International Journal of Agriculture Sciences
ISSN: 0975-3710&E-ISSN: 0975-9107, Volume 10, Issue 7, 2018, pp.-5705-5709.
Available online at http://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217

Research Article

REMOVAL OF LEAD FROM WATER BY WATER HYACINTH *Eichhornia crassipes* (Mart.) Solms

PATEL J.[1], KULKARNI G.[2], TEKADE A.[3*] AND MURKAR A.[4]

[1,2,3]Department of Fisheries Hydrography, College of Fisheries, Shirgaon, Ratnagiri, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, 415712, Maharashtra
[4]Department of Fisheries Aquaculture, College of Fisheries, Shirgaon, Ratnagiri, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, 415712, Maharashtra
*Corresponding Author: Email-ankicofsn@gmail.com

Received: April 03 2018; Revised: April 10, 2018; Accepted: April 11, 2018; Published: April 15, 2018

Abstract- Toxic heavy metal pollution of water is a major environmental problem, and there is no conventional remediation approaches and acceptable solutions. This study demonstrates the absorption capacity of water hyacinth for the heavy metal, lead. In tap water hyacinth was cultured and supplemented with 1, 5 and 10 mg/l of lead. They were harvested separately after 0, 15, 30, 45 and 60 days. Plant samples *viz.,* roots, laminae and petioles containing lead were analyzed using atomic absorption spectrophotometer. Results indicated that the maximum accumulation by water hyacinth was noted in roots as compared to petioles and laminae. The accumulation of Pb in roots, petioles and laminae increased with initial concentration and also with the exposure period. It was concluded that the trend of overall accumulation of lead by the water hyacinth between the treatments, days and plant organs were in the following order: roots > petioles > laminae $T_3 > T_2 > T_1 > T_0$.60th>45th>30th>15th> 0 days.

Key words- Water hyacinth, *Eichhornia crassipes* (Mart.) Solms., lead, heavy metal removal

Citation: Patel J., *et al.*, (2018) Removal of Lead from Water by Water Hyacinth *Eichhornia crassipes* (Mart.) Solms. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 10, Issue 7, pp.-5705-5709.

Introduction

Environmental pollution is the result of rapid industrialization, technological advancement and unprecedented increase in population. Human evolution has led to immense scientific and technological progress. Besides yielding several products, natural sources of water are fast depleting and are polluted due to release of wastes in haphazard manner. Billions of liters of waste water are generated every day from industries and domestic sources. Most of the industries discharge their waste directly (without any treatment) into the streams, lakes, oceans as well as in the open land that contaminate the ground water. These Wastes Range from Simple, Weak Sewage Containing Organic and Mineral Matters to Highly Toxic Kinds Containing Pesticides, Detergents, Heavy Metals and Other Toxic Substances. The effect is depletion of oxygen in an ecosystem, consequent death of biota, smothering of aquatic animals and degradation in water quality for domestic, agricultural, industrial and recreational use. Millions of gallons of water containing toxic heavy metals are generated annually from several metal processing industries. The main sources of heavy metal pollution are mining, milling and surface finishing industries, which discharge a variety of toxic metals into the environment [7]. Industrial effluents may be discharged directly into the sea, or via waterways or sewer but whatever the disposal route, these constitute an important source of contamination of the environment. Many industries discharge their heavy metals into the water [11]. Heavy metals produce undesirable effects, even if they are present in extremely minute quantities, on human, animals and plant life. The release of various heavy metals into aquatic environment is a worldwide problem of increasing magnitude. The toxic effects on the biota have been known for a very long time. The heavy metals can affect their survival, reproduction, physiological change and also behavior. Therefore, the need arises to constantly monitor these metals and find a way of removing them from the ecosystem before the threshold level is reached. One new and promising method that has been drawing interest is the use of aquatic plants. Aquatic plants are found to be the potential scavenger of heavy metals from aquatic environment and are being used in waste water renovation systems [10]. The benefits of aquatic macrophyte treatment system over conventional method is there, natural availability at low operating cost, low energy requirements, offering an alternative to the existing technologies and have potential to effectively remove heavy metals from waste water [17]. They have been frequently used to remove suspended solids, nutrients, heavy metals, toxic organics and bacteria from acid mine drainage, agricultural landfill and urban storm-water runoff. The aquatic vascular plants possess a tremendous capacity of absorbing nutrients and other substances from the water [5] and hence bring the pollution load down. Many aquatic plants like *Salvinia*, *Lemna* and *Spirodela* have been used for the removal of nitrogen and phosphorous from wastes [5]. The advantage of using aquatic vascular plants for wastewater treatment is the ease of harvesting and its rapid growth, high mineral uptake and accumulation. Many aquatic weeds have demonstrated as potential candidates for waste water treatment and nutrient absorption from the wastes. Although a number of aquatic weeds like *Pistia, Salvinia, Azolla, Wolffia, Spirodella*, *Lemna* etc. have been used, the water hyacinth stands out to be most promising among them [9].

Water hyacinth

Water hyacinth (*Eichhornia crassipes)* is a free-floating flowering and fast growing perennial aquatic macrophyte. It is known to improve effluent quality from oxidation ponds and also as a main component of one integrated advanced system for treatment of municipal, agricultural and industrial waste water [23, 24]. Water hyacinth is found to be most effective in removal of BOD, COD, nitrogen, phosphorous, organic carbon, suspended solids, phenols, heavy metals etc. from the wastewater. Laboratory studies of the water hyacinth have demonstrated the potential use of this species in removing metals from polluted water and have shown that metal concentrations of the plant and the water column are correlated [21]. Since this floating plant grows in heavily polluted water and has high capacity of metal accumulation, this plant has been selected for the experiment [Fig-1]. The present investigation was carried out with following objectives:

To evaluate the absorption lead by using floating weed, water hyacinth, in relation to physico – chemical parameters - temperature, pH, dissolved oxygen and hardness.

Fig-1 Water hyacinth (*Eichhornia crassipes*)

Materials and Methods

In the present study *Eichhornia crassipes* commonly known as water hyacinth was selected as test plant for assessing the absorption capacity of lead. The identification of water hyacinth was carried out by using the characters given by (C.S.I.R., 1982). Healthy aquatic weed of vegetative stage were collected from Rankala Lake, situated out skirts of Kolhapur and were brought to laboratory in wet condition for further live maintenance. After collecting, water hyacinth plants were rinsed with tap water to remove epiphytes and insect larvae grown on plants. The plants were then placed in plastic pools filled with tap water, under natural sunlight for one week so as to acclimatize them to the new captive environment. Plastic tubs were washed, thoroughly cleaned and dried properly. The total volume of water taken in each tub was 35 lit. Four treatments namely control (T_0), 1mg/l (T_1), 5mg/l (T_2), and 10mg/l (T_3) were taken as concentration for the metal, with five replicates for two months. Plants of vegetative stage having weight 10g fresh weight were selected for the experiment. Tubs with plants not exposed to metal served as control. All treatments were performed with five replicates. The test durations were 0, 15, 30, 45 and 60 days. Tap water was added daily to compensate for water loss through plant transpiration, water sampling and evaporation. Test solution was prepared by following the procedure given [2]. They were prepared to give 1mg/l from 1ml and the higher concentration i.e. 5 and 10mg/l were prepared for making higher proportionate which was used for absorption experiment.

Fig-2 Experimental setup of accumulation.

Water parameters *viz* water temperature; pH, hardness and dissolved oxygen at a weekly interval were measured from each experimental replicate.

Preparation and digestion of plant samples

Plant samples for heavy metal analysis were taken with utmost care to avoid contamination after every 15 days of interval from the plastic tubs. Each plant was separated into roots, laminae and petioles. The samples were oven dried for 2-3 days and ground to powder using glass mortar and pestle to ensure sample homogeneity with respect to particle distribution. The finely ground material was stored in sealed polyethylene bags at room temperature until acid digestion. Digestion unit (KEL PLUS-CLASSIC DX, Pelican equipment) was used for digestion of plant sample. Then final analysis was done on AAS.

Statistical analysis

Data on heavy metal content between treatment and days was designed as ANOVA. Significant difference was indicated by $P < 0.05$; the Students Newman Kuel's multiple comparison test was used to determine the significant difference between the treatments and days [20, 26]. Data on water parameters were analyzed by ANOVA. Correlation coefficient test was applied between parameters and treatment. The t – test was used to compare treatment at significant difference $P < 0.05$ (20, 26).

Results and Discussion

Accumulation of lead by the roots

The accumulation of lead by the roots of water hyacinth is given in [Fig-3]. Student's Newman - Kuel's multiple comparison test showed that the maximum accumulation of lead in roots in T_3 (10 mg/l) on 60th day and was significantly different ($P < 0.05$) from 0, 15th, 30th and 45thday while 0, 15th, 30th and 45th day did not differ significantly among themselves. There was a significant difference between treatments T_3 and T_0 while there was no significant difference between the treatments T_1 and T_2 among each other. As seen from the [Fig-3] the accumulation of lead in the roots consistently increased when the exposure time and lead concentration were increased. The trend of overall accumulation of lead by the roots of water hyacinth between the treatments was in the following order: $T_3 > T_2 > T_1 > T_0$. The trend of overall accumulation of lead by the roots of water hyacinth between the days of exposure was in the following order: 60th> 45th> 30th> 15th> 0 days. The accumulation of lead in the present study increased to the maximum levels of 102.75, 214.67 and 479.67 mg/g dry weight in roots, 65.63, 287.94 and 302.62 mg/g dry weight in petioles and 43.75, 198.83 and 205.96 mg/g dry weight in laminae in different concentrations of 1, 5 and 10 mg/l respectively. Lead accumulation in the plant tissues increased significantly with increasing concentrations and exposure time as also noted by Alonso – Castro, *et al.,* (2009) [1]. The maximum accumulation (479.67 mg/g) was observed from the roots in 10 mg/l concentration while, the minimum accumulation (43.75 mg/g) was observed from the laminae in 1mg/l concentration on 60th day Mishra, *et al.,* (2008) [14] found that the lead accumulation in water hyacinth increased linearly with the solution concentration in the order of laminae < petioles < roots in water hyacinth, the trend being similar to the present study.

Many reports illustrated a better accumulation of Pb when the exposure time and concentrations were increased. The aquatic plants displayed better accumulation of lead in the root portions of *Bacopa monnieri* [18], *Lemna gibba* [13], *Eichhornia crassipes* [25], *Typha latifolia* [1] and *Colocasia esculenta* [4].

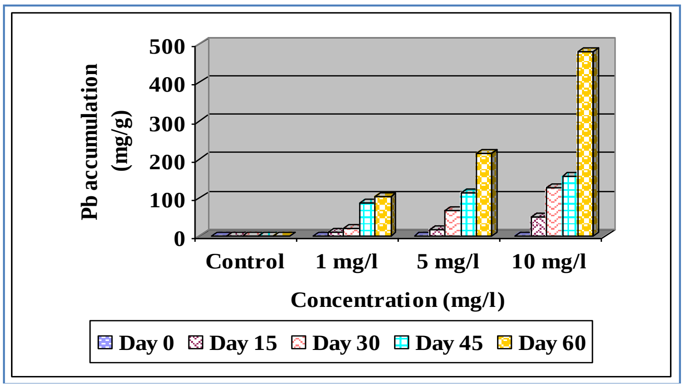

Fig-3 Accumulation of Lead by the Roots (Mg/G Dry Weight) of Water Hyacinth.

Accumulation of lead by the laminae

The accumulation of lead by the laminae of water hyacinth is given in [Fig-4]. The maximum accumulation of lead (205.96 mg/g) was in the treatment T_3 (10 mg/l) on 60^{th} day, whereas, the minimum accumulation (43.75 mg/g) was noted in the treatment T_1 (1 mg/l) on 15^{th} day. ANOVA showed significant difference ($P < 0.05$) in accumulation of lead by the laminae of water hyacinth between the treatments and days. Student's Newman - Kuel's multiple comparison test showed that the maximum accumulation of lead in laminae was in T_3 (10 mg/l) on 60^{th} day. As seen from the [Fig-4] the accumulation of lead in the laminae increased when the exposure time and lead concentration were increased. The overall trend of accumulation of lead by the laminae of water hyacinth between the treatments was in the following order: $T_3 > T_2 > T_1 > T_0$. The overall trend of accumulation of lead by the laminae of water hyacinth between days was in the following order: $60^{th} > 45^{th} > 30^{th} > 15^{th} > 0$ days. Water hyacinth has exhibited higher concentrations of lead in roots than in petioles or laminae. Roots function as a barrier to the translocation of lead to the above water part of water hyacinth thus, this indicates that plants have poor translocation and lead is largely retained within the roots against minimum in the laminae [18]. This is due to the presence of large amount of substances like glutathione and ascorbate in roots than in petioles which bind lead to the negatively charged binding sites in the cell wall. Cell walls of the roots are thus preferable site of accumulation of lead [6]. Presence of numerous thin roots in water hyacinth is also a reason for higher concentration of lead in roots in comparison to laminae and petioles. Minimum accumulation of lead in laminae may be due to transpiration process and prevention mechanism taking place in it, to inhibit lead uptake since lead is a non-essential element for plant metabolism. Similar nature of metal uptake was also noted by Win, *et al.,* (2003) on removal of lead from industrial waste water by water hyacinths [25].

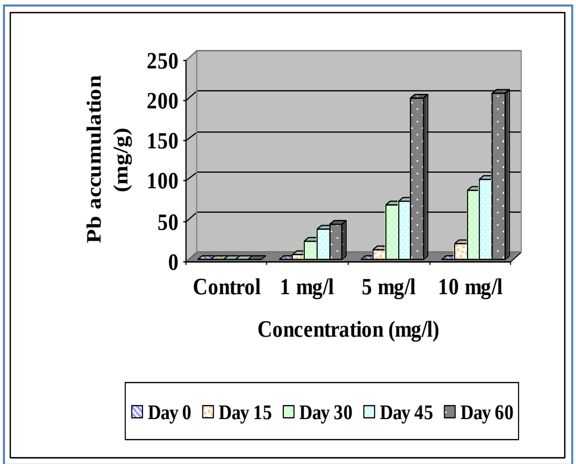

Fig-4 Accumulation of Lead by the Lamine (Mg/G Dry Weight) of Water Hyacinth.

Accumulation of lead by the petioles

The accumulation of lead by the petioles of water hyacinth is given in [Fig-5]. The maximum accumulation of lead (302.62 mg/g) was in the treatment T_3 (10 mg/l) on 60^{th} day, whilst, the minimum accumulation (65.63 mg/g) was observed in the treatment T_1 (1 mg/l) on 15^{th} day. ANOVA showed significant difference ($P < 0.05$) in accumulation of lead by the petioles of water hyacinth between the treatments and days. Student's Newman - Kuel's multiple comparison test showed that the maximum accumulation of lead in petioles was in T_3 (10 mg/l) on 60^{th} day and it was significantly different ($P < 0.05$) from other days at the same time 0, 15^{th}, and 30^{th} day did not differ significantly among each other. There was a significant difference between treatments T_3 and T_0. As seen from the [Fig-5] the accumulation of lead in the petioles constantly increased when the exposure time and lead concentration were increased. The overall trend of accumulation of lead by the petioles of water hyacinth between the treatments was in the following order: $T_3 > T_2 > T_1 > T_0$. The overall lead accumulation trend by the petioles of water hyacinth between the days was in the following order: $60^{th} > 45^{th} > 30^{th} > 15^{th} > 0$ days.

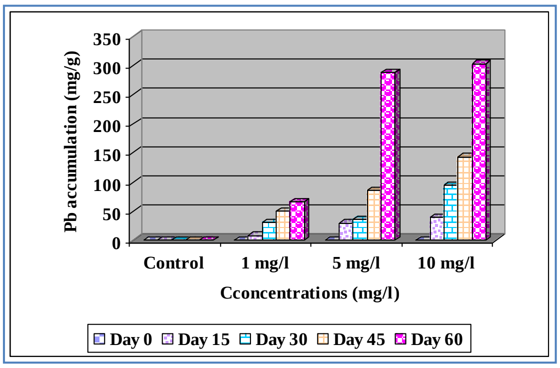

Fig-5 Accumulation of Lead by the Petioles (Mg/G Dry Weight) of Water Hyacinth.

Accumulation of Lead by Different Parts Taken Together

The accumulation of lead by water hyacinth in different parts taken together is given in [Fig-6].

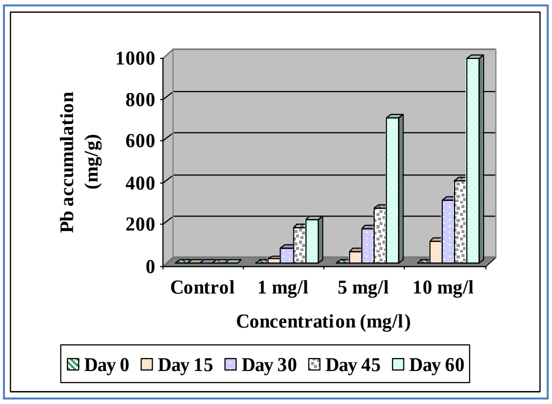

Fig-6 Accumulation of Lead by (Mg/G Dry Weight) Water Hyacinth in Different Parts Taken Together.

The maximum accumulation of lead (988.25 mg/g) was in the treatment T_3 (10 mg/l) on 60^{th} day, while, the minimum accumulation (212.13 mg/g) was noted in the treatment T_1 (1 mg/l) on 15^{th} day. ANOVA showed significant difference ($P < 0.05$) in accumulation of lead by water hyacinth in different parts taken together between days and treatments. Student's Newman - Kuel's multiple comparison test showed that the maximum accumulation of lead in water hyacinth in different parts taken together was in T_3 (10 mg/l) on 60^{th} day. The 60^{th} day was significantly different ($P < 0.05$) from 0, 15^{th}, and 30^{th} day while 0, 15^{th}, 30^{th} and, 45^{th} day did not differ significantly among each other [Table-1]. There was a significant difference between treatments T_3 and T_0 while there was no significant difference between the treatments T_1 and T_2 among each other. As seen from the [Fig-6] the accumulation of lead in water hyacinth in different parts taken together consistently increased when the exposure time and lead concentration were increased. The overall accumulation of lead by water hyacinth in different parts taken together between the treatments was in the following order: $T_3 > T_2 > T_1 > T_0$. The overall accumulation of lead by water hyacinth in different parts taken together between the days was in the following order:
$60^{th} > 45^{th} > 30^{th} > 15^{th} > 0$ days.

Residual Concentration of Dissolved Lead

The concentration of lead remaining in the test solution is given in [Fig-7]. The maximum concentration of residual solutions of lead (6.8805 mg/l) was observed in the treatment T_3 with a test concentration of10 mg/l on 60^{th} day. As seen from the [Fig-7] the residual concentration of lead decreased significantly with exposure time but increased with test concentration. The overall residual concentration of lead by water hyacinth between the treatments was in the order of $T_3 > T_2 > T_1 > T_0$.

Table-1 *Physicochemical parameters during absorption of lead by water hyacinth according to exposure period.*

Days	Temperature (°C)				Hardness (mg/l)				pH				Dissolved oxygen (mg/l)			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
0	28.3	28.3	28.3	28.3	115	115	115	115	7	6	5	4	6.1	6.1	6.1	6.1
15	27.5	25.2	27.5	27.5	106	106	102	101	7.2	6.2	5.1	4.2	6.3	6.4	6.1	5.5
30	28.1	24.2	28.2	28.1	99	99	95	92	7.5	6.2	5.2	4.5	6.4	6.5	6.4	5.3
45	26.5	23.5	26.5	26.5	90	89	85	82	7.3	6.3	5.2	4.8	6.7	7	7.1	7.2
60	27.9	25.2	27.9	27.8	80	80	75	72	7.5	6.5	5.3	5	7.4	7.1	7.7	6.6
Min	26.5	23.5	26.5	26.5	80	80	75	72	7	6	5	4	6.1	6.1	6.1	5.3
Max	28.3	28.3	28.3	28.3	115	115	115	115	7.5	6.5	5.3	5	7.4	7.1	7.7	7.2

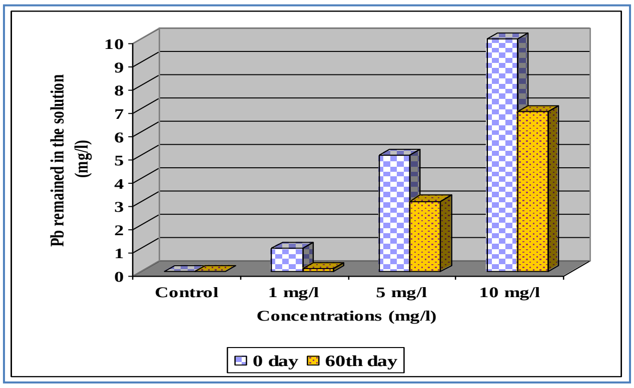

Fig-7 Residual lead level at different concentrations

Correlation analysis

The correlation co-efficient for the selected parameter (temperature, pH, dissolved oxygen, hardness) and lead accumulation by water hyacinth is given in [Table-2]. There was a significant positive correlation between dissolved oxygen and 1 mg/l (r = 0.9829) and dissolved oxygen and 5 mg/l (r = 0.9573) while a significant negative correlation co-efficient was recorded between hardness and 1 mg/l (r = -0.9811).

Table-2 *Correlation co-efficient among parameters and treatments in lead.*

Treatments	Parameters			
	Temperature (°C)	pH	Dissolved oxygen (mg/l)	Hardness (mg/l)
Control	-0.8669	0.3117	0.6355	-0.7282
1mg/l	-0.5951	0.9120	0.9829*	-0.9811*
5mg/l	-0.1053	0.8841	0.9573*	-0.9103
10mg/l	-0.1557	0.9150	0.4573	-0.9158

*Significant difference

Physicochemical Parameters during Bio-concentration.

In the present study water temperature ranged from 23.5- 28.3°C in all the treatments Maximum temperature was recorded (28.3°C) in all the treatments at the start of the experiment while minimum (23.5°C) was recorded in T_1 (1mg/l) on 45th day. Maximum pH (7.5) was observed in the treatment T_0 (control) on 60th day but, minimum [4] was observed in T_3 (10 mg/l) on 0 day. Dissolved oxygen increased from 5.3- 7.7 mg/l in all the treatments. Maximum DO was noted (7.7 mg/lit) in the treatment T_2 (5 mg/l) on 60th day whereas minimum (5.3 mg/l) was in T_3 (10 mg/l) on 30th day. Hardness varied 72- 115 mg/l. Maximum hardness (115 mg/l) was observed in observed in all the treatment at the start of the experiment, whereas minimum (72 mg/l) was observed in the treatment T_3 (10 mg/l) on 60th day. There was decrease in hardness with exposure period. The uptake of metal ion from water is influenced by various parameters such as temperature, pH, dissolved oxygen and hardness. Moreover, the energy derived from photosynthesis and oxygen released can improve conditions for the active absorption of metals. Balasooriya, *et al.*, (1983) [3] observed luxuriant growth of water hyacinth when the temperature was between 26- 35°C. In the present investigation, temperature of surface water fluctuated from a 23-28°C. There was no significant positive as well as negative correlation between temperature and accumulation of metal by water hyacinth. This suggested that there was no strong relationship between temperature and accumulation of metal but there was optimum growth of water hyacinth. The water pH is an important parameter in controlling ions availability and hence the uptake by an individual plant (22).

In the present study results reveal the relationship between some water parameter and metal accumulation. There was a significant positive correlation between pH and accumulation of metal by water hyacinth. Similarly, an increasing significant positive correlation between dissolved oxygen and accumulation of metal by aquatic plant was recorded.

Murugesan and Sukumarn (1997) [16] however observed decrease in concentration of dissolved oxygen due to dense cover of plants in small tubs which favoured the anaerobic condition. Contrary observation in the present study may be due to sufficient area present in the tubs which favored the aerobic condition. The process of photosynthesis is less affected since roots, that accumulate metals ions are usually at the underwater basal portion of a plant and the metals that are known to interfere with the photosynthesis, are kept isolated [19]. A significant negative correlation was observed in the present study between hardness and accumulation of metals. There was decrease in hardness of water with increase in metal accumulation and exposure period. Similar finding was reported by Kousar and Puttaiah (2009) on application of *Trapabipinosa* for the treatment of pulp and paper industry effluent [12]. The concentrations of lead remaining in the residual nutrient solutions significantly decreased with exposure period but increased with test concentration. This may be due to attainment of a saturation state. As soon as the saturation state was reached, it seems that it was not possible for these plants to further absorb lead significantly. Metal content in water decreases with the passage of time. Similar results were also reported by Muramoto and Oki (1983) [15] for water velvet and duckweed.

The present study reveals that the root of water hyacinth is an efficient organ for accumulation of metals as compared to laminae and petioles. Therefore, in an ecosystem or waste water system of abundant lead the plant, *Eichhorniacrassipes* can be used effectively to remove the metal contaminants. Therefore, serving is an important biotechnological tool

Conclusion

The maximum accumulation (479.67 mg/g) of lead was observed from the roots in 10 mg/l concentration whereas; the minimum accumulation (43.75 mg/g) was from the laminae in 1mg/l concentration on 60th day. The trend of overall accumulation of lead by the water hyacinth between the treatments, days and plant organs were in the following order:$T_3 > T_2 > T_1 > T_0$. 60th> 45th> 30th> 15th> 0 days. Laminae < petioles < roots. Water temperature was in the range of 22.3°C - 28.3°C. While pH varied from 4- 7.5 Dissolved oxygen increased was in the range of 5.3- 7.7 mg/l. Total hardness decreased from115-72 mg/l during the period of 60 days under the experimental conditions. Based on the present study regarding the absorption capacity of water hyacinth it can be concluded that the roots of water hyacinth are most efficient organ for accumulation of metals as compared to petioles and laminae. Therefore, in an ecosystem or waste water system of abundant lead the plant, *Eichhornia crassipes* can be used effectively. As it is also an eco- friendly way of removing the toxic wastes from the aquatic environment.

Application of research: Toxic heavy metal pollution of water is a major environmental problem, and there is no conventional remediation approaches and acceptable solutions. This study demonstrates the absorption capacity of water hyacinth for the heavy metal, lead. It will be useful in aquaculture for fish farmers.

Research Category: Heavy metal, Pollution, Toxicology

Acknowledgement / Funding: Author thankful to College of Fisheries, Shirgaon, Ratnagiri, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, 415712, Maharashtra. Authors are also thankful to Associate Dean and other staff members of, College of Fisheries, Shirgaon, Ratnagiri, DrBalasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, 415712, Maharashtra for providing necessary facilities during research work.

***Research Guide or Chairperson of research: Dr G. N. Kulkarni**
University: Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, 415712, Maharashtra
Research project name or number: Nil

Author Contributions: All author equally contributed

Author statement: All authors read, reviewed, agree and approved the final manuscript

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

References

[1] Alonso-Castro A. J., Carranza-Alvarez C., Torre M. C. A., Chavez-Guerrero L. C. and Cruz R.F. (2009) *Archives of Environmental Contamination and Toxicology*, 57 (1), 688–696.
[2] APHA (2005) 21st edition Standard methods for the examination of water and wastewater. American Public Health Association, American water works association. Water environment Federation, Washington DC, U.S.A., 30112.
[3] Balasooriya I., Paulraj P. J., Abeygunawardena S. I. and Nanayakkara C. (1983) Biology of water hyacinth: physico-chemical properties of the water supporting "*Eichhornia crassipes* (Mart.) Solms." In: *Proceedings of the International Conference on Water Hyacinth*, Hyderabad (Ed. Thyagarajan, G.), 318-332.
[4] Bindu T., Sumi M. M. and Ramasamy E. V. (2010) *Environmentalist*, 30 (1), 35-44.
[5] Boyd C. E. (1970) *Economic Botany*, 24 (2), 95-103.
[6] Cutler J. M. and RainsD. W. (1974) *Plant physiology*, 54, 147-152.
[7] Figueira M. M., Volesky B., Ciminelli V. S. T. and Roddick F. A. (2000) *Water Research*, 34 (1), 196-204.
[8] Gopal B. and Sharma K. P. (1981) Water hyacinth (*Eichhornia crassipes*) the most troublesome weed of the world. Published by Hindasia in New Delhi, 128-132.
[9] Gupta G. C. (1982) *Journal of Environmental Health*, 43 (2), 80-82.
[10] Kadlec R.H., Knight R. L., Vymazal J., Brix H., Cooper P. and Haberl R. (2000) Constructed wetlands for pollution control - Processes, performance, design and operation. IWA Published in London, 9, 1- 56.
[11] Kim Y. H., Park J. Y., Yoo Y. J. and Kwak J. W. (1999) *Process Biochemistry*, 34 (3), 647-52.
[12] Kousar H. and Puttaiah E. T. (2009) *Journal of Environmental Biology*, 30 (5), 659-661.
[13] Miranda M. G., Quiroz A. and Salazar M. (2000) *Hidrobiologica*, 10 (1), 7-12.
[14] Mishra V. K., Upadhyay A. R., Pandey S. K. and Tripathi B. D. (2008) *Environmental Monitoring and Assessment*, 141(1-3), 49-58.
[15] Muramoto S. and Oki Y. (1983) *Bulletin of Environmental Contamination and Toxicology*, 30 (2), 170 – 177.
[16] Murugesan A. G., and Sukumaran N. (1997) *International Journal of Environmental Pollution*, 17 (6), 502- 507.
[17] Scott C. D. (1992) *Biotechnology and Bioengineering*, 39 (10), 1064-1068.
[18] Sinha S. (1998) *Environmental monitoring and assessment*, 57 (3), 253–264.
[19] Skinner K., Wright N. and Goff E. P. (2007) *Environmental Pollution*, 145 (1), 234–237.
[20] Snedecor G. W. and Cochran W. G. (1967) Statistical methods. Sixth ed. Oxford and IBM publishing Co., New Delhi, 593.
[21] Soltan M. E. and Rashed M. N. (2003) *Advance Environmental Research*, 7 (2), 321-34.
[22] Vardanyan L. G. and Ingole B. S. (2006) *Environment International*, 32 (2) 208 – 218.
[23] U.S.E.P.A. (1988) Design Manual- Constructed Wetlands and Aquatic Systems for Municipal Wastewater Treatment. U.S. Environmental Protection Agency. Report no. EPA/625/1-88/022.Office of Research and Development, Washington, DC., 4 (2), 83-88.
[24] Wilston J. R., Holst N. and Rees M. (2005) *Aquatic Botany*, 81, 51-67.
[25] Win D. T., Than M. M. and Tun S. (2003) *American- Eurasion Journal of Toxicological Sciences*, 6(4) , 187-192.
[26] Zar J.H. (2004) Biostatistical analysis. Fourth ed. Tan prints (I) Pvt. Ltd., Delhi, India, 663.