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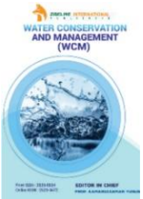

RESEARCH ARTICLE

PHYTOREMEDIATION OF CADMIUM POLLUTANTS IN WASTEWATER BY USING CERATOPHYLLUM DEMERSUM L. AS AN AQUATIC MACROPHYTES

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ABSTRACT

The current study carried out a test of phytoremediation for the removal of cadmium Cd pollutants, which is one of the most important heavy metal pollutants in the aquatic environment, by using the submerged *Ceratophyllum demersum* L., as one of the aquatic macrophytes which is commonly named coon tail or rigid hornwort, and evaluating its effectiveness in phytoremediation of cadmium Cd pollutants from different sources of wastewater under the current study which includes Cooling Electric Generators (CEG), Domestic Sewage Water (DSW), and Washing and Lubricating Cars (WLC). 15 random water samples were collected during February and March of 2021, with 3 replicates for each sample. *C. demersum* (9) plant samples were also randomly collected in 2021, with three replications. A sampling of plants included withdrawing the entire plant (roots-like, stems-like and leaves-like branchlets) with an amount of river water. It was found from the current study that the best values for Cd removal were observed during the fifteenth and twelfth days of the aquaculture durations which were represented by the lowest values of Cd concentrations as 7.9 ± 4.3 µg/L and 31.5±20.2 µg/L respectively, while the worst values for Cd removal were showed during the third and sixth days of the aquaculture durations which represented by the highest values of Cd concentrations as 86.9±40.8 µg/L and 38.6±19 µg/L respectively. The best significant abilities of *C. demersum* L. to reduce Cd levels were in aquaculture treated with (CEG) wastewater as about 97.9%, 94.1%, and 91.3 % during 15, 12, and 9 respectively days of aquaculture durations followed by removal percentages in aquaculture treated with (DSW) as 92% and 89.0% during 15 and 6 respectively days of aquaculture durations and (WLC) wastewater, as 85.3% in the fifteenth day of aquaculture durations. These results mean that *C. demersum* probably has contributed to high phytoremoval rates for Cd pollutants from its *in vitro* polluted aquaculture, especially in the late durations of aquaculture durations. It was also found that the highest accumulation levels for Cd were in the tissues of leaves-like, which were about 189.9±74.7 µg/g, followed by tissues of roots-like, as about 133.2±65.4 µg/g, while the lowest values were in the tissues of stems-like, as about 72.9±28.8 µg/g. The best significant cumulative adsorption percentage values for Cd in leaves-like tissues of *C. demersum* L. were ascending as about 81.1%, 80.3%, **78.7**%, and **75.9**% during 15, 12, 9, and 6 respectively days of aquaculture durations followed by percentage values for Cd adsorption percentage in roots-like as 74.7% and 73.5 % during 15 and 12 respectively days of aquaculture durations. The less significant cumulative adsorption percentage value for Cd in stems-like tissues of *C. demersum* L. was 11.8% followed by 32.5% in roots-like during the third day of the aquaculture duration. These results mean that cumulative tissue adsorption for Cd particularly tends to concentrate progressively more in leaves-like tissues than in the roots-like of *C. demersum*, and tends to be less concentrated in the stem-like internodes of these submerged aquatic plants.

KEYWORDS

Phytoremediatio, heavy metals, cadmium, Cd, *Ceratophyllum demersum*, coon tail, rigid hornwort, submerged, aquatic Macrophytes

1. INTRODUCTION

Natural sources of heavy metal pollution include erosion, weathering of rocks, and volcanic eruptions, the parent material during weathering is the primary natural source of heavy metals (El-Gammal et al., 2014; Ali et al., 2020). Cadmium contamination has been observed in groundwater and soil all over the world (Chellaiah , 2018).Inputs of heavy metals to agricultural land through excessive use of fertilizers raise concerns about their potential risks to the environment (Czarnecki and Düring ,2015).Cadmium is highly bio-persistent but has toxic effects and remains present for many years in the environment even after it has been consumed by living organisms (Haider et al., 2021). Cadmium is an impurity found in the components of refined petroleum products that has the potential to move to the food chain and is often toxic to biota (Grant,2011). Heavy metals can move up the food chain and so can increase their levels through biological magnification (Cardwell et al., 2002; Jawad et al., 2018) .Cadmium has toxic effects on the kidneys, skeletal system, and respiratory system, Prolonged exposure to cadmium may lead to respiratory failure, acute pneumonitis with pulmonary edema, which may be fatal (WHO, 2010; Dogan et al., 2018). Cadmium and its compounds are classified as Group I carcinogens to humans by the International Agency for Research on Cancer (IARC) (Attia et al., 2022; Mahmoud et al., 2018). Cadmium has harmful and toxic effects on plants, as is the case with animals and humans (Nagajyoti et al., 2010). Exposure to cadmium in plants causes severe damage such as slowing growth, yellowing of the leaves due to the decomposition of chlorophyll pigment,

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browning of the tops or ends of plant roots, and death. Cadmium can also inhibit photosynthesis by stopping chlorophyll biosynthesis (Nagajyoti et al., 2010; Dogan et al., 2018).

The removal of toxic pollutants from water sources is extremely important to reduce the risk to human health and the surrounding environment, Removal of heavy metals through various techniques has been studied such as reverse osmosis, ion exchange, chemical precipitation, adsorption, and solvent recovery (Al-Alawy and Salih, 2017; Levchuk et al., 2018; Huang et al., 2017; Burakov et al., 2018). These traditional techniques for the treatment of heavy metals in aquatic sources were generally costly and time-consuming (Ali et al., 2020), and are usually not environmentally friendly (Huang et al., 2017), and in the end often generate another or additional problem related to the disposal of sludge resulting from the use of these traditional methods in Processing (Grandclément et al., 2017). The most common heavy metals found in wastewater are arsenic, cadmium, chromium, copper, lead, nickel, and zinc, all of which pose risks to human health and the environment (Kastratović et al., 2016; Mahmoud et al., 2018).

Removal of cadmium by crop harvesting is a possible cause of low soil cadmium enrichment (Kubier et al., 2019). While in order to treat wastewater contaminated with heavy metal pollutants, an environmentally friendly and economical treatment technology is needed (Shahid et al,2018). Recently, phytoremediation has emerged as an alternative process in the treatment of polluted water, sediment, and soil, this sustainable technology uses plants to remove toxic or unwanted heavy metals from polluted media (Singh et al., 2012; Rashid et al., 2022). It was found that the effluent from waste water can be mitigated by aquatic plants, causing less damage to the surrounding environment and that there is a wide range of aquatic plants such as water hyacinths, water lettuce, duckweed giant which showed tremendous ability on the phytoremediation of several types of wastewater (Rodríguez and Brisson, 2015). Macrophytes are immutable biological filters that purify water bodies by accumulating dissolved minerals and toxins in their tissues; It is also relatively inexpensive and environmentally friendly (Singh et al., 2012). Aquatic plants remove heavy metals by adsorption or through surface adsorption and incorporate them into their system, thereby accumulating them into specific polymorphs (Sas-Nowosielska et al., 2008; Ali et al., 2020). Examples of well-known floating and submerged plants for phytoremediation of metal pollutants are *Potamogeton malaianus* and *Potamogeton pectinatus*, *Eichhornia crassipes* and *Pistia stratiotes*, *Ceratophyllum demersum*, all of which have the ability to accumulate zinc. , chromium, iron, copper, cadmium, nickel, mercury, and lead in their tissues (Peng et al., 2008; Victor et al., 2016; Borisova et al., 2014; Dogan et al., 2018; Mahmoud et al., 2018; Sas-Nowosielska et al., 2008; Casagrande et al., 2018; Dogan et al., 2018; Jawad et al., 2018; Peng et al., 2008). Phytoremediation in the aquatic ecosystem is a cost-effective and resourceful cleaning technique for phytoremediation of highly polluted aquatic areas, as aquatic plants act as natural adsorbents for pollutants and heavy metals in aquatic ecosystems (Ali et al., 2020).

The purpose of the current study is to treat wastewater contaminated with heavy metal pollutants, specifically cadmium, from various sources, including (CEG),(DSW), and (WLC) wastewater by using an environmentally friendly removal technique, which is phytoremediation, to remove cadmium pollutants on Long-term through the use of *Ceratophyllum demersum* L. which is commonly named coon tail or rigid hornwort ,as one of the submerged an aquatic macrophytes and evaluation of its effectiveness in the bioremediation of cadmium pollutants.

2. MATERIALS AND METHODS

2.1 Studied Area

The current study included different locations in Diyala Governorate/Iraq, including residential and industrial areas for the purpose of drawing random samples of polluted wastewater resulting from the Cooling Electric Generators (CEG), Washing and Lubricating Cars (WLC), and Domestic Sewage Water (DSW). The study also included collecting samples of *Ceratophyllum demersum*, which is an aquatic macrophyte , were collected from Diyala River passing through Baquba District / Diyala Governorate, which is confined between latitudes (33.70º and 33.78º) (Al-Yaqoubi and Ahmed,2000) .

2.2 Sampling and Growing Of *C. Demersum* L. *in Vitro*

Aquatic plants were collected randomly as 9 samples with three replications in 2021, Plant modeling included drawing the whole plant (roots-like, stems-like and leaves-like branchlets) with some water of river water, and special clean and sterile glass bottles 2 L were used, Samples were taken according to standard methods used by (Carroll et al,2002). They were washed gently in distilled water for several times and grown in 500 ml glass bottles filled with Allen and Arnon's solution as a half strength nutrient medium with a pH of 7.0 and a temperature of (29 °C ± 2) about four weeks and replaced after every 3 days (Marín and Oron,2007).

2.3 Sampling of Polluted Wastewater

About 15 polluted wastewater samples were collected randomly from modeling sites included the wastewater resulting from the Cooling Electric Generators (CEG), Washing and Lubricating Cars (WLC), and Domestic Sewage Water (DSW), during February and March of 2021, with 3 replications for each sample. Samples were taken using clean and sterile 1 L plastic bottles, Samples were taken according to standard methods used by (Khudhair et al., 2020).

2.4 Culturing of *C. Demersum* L. in Polluted Aquacultures *in Vitro*

The plant was removed from the nutrient medium and washed gently with deionized distilled water, and then parts of the *C. demersum* L. similar in terms of the ratio of roots-like and leaves-like branchlets were collected and the number of nodes was determined by about 5 stem-like nodes for each plant. The cut plant parts were cultured in aqueous samples of diluted polluted wastewater with Allen and Arnon's solution in a ratio (1:4) by using clean, dry, glass bottles 500 ml after measuring the cadmium concentration in them. Cadmium levels were measured in the cultures of plants in polluted water once every three days for a duration of 15 days.

2.5 Determination of Residual Cadmium in Polluted Aquacultures

According to the modified method described for the spectroscopic determination of cadmium in aqueous media by using Alizarin Red S Solution, 1. 39 $\times 10^{-3}$ M was followed according to (Ullah and Haque, 2010). Alizarin Red S reagent was prepared by dissolving the required amount of about 0.3 g of alizarin red S (1, 2-dihydroxyanthraqui-none-3-sulphonic acid, sodium salt) in 100 mL of deionized water. The modified method included adjusting the pH of 1 ml from aqueous sample solution to pH:6 (neutral), followed by adding 1 ml of Alizarin red S reagent solution (1.39 $\times 10^{-3}$ M) and mixed using a shaker for two minutes. Followed by the addition 1 ml of 0.05 M sulfuric acid (or pH 5.5 - 6.1) and left for one minute. The mixture was diluted up to the mark on the cuvette. The absorbance was measured at 422 nm against the Planck device. The residual cadmium concentration was determined using a calibration curve prepared simultaneously by using stock solution (1 mg/ mL) of divalent cadmium which was prepared by dissolving 0. 2 mg of cadmium sulfate (Merck) in deionized water and aliquots from this solution were standardized by EDTA titration using xylenol orange as indicator. More dilute standard solutions were prepared by appropriate dilution of aliquots from the stock solution with de-ionized water as and when required.

2.6 Determination of Adsorbed Cadmium in Plant Tissues

Plant tissues were digested following the method described by Allen et al. (Akinola et al., 2008). 3 grams of plant tissue powder are weighed into a conical flask. Drop by adding 3 ml of 60% hydrochloric acid and 10 ml of 70% nitric acid. The mixture was then heated on a hot plate for digestion until the white smoke from the conical flask turned brown. Then, it was allowed to cool and filtered with Whatman filter paper, and the filtrate was diluted to 50 ml with distilled water and kept for further analysis. Cd contents were measured in digested plant tissue samples using an atomic absorption spectrometer (PerkinElmer-3100-AAS).

2.7 Statistical Analysis

Data were subjected to statistical analysis which was carried out according to the Completely Randomized Block Design (CRBD) and the Completely Randomized Design (CRD) at a significant level of 0.05 (Al-rawi, 2000)., using the SPSS version 22 of 2019.

3. RESULTS AND DISCUSSION

According to the average values of the Optical Density (OD) absorbance readings and the corresponding standard cadmium concentrations μg/L, which were obtained by following the colorimetric method of Alizarin red S reagent (Ullah and Haque, 2010). An equation of slope was derived from the standard curve as shown in Figure 1, to convert the absorbance readings to the real value of residual cadmium concentration in experimental samples.

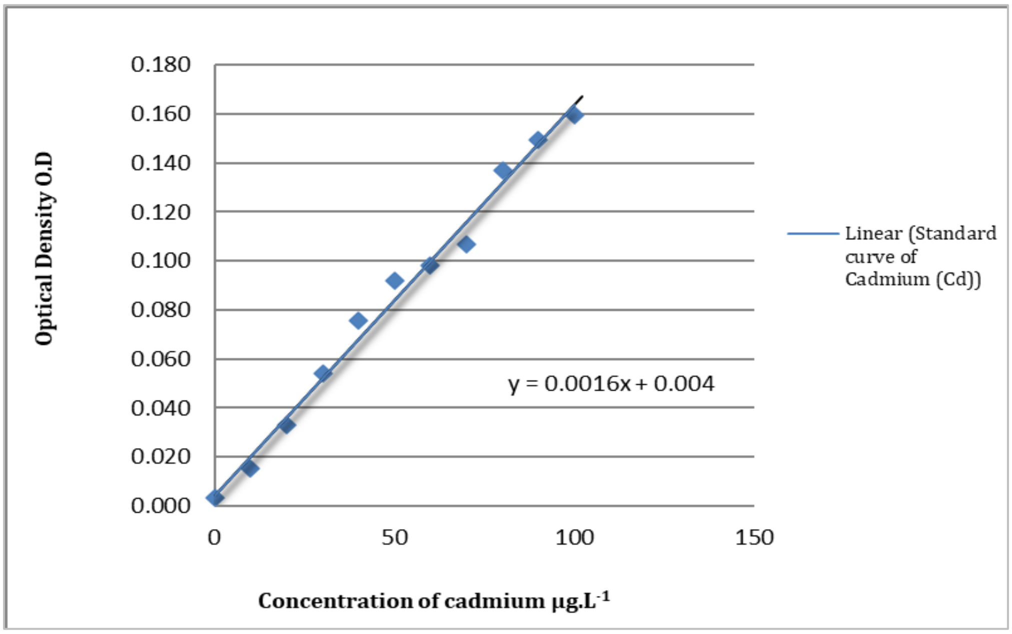

Figure 1: Standard curve of Cadmium Cd (µg.L-1)

3.1 Residual Cadmium in Polluted Aquacultures of *C. Demersum*

After conducting the statistical analysis of the values shown in Table 1, it was found that there were no significant differences in the residual cadmium concentrations in concern the quality of polluted wastewater used in the aquaculture of *C. demersum* L., and it was shown from the current study that the lowest values for the residual Cd levels were in the aquacultures treated with (WLC) wastewater, which about (43.6 ± 19.3) µg/L, followed by aquacultures treated with (DSW) wastewater, which about (59.4 ± 51.4) µg/L, while the highest values for the residual Cd were in aquacultures treated with (CEG) wastewater, as (60.2 ± 65.8) µg/L. These results may be consistent with what was mentioned in scientific research on the use of aquatic macrophytes in the purification of wastewater sources contaminated with heavy metals, including the use of the submerged *Ceratophyllum sp.* plant to remove heavy metals and it can be a biological filter for heavy metals (Fawzy et al., 2012; Matache et al., 2013).

On the other hand, the statistical analysis showed significant differences in the values of the rates for residual cadmium concentrations during the different aquaculture durations under study to test the capabilities of *C. demersum* L. in the phytoremediation of cadmium pollutants compounds present in the wastewater used in its aquacultures. The best values for Cd removal were observed during the fifteenth and twelfth days of the aquaculture duration which represented by the lowest values of Cd concentrations as (7.9 ± 4.3) µg/L and (31.5±20.2) µg/L respectively, while the worst values for Cd removal were showed during the third and sixth days of the aquaculture durations which represented by the highest values of Cd concentrations as (86.9±40.8) µg/L and (38.6±19) µg/L respectively, and as shown in Figure 2, the best significant abilities of *C. demersum* L. to reduce Cd levels were in aquaculture treated with (CEG) wastewater as about 97.9%, 94.1%, and 91.3 % during 15, 12, and 9 respectively days of aquaculture duration followed by removal percentages in aquaculture treated with (DSW) as 92% and 89.0% during 15 and 6 respectively days of aquaculture duration and (WLC) wastewater, as 85.3% in the fifteenth day of aquaculture duration.

These results mean that *C. demersum* probably has contributed to high phytoremoval rates for Cd pollutants from its *in vitro* polluted aquacultures, especially in the late durations of aquaculture, This generally corresponds to what was recorded about the description of heavy metals as an event that is dependent on duration and concentration-dependent and in particular consistent with what was mentioned previously that the concentrations of Cd and Pb in the *C. demersum* increased with increasing exposure concentration and duration (Mazzei et al., 2013; Chen et al., 2015; Dogan et al., 2018). And from another side, as shown in Figure 2, the less significant abilities of *C. demersum* L. to reduce Cd levels were in aquaculture treated with (WLC) and (CEG) wastewater as about 6.9% and 10.8% respectively during the third day of aquaculture duration followed by removal percentages in aquaculture treated with (WLC) as 27.4%. These results mean that *C. demersum* as an aquatic submerged macrophyte may require an appropriate adaptation period during the early duration of aquaculture to bear the toxicity of high Cd concentration (Rai et al., 2003; Nagajyoti et al., 2010), especially in (WLC) and (CEG) wastewater, on its vital activities represented in the development of a suitable semi-root and semi-foliar system in terms of negatively charged adsorption sites on the walls of its plant cells to accommodate the adsorption and uptake of Cd pollutants. And these results agree with earlier reports (Matache et al., 2013; Victor et al., 2016; Ali et al., 2020) in terms of its resistance to Cd toxicity on the one hand or the large number of sites charged with an active negative charge on parts of the plant immersed in water on the other hand. So the results obtained through the current study are consistent with previous studies which indicated that those plants immersed in water have the ability to remove heavy metals from water and mud sediments (Jawad et al., 2018; Ismael et al., 2019).

Table 1: Residual Concentration of Cadmium Mg/L In Aquacultures of *C. Demersum* L. Treated with Polluted Wastewater.

Wastewater in Aquaculture	**Cd residual concentration (µg/L)**						**mean ± standard deviation**
	Aquaculture duration (day)						
	0	**3**	**6**	**9**	**12**	**15**	
Cooling Electric Generators (CEG)	**150.0**	**133.8**	**52.5**	**13.1**	8.8	3.1	60.2±65.8
Domestic Sewage Water (DSW)	**153.7**	**67.5**	**16.9**	**59.4**	47.5	11.3	59.4±51.4
Washing and Lubricating Cars (WLC)	**63.8**	**59.4**	**46.3**	**44.4**	38.1	9.4	43.6±19.3
mean ± standard deviation	123±50.9	86.9±40.8	38.6±19	38.9±23.6	31.5±20.2	7.9±4.3	54.4±47.2
CRBD-ANOVA-TABLE	P.value $_{(\alpha\ 0.05)\ (2\ ,\ 15)}$ = 3.66			F = 2.16	Differences in aquaculture wastewater L.S.D.$_{(\alpha\ 0.05)(15)}$ = 60.87		
	P.value $_{(\alpha\ 0.05)\ (5\ ,\ 12)}$ = 3.11			F = 5.70*	Differences in aquaculture durations L.S.D.$_{(\alpha\ 0.05)(12)}$ =84.34		

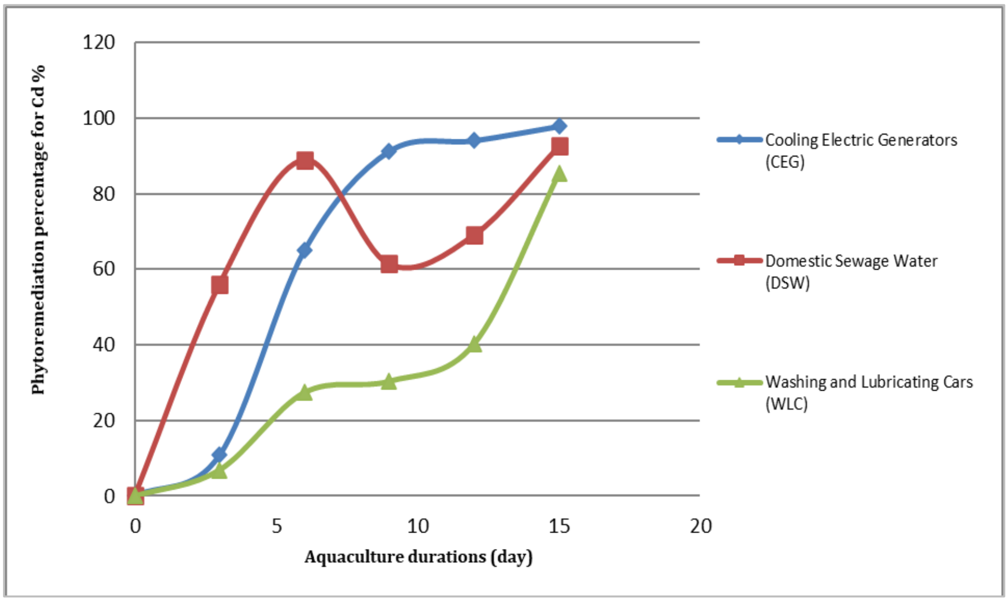

Figure 2: Phytoremediation percentage for Cd %in aquaculture of C. demersum L. treated with polluted wastewater.

3.2 Adsorbed Cd in Plant Tissues of *C. Demersum* Grown in Polluted Aquacultures

As shown through the statistical analysis of the table Table 2, it was found that there were significant differences in the accumulated Cd concentration values in plant tissues under the current study of *C. demersum* L., which grew *in vitro* by polluted aquacultures. It was observed that the highest values of the tissue accumulation levels for Cd were in the tissues of leaves-like, which were about (189.9±74.7) µg/g, followed by tissue of roots-like, as about (133.2±65.4) µg/g, while the lowest values were in the tissues of stems-like, as about (72.9±28.8) µg/g. These results may be agreement that aquatic plants remove heavy metals via absorption or through surface adsorption and integrate them into their system, and then accumulate them in certain bounded forms (Sas-Nowosielska et al., 2008) and aquatic plants always develop an extensive system of roots that helps them and makes them the best option for the accumulation of contaminants in their roots and shoots (Victor et al., 2016 ; Ali et al., 2020). It may also confirm that submerged *C. demersum* are aquatic macrophytes that are unchangeable biological filters and they carry out purification of the water bodies by accumulating dissolved metals and toxins in their tissue; also relatively inexpensive and eco-friendliness (Singh et al., 2012; Mahmoud et al., 2018).

Table 2: Cadmium Concentration Mg/G Dry Wet in Plant Tissue of *C. Demersum* L. Treated with Polluted Wastewater.

Plant tissues	**Cd concentration** (µg/g dry wet)						**mean ± s.d**
	Aquaculture duration (day)						
	0	**3**	**6**	**9**	**12**	**15**	
Leaves like	**47.5**	**180.0**	**196.9**	**222.5**	241.3	251.3	189.9±74.7
Stems like	**38.1**	**43.2**	**72.5**	**80.0**	89.4	114.4	**72.9±28.8**
Roots like	**54.4**	**80.6**	**110.0**	**134.4**	205.0	215.0	133.2±65.4
mean ± s.d	46.7±8.2	**101.3±70.7**	126.5±63.8	145.6±71.9	178.6±79.3	193.6±70.9	132.0±73.4
CRBD-ANOVA-TABLE	P.value $_{(\alpha\ 0.05)\ (2,15)}$ = 3.66			F = 5.867* Differences in plant tissues L.S.D. $_{(\alpha\ 0.05)(15)}$ = 73.91			
	P.value $_{(\alpha\ 0.05)\ (5,12)}$ = 3.11			F = 20.04* Differences in aquaculture durations L.S.D. $_{(\alpha\ 0.05)(12)}$ = 117.77			

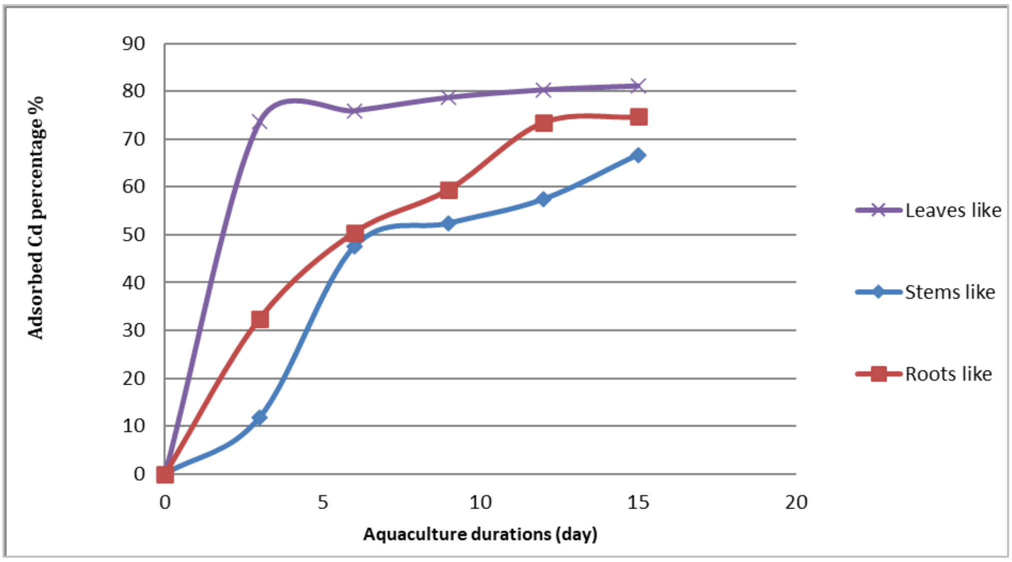

Figure 3: Adsorbed Cd percentage % in plant tissue of C. demersum L. treated with polluted wastewater.

It was clear too by statistical analysis there were significant differences in the values of accumulation levels for Cd in plant tissues of *C. demersum* L. within polluted aquaculture durations under study. The highest values for adsorbed Cd levels were observed during the fifteenth and twelfth days of the aquaculture durations which were about (193.6±70.9) µg/g and (178.6±79.3) µg/g respectively, while the lowest values were observed in the third and sixth of the aquaculture durations as (101.3±70.7) µg/g and (126.5±63..8) µg/g respectively, and as shown in Figure 3, the best significant cumulative adsorption percentage values for Cd in leaves-like tissues of *C. demersum* L. were ascending as about 81.1%, 80.3%, 78.7%, and 75.9% during 15, 12, 9, and 6 respectively days of aquaculture durations followed by percentage values for Cd adsorption percentage in roots-like as 74.7% and 73.5 % during 15 and 12 respectively days of aquaculture durations.

From the above results, it was clear that cumulative tissue adsorption for Cd particularly tends to concentrate progressively more in leaves-like tissues than in the roots-like of *C. demersum* , especially during the late durations of aquaculture for its polluted *in vitro* aquacultures. And this is consistent with what was recorded by (Chen et al., 2015) and it also may have agreed with what was referred to as the role of leaves or leaves-like branches providing an increase in the surface area exposed to the cumulative adsorption of Cd (Rai,2009). And from another side and as shown in Figure 3, the less significant cumulative adsorption percentage value for Cd in stems-like tissues of *C. demersum* L. was 11.8% followed by 32.5% in roots-like during the third day of the aquaculture duration. This result means that cumulative tissue adsorption for Cd tends to be less concentrated in the stem-like internodes of submerged aquatic plants, Perhaps the reason for this is due to the tendency of heavy elements, including Cd, to accumulate and store in cell walls, vacuoles, and intercellular spaces as mentioned in a structural study by (Sharma and Dubey,2005), so the increase in the size of cortical tissues of internodes in stems-like may play a role in raising the resistance of plants to solute flow (DalCorso et al., 2008; Ismael et al., 2019), hence reduce the chance for adsorption and storing of Cd in those portions.

4. CONCLUSION

It was found that there were significant differences in the values of the rates for residual Cd concentrations during the different aquaculture durations under study, The best values for Cd removal were observed during the fifteenth and twelfth days of the aquaculture duration which represented by the lowest values of Cd concentrations, while the worst values for Cd removal were showed during the third and sixth days of the aquaculture durations which represented by the highest values of Cd concentrations. So *C. demersum* which is commonly named coon tail or rigid hornwort probably has contributed to high phytoremoval rates for Cd pollutants from its *in vitro* polluted aquaculture, especially in the late durations of aquaculture periods. And *C. demersum* as an aquatic submerged macrophyte may require an appropriate adaptation period during the early duration of aquaculture to bear the toxicity of high Cd concentration, especially in (WLC) and (CEG) wastewater.

It was found also that there were significant differences in the accumulated Cd concentration values in plant tissues under the current study of *C. demersum* L., which grew *in vitro* by polluted aquacultures. It was observed that the highest values of the tissue accumulation levels for Cd were in the tissues of leaves-like, followed by tissue of roots-like, while the lowest values were in the tissues of stems-like. And there were significant differences in the values of accumulation levels for Cd in plant tissues of *C. demersum* L. within polluted aquaculture durations under study. Where the highest values for adsorbed Cd levels were observed during the fifteenth and twelfth days of the aquaculture durations, while the lowest values were observed in the third and sixth of the aquaculture durations. It was clear that cumulative tissue adsorption for Cd particularly tends to concentrate progressively more in leaves-like tissues than in the roots-like of *C. demersum* , especially during the late durations of aquaculture durations for its polluted *in vitro* aquacultures. Further, the less significant cumulative adsorption percentage value for Cd in stems-like tissues of *C. demersum* L. was on the third day of the aquaculture duration, this result means that cumulative tissue adsorption for Cd tends to be less concentrated in the stem-like internodes of submerged aquatic plants.

ACKNOWLEDGEMENTS

Based on the aforementioned results, the current study recommends using *C. demersum* L., which is an aquatic macrophyte in phytoremediation to purify wastewater sources polluted with heavy metals and it could be a good biological filter for heavy metals, including cadmium. In addition to conducting extensive research in the field of using aquatic and terrestrial plants in the phytoremediation of various environmental pollutants.

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