5).

**Figure 5. Uptake of heavy metals from 50% paint effluent (TRT 3)**

**Uptake of Heavy Metals from Treatment 4 Paint Effluent by *Cymbopogon citratus***

This is the fourth and last treatment in this study and it had 25% concentration of the paint effluent. This also lasted for a period of 8 weeks with the analysis of both initial and final concentrations of the heavy metals just as the other treatments. Chromium was reduced from 0.22 ppm to 0.08 ppm. Copper and cadmium had initial concentrations of 0.23 ppm and 0.16 ppm while the final concentrations were 0.07 ppm and 0.10 ppm respectively. Lead had significant reduction from 0.56 ppm to 0.32 ppm (Figure 6).

**Figure 6. Uptake of heavy metals from 25% paint effluent (TRT 4)**

**Removal Efficiency of the Heavy Metals from the Paint Effluent by** ***Cymbopogon citratus***

The percentage removal efficiency of the heavy metals was evaluated for all the treatment at the end of the study. For treatment 1, chromium had the highest removal efficiency at 98%. Lead had the second highest removal at 83%. Cadmium and copper were reduced by 46% and 6% respectively. In treatment 2, the highest removal efficiency was observed for chromium at 86%. Lead, copper and cadmium recorded 78%, 30% and 27%. For the third treatment, the highest removal was for chromium at 77%. Lead (57%), copper (54%) and cadmium (12%). The treatment four went in the order; copper (69%), chromium (65%), lead (42%) and cadmium (33%) respectively (Figure 7).

**Figure 7. Removal Efficiency of the Heavy Metals by *Cymbopogon citratus***

**Bioaccumulation of the Heavy Metals unto the Root and Shoot of *Cymbopogon citratus***

The bioaccumulation of the four heavy metals in the root and shoot of the plant *Cymbopogon citratus* was evaluated and the results showed that all the heavy metals (chromium, copper, cadmium and lead) were more concentrated in the root than in the aerial parts of the plant at the end of the period of exposure. For treatment 1, Chromium in root and shoot were 0.63 mg/kg and 0.39mg/kg. Copper was seen at 0.83 mg/kg (root) and 0.52 mg/kg (shoot), cadmium concentrations in the root and shoot were 0.17 mg/kg and 0.10 mg/kg, lead had 0.43 mg/kg (root) and 0.27 mg/kg. In treatment 2, chromium roots (0.51 mg/kg) and shoots (0.32 mg/kg). Copper concentration in the root (0.73 mg/kg) and shoot (0.46 mg/kg). Cadmium for root was 0.14 mg/kg and 0.09 mg/kg for the shoot while lead had 0.34 mg/kg for the root and 0.21 mg/kg for the shoot. For treatment 3, chromium root and shoot concentrations were 0.47 mg/kg and 0.29 mg/kg. Copper root and shoot had 0.68 mg/kg and 0.42 mg/kg. For cadmium, the concentrations were 0.18 mg/kg and 0.10 mg/kg and lead had 0.40 mg/kg for the root and 0.26 mg/kg for the shoot. The last treatment which was treatment 4 had the root and shoot concentrations of chromium 0.45 mg/kg and 0.28 mg/kg. For copper, the root had 0.91 mg/kg while for the shoot was 0.57 mg/kg. Cadmium was seen at 0.20 mg/kg (root) and 0.13 mg/kg (shoot). Lastly, the concentration of lead in the root was 0.39 mg/kg and 0.18 mg/kg for the shoot (Figure 8).

**Figure 8. Bioaccumulation of the Heavy Metal in the Plant after Phytoremediation.**

**Bio-concentration Factor (BCF) of Heavy Metals in *Cymbopogon citratus***

To ascertain the phytoremediative potential of *Cymbopogon citratus,* the BCF was calculated and the values for each of the four treatments are presented in Table 2.

**Table 2. BCF of Heavy Metals in *Cymbopogon citratus*.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heavy Metals | TRT 1 | TRT 2 | TRT 3 | TRT 4 |
| Chromium | 1.52 | 1.22 | 1.00 | 1.00 |
| Copper | 1.64 | 1.49 | 1.41 | 1.54 |
| Cadmium | 0.90 | 0.73 | 0.60 | 0.49 |
| Lead | 2.90 | 2.25 | 1.78 | 1.14 |

**Translocation Factor (TF) Heavy Metals Root-Shoot of *Cymbopogon citratus***

The translocation factor (TF) of the four studied heavy metals from the root to the shoot of the *Cymbopogon citratus* was evaluated in this study and the results are presented in table 3.

**Table 3. TF of Heavy Metals from the Root to the Shoot of *Cymbopogon citratus.***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heavy Metals | TRT 1 | TRT 2 | TRT 3 | TRT 4 |
| Chromium | 160 | 159 | 160 | 160 |
| Copper | 160 | 160 | 162 | 160 |
| Cadmium | 160 | 159 | 178 | 155 |
| Lead | 216 | 164 | 162 | 159 |

**Relative Growth Rate (RGR) of *Cymbopogon citratus.***

The relative growth rate was evaluated for the plant in the different treatments in order to measure the growth index. At the end of the study, the RGR determined showed slight increase in the growth of *Cymbopogon citratus* in TRT 1 while the three other treatments had reduced growth (figure 9).

**Figure 9. Relative Growth Rate for *Cymbopogon citratus*.**

**The Biomass of *Cymbopogon citratus* after Study.**

At the start of the study, the initial weight of the plant was taken. All the treatments had the initial weight of 2kg each. The highest biomass after the study was observed in the treatment 1 which had the final weight of 2.1 kg. The control which was just tap water had the final weight of 2.01 kg. Treatments 2, 3 and 4 had the final concentrations of 1.9 kg; 1.8 kg and 1.6 kg respectively (figure 9).

**Effect of *Cymbopogon citratus* on the Physico-Chemical Parameters after the Study.**

The initial and final levels of the physico-chemical parameters were compared to see the effect of the test plant, *Cymbopogon citratus* on them. The data obtained showed significant reductions in the levels of the biochemical oxygen demand (BOD) from 216 mg/L to 107 mg/L, (COD) had initial and final concentrations of 602 mg/L and 254 mg/L. The Electrical conductivity (EC) concentration also dropped from 2618 mS/m to 2368 mS/m. However, there was slight increase in the concentration of Turbidity which rose from 5202 NTU to 5566 NTU (figure 7 a & b).

**Figure 10 a &b. Initial and Final Levels of the Physico-Chemical Parameters.**

The concentration of the total solids (TS) significantly dropped from 47829 mg/L to 22876 mg/L (figure 8).

**Figure 11. Initial and Final Levels of the Total Solids**

**DISCUSSION**

**Uptake of Heavy Metals from the Paint Effluent by *Cymbopogon citratus*.**

The final concentration of the effluent for the four heavy metals was carried out to determine the phytoremediative potential of *Cymbopogon citratus*. Four treatments (TRT 1, TRT 2, TRT 3 and TRT 4) with varying dilution factors (100%, 75%, 50% and 25% of the effluent) were used. At the end of the study, the highest removal that was obtained in TRT 1 was in the uptake of chromium which had a significant removal efficiency of 98%. While lead, cadmium and copper had 83%, 46% and 6% removal respectively. For TRT 2, a similar result to that in TRT 1 was obtained in which the highest removal efficiency was observed in the uptake of chromium at 86% followed by lead at 78%. Copper had the removal efficiency of 30% and the lowest removal obtained in TRT 2 was the uptake of cadmium which had 27% removal efficiency. In TRT 3, chromium also had the highest removal efficiency of 77%, lead 57%, copper 54% and cadmium 12%. For the last treatment, TRT 4, the uptake of copper from the media recorded the highest removal at 69%. Chromium, lead and cadmium had 65%, 42% and 33% respectively. Of late, research findings have brought to light the possibility of using *Cymbopogon citratus* (lemon grass) as a promising heavy metal accumulator and hence, its usefulness for the remediation of systems polluted with heavy metals (Israila *et al*, 2015; Gautam *et al*, 2017). The management of environmental pollution has become a compelling exigency that necessitates an economical approach and phytoremediation has come up with a novel and renewable dimension in handling the menace of environmental pollution particularly with that of heavy metals (Mukaka, 2018; Pandey, Verma and Singh, 2020). Plants have been used over the years for the purpose of phytoremediation of different effluents containing heavy metals. However, there are limited studies on the evaluation of *Cymbopogon citratus* and its potency in the phytoremediation of heavy metals containing wastes and also on paint-based effluents. *Cymbopogon citratus* has been reported in previous study to have significantly reduced the concentration of lead and cadmium in a media by 95% and 83% (Oguche, Agbo, Oyegoke and Emeniru, 2022). In addition, this plant revealed high potency in the accumulation of copper in its root system from an environment containing heavy metals and other toxic elements that are known to be harmful to the environment (Das and Maiti, 2009). Reports have shown that *Cymbopogon citratus* has been cultivated effectively on soils that were known to be polluted with heavy metals like lead and cadmium (Angelova, 2024). *Cymbopogon citratus* was able to bio-accumulate lead and nickel which suggests its suitability as phyto-extractor of some heavy metals and its recommendation to be grown on polluted sites with reduced risk of food change alterations as the essential oil found in the plant after growth on a polluted site was found to be within the permissible limit (Pandey *et al*, 2020). *Cymbopogon citratus* has been effectively utilized for the phytoremediation of mercury from contaminated water (Chavan *et al*, 2025). *Cymbopogon citratus* was selected for this study due to the aforementioned abilities and also, its resilience in growing in polluted environments. It has been reported that this plant could survive on a red mud soil and bio-accumulated chromium and vanadium and also, as it had been recognized to have outstanding ability in the refurbishment of polluted systems (Kaur *et al*, 2023; Fitranto *et al*, 2025). A submission has been drawn by Israila et al (2015) on the utilization of *Cymbopogon citratus* for the remediation of systems contaminated with heavy metals due to its potentiality as heavy metal (particularly, lead, nickel and cadmium) accumulator.

**Bioaccumulation of the Heavy Metals unto the Root and Shoot of *Cymbopogon citratus***

The bioaccumulation of the heavy metals (chromium, lead, cadmium and copper) unto the plant was evaluated and the results obtained from all the treatments showed that all the four heavy metals were more concentrated in the root of *Cymbopogon citratus* than in the aerial part of the plant. The highest concentration of chromium was observed in TRT 1 (0.63 mg/kg root and 0.39 mg/kg shoot). For copper, TRT 4 had the highest concentration of this element and it had 0.91 mg/kg (root) and 0.51 mg/kg (shoot). Also, TRT 4 showed the highest concentration of cadmium in the plant (root 0.2 mg/kg and shoot 0.12 mg/kg). Finally, the highest concentration of lead in the plant was observed in the TRT 1 at 0.43 mg/kg for the root and 0.28mg/kg for the shoot. The fundamental bearing part of the plants that is known for the maximum accumulation of metallic ions is the root system (Emamverdian *et al*, 2015). Similar observation has been made in a study carried out by Adeyeye et al (2007), it was reported that the heavy metals (cadmium, lead and copper) had higher concentration in the root than in the shoot. Conversely, chromium had a higher shoot concentration than in the root. A higher concentration of lead has been found in the root of *Cymbopogon citratus* than in the shoot (Mukaka, 2018). According to Paragamac and Bonghan (2019), plants have developed mechanism that helps in the absorption and movement of heavy metals to the different plant parts, this enables their survival and domination even when exposed to elevated levels of these toxicants. The confinement of the ions of the heavy metals in the cells of the root is a major contributing factor in the higher accumulation of these elements in the root system than in the aerial parts of the plant (Oliveira, 2010; Nematshahi, 2012).

**The Bio-Concentration Factor (BCF) and the Translocation Factor (TF)**

The BCF and TF were evaluated in this study. The BCF for chromium were >1 in TRT 1 and 2. Whereas, TRT 3 and 4 had the value of 1. For copper and lead, all the BCF values were above 1. However, cadmium BCF values were below 1. For the TF, the values in all the treatments for all the heavy metals were significantly >1. Significant TF and BCF of cadmium and lead has earlier been observed in the biomass of *Cymbopogon citratus* with TF value >1 for cadmium and lead and BCF value of <1 (Angelova, 2004). Also, TF value >1 has been observed for nickel and lead in *Cymbopogon citratus* (Pandey et al, 2020). Similarly, Pandey et al (2019), had earlier reported TF of >1 for lead and <1 for chromium and cadmium. On the other hand, BCF and TF values <1 has for heavy metal in *Cymbopogon citratus* been reported (Mukaka, 2018).

**Relative Growth Rate (RGR)**

The evaluation of the relative growth rate of *Cymbopogon citratus* was done at the end of the study period. There was a slight growth of the plant in the control pot and the TRT 1 with biomass increase from 2kg each to 2.01kg and 2.10 kg respectively. However, for the *Cymbopogon citratus* in the TRT 2, TRT 3 and TRT 4, there was reduced growth and also reduced biomass from 2kg to 1.9 kg (TRT 2), 1.8 kg (TRT 3) and 1.6 kg (TRT 3). For the length of the plant, no obvious change was observed as they all had a uniform initial length of 24 cm and also final length of 25 cm (control), 25.5 cm (TRT 1), 24.9 cm (TRT 2), 24.1 cm (TRT 3) and 24.0 cm (TRT 4). As observed during the pot trials, the plant seemed to be growing fine after the first few days of exposure, however, after the few weeks, some of the leaves started fading accompanied by changing from green to yellow and became brownish. Stressful conditions have been observed in *Cymbopogon citratus* grown on tannery sludge have been linked to the high levels of heavy metals that was present (Khilji and Sajod, 2020). Also, reduced root and shoot and the total plant biomass of *Cymbopogon citratus* grown on a fly ash amended soilhas been documented (Panda *et al*, 2018). According to Kulsoom et al (2024), there were inhibitions in the physiological activity of the plant that was exposed to cadmium. One of the harsh effects of toxic metals can be abrupt disturbance in the root physiology which can hinder the ingestion and mobility of essential enrichments in the plant and as a result impacting the total biomass of the plant (Boonya-Pookana *et al*, 2005). Additionally, the presence of these toxic metals in the plant may lead to hindrances in the photosynthetic ability and the activities of enzymes and other normal biological processes that occur in plants (Khilji and Sajid, 2020). Maksymiec (2007), is of the opinion that, *Cymbopogon citratus* (lemon grass) have the potential of bioaccumulating smaller levels of heavy metals as extremely high concentrations may result to fatality of the plant.

**Effect of *Cymbopogon citratus* on the Physico-chemical Parameters of the Paint Effluent.**

The initial and final levels of the physico-chemical parameters of the effluent were evaluated to check if the plant has the potential in bringing about changes in the levels of these parameters. The result obtained shows that *Cymbopogon citratus* was able to significantly reduce the concentrations of chemical oxygen demand (COD) by 79%, Total solids (TS) by 52%, biochemical oxygen demand (BOD) by 50% and Electrical conductivity (EC) by 10%. There was however, a slight increase in the concentration of the effluent’s turbidity. A similar result of removal efficiency *Cymbopogon citratus* for COD (525-83%) and TS (93%-97%) has been reported (de Nosari *et al*, 2021). Additionally, *Cymbopogon citratus* showed the highest removal efficiency of 82% for BOD among other plants in a study carried out by Adonadaga et al (2020).

**CONCLUSION**

The aim of the present study was to check for the heavy metal bioremediative potential of *Cymbopogon citratus.* The data obtained from this study has revealed that *Cymbopogon citratus* has high potential in the uptake of heavy metals (cadmium, lead, copper and chromium). Also, the BCF for values for all the heavy metals aside for cadmium were seen >1 and TF values for heavy metals across all the treatments were all >1 which suggests that *Cymbopogon citratus* is a hyper-accumulator plant.

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3.

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