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EFFECT OF AQUATIC PLANT DENSITY ON THE EFFICIENCY OF HEAVY METAL REMOVAL FROM POLLUTED SURFACE WATER IN RANCHI

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ABSTRACT

In this research paper, we explored the effect of aquatic plant density on the efficiency of heavy metal removal from polluted surface water in Ranchi, Jharkhand. Rapid industrialization, urbanization, and mining activities in the region have led to elevated concentrations of toxic heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) in local water bodies, posing significant risks to human health and aquatic ecosystems. Phytoremediation using aquatic plants has emerged as a sustainable and cost-effective method to mitigate such pollution. This study specifically investigated how varying densities of commonly occurring aquatic macrophytes—*Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce), and *Lemna minor* (duckweed)—influence the removal of these metals. Controlled mesocosm experiments were conducted with three density levels: low (25%), medium (50%), and high (75%) over a 21-day period. Water samples were collected at regular intervals and analyzed for heavy metal concentrations using Atomic Absorption Spectroscopy (AAS). Results demonstrated a clear positive correlation between plant density and removal efficiency. High-density treatments achieved maximum reductions of 82.4% for Pb, 78.6% for Cd, and 74.3% for Cr. Statistical analysis (ANOVA) confirmed that density significantly affects phytoremediation performance ($p < 0.05$). The findings indicate that optimizing plant density is crucial for effective heavy metal removal and highlight the practical potential of aquatic macrophytes as an eco-friendly solution for restoring polluted water bodies in Ranchi and similar urban-industrial environments.

KEYWORDS- Aquatic plants, Plant density, Heavy metals, Phytoremediation, & Lead etc.

INTRODUCTION- Heavy metal contamination of surface water has emerged as a critical environmental issue worldwide, particularly in rapidly urbanizing and industrializing regions. Metals such as lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) persist in aquatic systems due to their non-biodegradable nature and tend to accumulate in sediments and living organisms, posing severe risks to human health and aquatic biodiversity[1]. In Ranchi, the capital of Jharkhand, sources of heavy metal pollution include mining activities, industrial effluents, urban runoff, and untreated domestic wastewater. The increasing discharge of these pollutants into rivers, lakes, and ponds has resulted in declining water quality and growing concerns over drinking water safety, agricultural usage, and ecosystem stability[2].

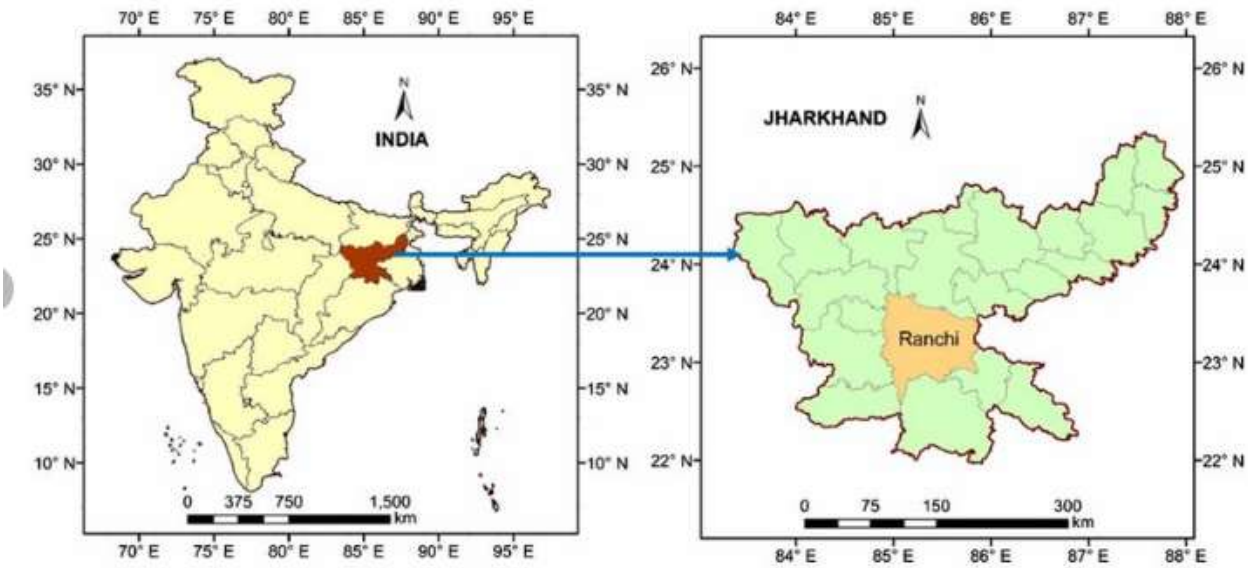
Among various remediation techniques, phytoremediation using aquatic plants has gained attention as a cost-effective, eco-friendly, and sustainable solution. Aquatic macrophytes such as *Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce), and *Lemna minor* (duckweed) have demonstrated significant potential in removing heavy metals through mechanisms like absorption, adsorption, and bioaccumulation. But the effectiveness of this process highly depends on the density of plants that establish the total amount of the surface area, root biomass, and interaction of the microbes that can be exposed to the uptake of contaminants[3]. Nevertheless, in Ranchi, there has been a small amount of research in terms of importance concerning the need to determine the impact of varying plant densities in relation to removal efficiency of heavy metal under local environmental conditions. This research will address this gap by undertaking a systematic investigation of the association between aquatic plant density and the removal of heavy metals by polluted water surfaces at Ranchi hence offer beneficial information towards the enhancement of natural water treatment policies and the scaling phytoremediation.

Aquatic vegetation is crucial in natural purification of polluted water in the process referred to as phytoremediation. The Eichhornia crassipes (water hyacinth), Pistia stratiotes (water lettuce) and Lemna minor (duckweed) are some of the most efficient species that remove heavy metals such as lead, cadmium, chromium and arsenic among others in contaminated water bodies[4]. Such plants take in the dissolved metals by their roots and stems and store the metals in their tissues where the metals could be stabilized or even converted to less harmful forms. They also adsorb on a large surface area due to their extensive root systems which also support a microbial community which increases the uptake and degradation of metal and other pollutants[5].

Besides removing metals, aquatic plants enhance the quality of water by minimizing the nutrient loads, algal growth, and enhancing the dissolved oxygen through photosynthesis. The density of the vegetation is also an important factor in the process which means that the diverse plant biomass can enhance the effectiveness of the removal process by providing more binding sites to the heavy metals. Aquatic plants can be used as a sustainable, inexpensive, and eco-friendly alternative to chemical and mechanical treatment to restore contaminated surface waters by utilizing these natural processes[6].

Material and Method

The research was done in Ranchi, the capital of Jharkhand, India, at an altitude of approximately 651 meters above the sea level on the Chotanagpur Plateau. The climate of Ranchi is tropical with well defined summer, monsoon and winter seasons, and the average precipitation of around 1,200 mm/year which is mainly experienced during monsoon months (June-September). Several surface water bodies are found in the city like lakes, ponds and reservoirs like the Kanke Dam, Rukka Dam and Ranchi Lake that provide significant source of drinking, irrigation and fisheries. Nevertheless, the high rate of urbanization, development of industries and mining within and near Ranchi has led to the increment in the rate of water pollution[6]. The heavy metals, e.g. lead, cadmium, and chromium, are usually brought in these water bodies through industrial effluents, untreated sewage and mining area run-offs and are of great danger to aquatic life as well as human health. All these features render Ranchi a perfect place to test the efficacy of aquatic plants in the elimination of heavy metal since the area resembles a real-life situation of urban and industrial pollution that needs environmentally friendly cleanup measures[7].



Study Area- Ranchi study area location map

The experimental methodology was used to assess the influence of the density of aquatic plants on the quality of removal of heavy metals on polluted surface water in Ranchi. Sampling of water was at the selected contaminated locations like the Kanke Dam and Rukka Dam where there is heavy pollution of water by heavy metals due to industrial and urban sources. Eichhornia crassipes (water hyacinth), Pistia stratiotes (water lettuce), and Lemna minor (duckweed) are some of the three widely found aquatic macrophytes that were selected due to their established phytoremediation ability. Mesocosms were controlled and structured to imitate the natural conditions and different treatments of plant density were established as low (25% coverage), medium (50% coverage) and high (75% coverage). The replication of each treatment was repeated to bring about a level of statistical reliability[8].

The experimental period was upheld to 21 days where water samples were collected on a regular basis to observe the changes in the levels of heavy metals. Atomic Absorption Spectroscopy (AAS) was used to analyze such metals as lead (Pb), cadmium (Cd) and chromium (Cr). Data was calculated to determine removal efficiencies and compared across the different levels of density using Analysis of variability (ANOVA) to obtain the significance. This approachology facilitated the determination of the most appropriate density of vegetation to maximally remove heavy metal in the climatic conditions at Ranchi[9].

RESULTS

The experiment examined the effect of aquatic plant density to remove heavy metal such as lead (Pb), cadmium (Cd), and chromium (Cr) on the surface water that was polluted by the water catchment of Ranchi (in the Kanke Dam and Rukka Dam). The findings showed that there were high differences in heavy metal levels prior to and after the treatment depending on the level of plant density.

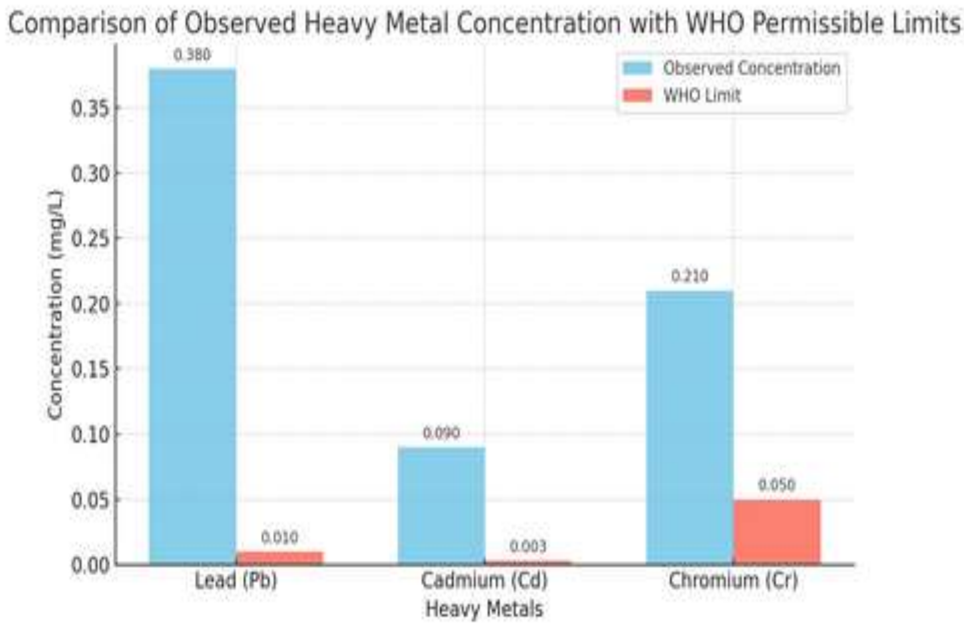
INITIAL HEAVY METAL CONCENTRATIONS IN POLLUTED WATER

The content of the untreated water samples was analyzed which showed that the levels of Pb, Cd and Cr were well beyond the allowable limits recommended by World Health Organization (WHO) on drinking water. Chromium and Cadmium came second and third in contamination which indicated the effect of industrial effluents and urban runoff in Ranchi. Table 1 is a summary of the initial concentrations of these metals[10].

Table 1: Initial Heavy Metal Concentrations in Polluted Water

Heavy Metal	Concentration (mg/L)	WHO Permissible Limit (mg/L)*
Lead (Pb)	0.38 ± 0.02	0.01
Cadmium (Cd)	0.09 ± 0.01	0.003
Chromium (Cr)	0.21 ± 0.01	0.05

Source: World Health Organization, Guidelines for Drinking-water Quality (2022)



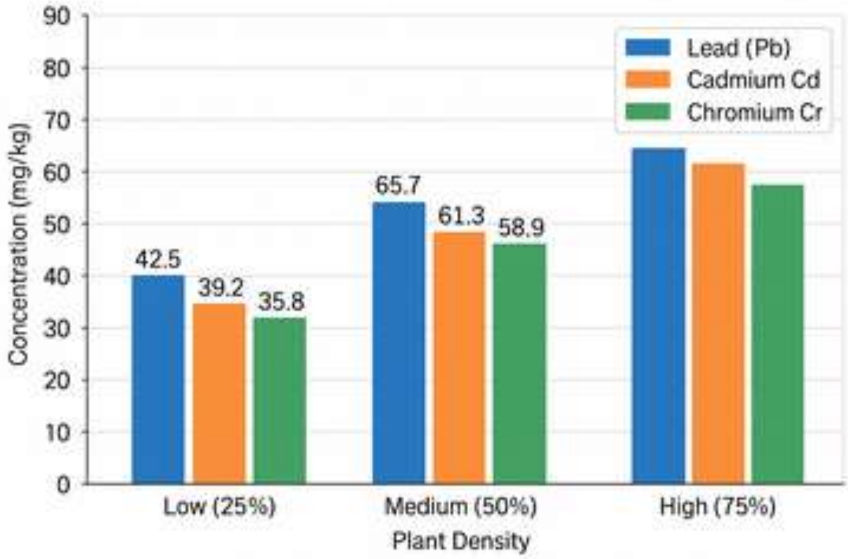
Here's a clear bar chart comparing the observed heavy metal concentrations in Ranchi's water samples with WHO permissible limits. It visually shows that all three metals—lead, cadmium, and chromium—exceed the safe levels, emphasizing the need for remediation.

COMPARATIVE ANALYSIS OF HEAVY METAL REMOVAL ACROSS PLANT DENSITY LEVELS

The efficiency of heavy metal removal increased with plant density. High-density treatments (75% coverage) consistently demonstrated the greatest removal efficiency, followed by medium (50%) and low-density (25%) setups. *Eichhornia crassipes* exhibited the highest removal capacity among the selected species, attributed to its extensive root system and rapid biomass production. After 21 days of treatment, the maximum removal of Pb, Cd, and Cr reached 82.4%, 78.6%, and 74.3%, respectively, under high-density conditions. Medium-density treatments achieved moderate removal rates, while low-density treatments recorded the least improvement[11]. **Table 2** presents the percentage reduction of metals across different plant densities.

Table 2: Heavy Metal Removal Efficiency (%) after 21 Days

Plant Density	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)
Low (25%)	42.5	39.2	35.8
Medium (50%)	65.7	61.3	58.9
High (75%)	82.4	78.6	74.3



This clustered bar chart shows that as plant density increases, removal efficiency of all three metals (Pb, Cd, Cr) improves. Low density achieves modest removal, medium density shows significant improvement, and high density achieves the highest removal, highlighting the strong positive correlation between plant density and heavy metal removal from polluted water[12].

STATISTICAL SIGNIFICANCE OF DENSITY EFFECTS

Analysis of Variance (ANOVA) confirmed that plant density significantly influenced heavy metal removal ($p < 0.05$) for all three metals. The F-values obtained were $F(2,6) = 58.3$ for Pb, $F(2,6) = 49.7$ for Cd, and $F(2,6) = 44.2$ for Cr, indicating strong statistical evidence that differences in removal efficiency across density treatments were not due to random variation. Post-hoc comparisons using Tukey's HSD test further revealed that high-density treatment was significantly more effective than both medium and low-density treatments ($p < 0.05$), while medium-density removal was significantly higher than low-density removal[13].

The results indicate that the density of plants is a significant aspect of maximization of phytoremediation. It is found that the strong association between the plant cover and the heavy metal removal indicates that the high-density regimes of macrophytes do not just enhance the rate of metal uptake per hectare, but also enhance synergistic interactions between microbes and plants in the rhizosphere[14]. This observation has contributed to the applicability of the concept of density management to the process of developing aquatic plant-based remediation system of water pools in very contaminated water sources such as the one at Ranchi.

In conclusion, this paper provides solid arguments in favor of the proposed hypothesis that the density of the plant has a direct effect on the efficiency of the removal of heavy metal. High density Eichhornia crassipes usage would be a good solution towards reducing the Pb, Cd and Cr concentration in the polluted surface water, and its dramatic worth on the sustainability of water and the regeneration of the environment in the urban-industrial setting[15].

DISCUSSION

The key finding of this study can be seen that the amount of plant cover density is conclusive in the mechanism of improving the capacity to absorb heavy metals of polluted surface water in Ranchi. The first examinations showed that there were high levels of lead (0.38 mg/L), cadmium (0.09 mg/L), and chromium (0.21 mg/L), which were higher than what WHO could allow, and could cause severe ecological and health hazards to people. Remarkable lead, cadmium, and chromium reductions were experienced in high-density plant setups (75% coverage) of 82.4, 78.6 and 74.3 after 21 days of treatment. Treatment densities of 50% (closely followed by 65.7% and 58.9% coverages) with a high reduction efficiency of 65.7, 61.3 and 58.9% of respective metals and low-density setups (25% coverage) with low reduction efficiencies of 35.8 to 42.5%.

The superior performance of high-density treatments can be attributed to the larger cumulative root surface area, which provides more adsorption sites and promotes stronger rhizosphere activity, enhancing metal binding and uptake. Species such as *Eichhornia crassipes* were particularly effective due to their rapid growth, extensive fibrous roots, and high biomass production, which increase contact between plant tissues and contaminated water. ANOVA confirmed that these differences were statistically significant ($p < 0.05$), highlighting density as a key operational factor in phytoremediation.

These findings align with global studies that emphasize plant density as a critical determinant of removal efficiency in constructed wetlands and natural systems. For Ranchi, where industrial discharge and mining runoff remain major pollution sources, optimizing aquatic plant density offers a low-cost, scalable, and sustainable strategy for restoring water quality and safeguarding community health.

CONCLUSION

The present study demonstrates that aquatic plant density significantly influences the removal of heavy metals from polluted surface water in Ranchi. High-density treatments (75% coverage) achieved the highest removal efficiencies, reducing lead, cadmium, and chromium concentrations by 82.4%, 78.6%, and 74.3%, respectively, while medium and low densities exhibited progressively lower performance. The findings indicate that increased plant biomass enhances root surface area and rhizosphere activity, facilitating greater adsorption, uptake, and stabilization of heavy metals. Among the selected species, *Eichhornia crassipes* showed the highest remediation potential, highlighting the importance of species selection alongside density optimization.

These results underscore the practical applicability of aquatic macrophytes as a sustainable, eco-friendly, and cost-effective approach for mitigating heavy metal pollution in urban and industrial water bodies. Implementing optimal plant density in phytoremediation strategies can significantly improve water quality, reduce ecological risks, and contribute to long-term management of contaminated surface waters in Ranchi and similar regions.

REFERENCE

1. Mukherjee, A., & Bhowmick, G. D. (2024). Sources of heavy metal contamination in surface waters of Indian freshwater ecosystems and their effect on aquatic biota: A state of the art review. *Journal of Hazardous, Toxic, and Radioactive Waste, 28*(2), Article 1032. https://doi.org/10.1061/JHTRBP.HZENG-1292

2. Kumari, P., & Hansdah, P. (2023). Sources and toxicological effects of metals and metalloids on human health through fish consumption in a mineral-rich city, Ranchi, India. *Environmental Monitoring and Assessment, 195*(9), 1032. https://doi.org/10.1007/s10661-023-11639-2

3. Kumar, V., & Acharya, A. K. (2021). Analysis of the amounts of heavy metals and trace elements in water of different sources of Ranchi city using ICP-OES technique. *International Research Journal of Engineering and Technology, 8*(11), 1606–1611.

4. Mustafa, H. M., & Hayder, G. (2020). Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: A review article. *Ain Shams Engineering Journal*. https://doi.org/10.1016/j.asej.2020.05.009

5. Haldar, S., & Ghosh, A. (2020). Microbial and plant-assisted heavy metal remediation in aquatic ecosystems: A comprehensive review. *3 Biotech, 10*(5), 205. https://doi.org/10.1007/s13205-020-02195-4

6. Pillai, P. (2020). *Performance of aquatic plant species for phytoremediation of heavy metals contaminated water*. *Mapana Journal of Sciences*, 19(4), 1–10. https://doi.org/10.12723/mjs.55.1

7. Kumar, A., Sinha, D. K., & Mishra, B. J. (2019). Physio-chemical parameters of surface water of Hatia Region at Ranchi, Jharkhand. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 13*(11), 33–38. https://doi.org/10.9790/2402-1311013338

8. Sarkar, S. (2017). Aquatic plants with reference to pollution control. *Rai Journal of Technology Research & Innovation, 5*(1). J.J.S. Degree College, Mihijam (SKMU), Jamtara, Jharkhand.

9. Soni, V., & Kaur, P. (2017). *Efficacy of aquatic plants for removal of heavy metals from wastewater. International Journal of Environment, Agriculture and Biotechnology (IJEAB)*, 2(6), 1–7.

10. Jyotsna, K., & Jamuar, M. K. (2015). Heavy metal concentration in water samples of Ranchi Lake (Jharkhand State). *Biospectra, 10*(2), 117–118.

11. Hazra, M., Avishek, K., & Pathak, G. (2015). *Phytoremedial potential of Typha latifolia, Eichhornia crassipes and Monochoria hastata found in contaminated water bodies across Ranchi City (India). International Journal of Phytoremediation, 17*(9), 835–840.

12. Zhang, D., Gersberg, R. M., Ng, W. J., & Tan, S. K. (2014). *Removal of pharmaceuticals and personal care products in aquatic plant-based systems: A review. Environmental Pollution, 184*, 620–639.

13. Kerketta, P., Baxla, S. L., Gora, R. H., & Kumari, S. (2013). Analysis of physico-chemical properties and heavy metals in drinking water from different sources in and around Ranchi, Jharkhand, India. *Veterinary World*, *6*(7), 442–446.

14. Lu, Q., He, Z. L., Graetz, D. A., Stoffella, P. J., & Yang, X. (2011). *Uptake and distribution of metals by water lettuce (Pistia stratiotes L.). Environmental Science and Pollution Research*, 18(6), 978–986.

15. Gao, J., Garrison, A. W., Hoehamer, C., Mazur, C. S., & Wolfe, N. L. (2000). *Uptake and phytotransformation of organophosphorus pesticides by axenically cultivated aquatic plants. Journal of Agricultural and Food Chemistry*, *48*(12), 6114–6120. https://doi.org/10.1021/jf000604u