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ENVIRONMENTAL RISKS OF HEAVY METAL ACCUMULATION IN NATURAL ECOSYSTEMS

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Abstract:
This paper analyzes the anthropogenic pollution of water resources by heavy metals, which represent a significant environmental threat. The study systematizes data on the chemical forms and migration pathways of metals within the hydrosphere, while also outlining current maximum permissible concentration (MPC) standards. Primary focus is placed on innovative bio-purification methods, specifically phytoremediation and biosorption. The author demonstrates the high efficiency of using microorganisms and macrophytes to neutralize ions of manganese, lead, chromium, iron, and strontium. Ultimately, the study argues for the viability of implementing integrated bio-sorption and phytoremediation technologies to restore the quality of both natural and waste waters.

Keywords: heavy metals; water pollution; biosorption; phytoremediation; macrophytes; maximum permissible concentration; water treatment.

INTRODUCTION.

In modern ecology, one of the most pressing issues remains the contamination of the hydrosphere with heavy metals (HMs). The rapid development of metallurgy, mining, and the chemical industry leads to a constant increase in the volume of wastewater saturated with metal ions. Unlike organic matter, HMs are not subject to decomposition; they only transform their form and valence, which leads to their long-term accumulation in food chains and a detrimental impact on human health. The term "heavy metals" refers to a group of elements with high density and an atomic weight of more than 50 amu (such as Cr, Mn, Cu, Zn, Pb, etc.), which exhibit toxic properties even in minimal doses. Of particular concern is the condition of irrigation canals, which accumulate agricultural runoff and industrial emissions. The accumulation of Pb, Cd, Cu, and Zn in water poses a threat to the safety of agricultural products, as metals easily migrate through the "soil — plant" chain. [2].

The defining characteristics of heavy metals are toxicity at low concentrations and the capacity for bioaccumulation. [3].

Under modern conditions, one of the most critical environmental problems is the degradation of irrigation systems, which are subject to anthropogenic heavy metal (HM) pollution resulting from agricultural runoff and industrial emissions. Irrigation canals serve as the key transport arteries for agriculture. However, the leaching of mineral fertilizers and wastewater leads to the accumulation of toxic elements within their ecosystems: lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), manganese (Mn), chromium (Cr), iron (Fe), and strontium (Sr). Using such water for irrigation creates risks of metal transfer into the "soil–plant" system, directly threatening the environmental safety of agricultural products and public health.Aquatic plants act as natural bioaccumulators, concentrating metals in doses that significantly exceed their concentration in the water. These plants accumulate metals through passive adsorption on the surface of cell walls—due to the presence of carboxyl and sulfate groups—as well as through active uptake into the cells. The bioaccumulation capacity of algae makes them ideal objects for biomonitoring and effective candidates for bioremediation methods.Biosorption has emerged as a promising "green" alternative that utilizes the natural ability of biomass to bind metal ions. One of the most common plant species in the water bodies of Uzbekistan is the hornwort (Ceratophyllum demersum)—a simple yet versatile pond plant.

Ceratophyllum demersum (commonly known as hornwort) is recognized as one of the most effective tools for phytoremediation. It is a perennial herbaceous plant that develops entirely within the water column. Due to its structural characteristics and metabolic activity, it is capable of absorbing and retaining high concentrations of toxic metals.

Hornwort efficiently removes nitrates and phosphates from water. Since it lacks true roots, nutrient and ion uptake occurs across the entire surface of the plant, primarily through the leaves, via both passive and active ion transport mechanisms. These substances are accumulated in plant tissues as part of its adaptation to varying environmental conditions.

The mechanism of metal uptake involves complex cellular and physiological regulation. Functional groups located on the cell walls (carboxyl, hydroxyl, and amino groups) attract metal ions like "magnets." Metals are further bound by specific proteins and sequestered in vacuoles to minimize toxicity, especially under polluted conditions [6].

Hornwort is considered a hyperaccumulator, meaning it can accumulate metals at concentrations many times higher than those found in the surrounding environment.

- **Lead (Pb):** The plant removes up to 95–96% of lead from water. Maximum accumulation in tissues can reach 17,000 µg/g.
- **Cadmium (Cd):** Hornwort extracts cadmium very efficiently even at low concentrations (accumulation factor >3000).
- **Copper (Cu) and Zinc (Zn):** The plant actively absorbs these elements, reaching maximum adsorption capacities of up to 6.17 mg/g for copper and 13.98 mg/g for zinc.
- **Chromium (Cr), Nickel (Ni), and Cobalt (Co):** These metals are also effectively removed from water, with cobalt often being absorbed even more actively than other metals.

Hornwort inhabits freshwater bodies, primarily stagnant waters, making it an indispensable natural agent for pond purification. [7].

Migration and Speciation of Heavy Metals in Aquatic Environments

Heavy metal compounds contaminate the atmosphere, soils, and water bodies, migrate through biogeochemical cycles, and enter the human body via food chains. Soil serves as the primary accumulator of heavy metals and as a source of their secondary input into surface and groundwater. It has been established that metals accumulate relatively rapidly in soils but are removed from them extremely slowly, which determines the long-term nature of contamination [8].

Metal ions are natural components of aquatic systems and may occur in dissolved, colloidal, and suspended forms. Truly dissolved forms include free ions, hydroxo-complexes, and complexes with organic and inorganic ligands. The speciation of metals depends on pH values, redox potential (Eh), temperature, and the concentration of organic matter.

Many heavy metals form stable chelate complexes with humic substances, which enhances their migration capacity in surface waters. The transformation of metals into complexed forms may alter their toxicity and bioavailability. For example, chelated forms of copper, cadmium, and mercury are generally less toxic compared to their free ionic forms [9].

An increase in heavy metal concentrations in water bodies is often associated with environmental acidification. Acid precipitation contributes to a decrease in pH and promotes the transition of metals from sorbed states into dissolved forms, thereby increasing their mobility and ecological risk [10]

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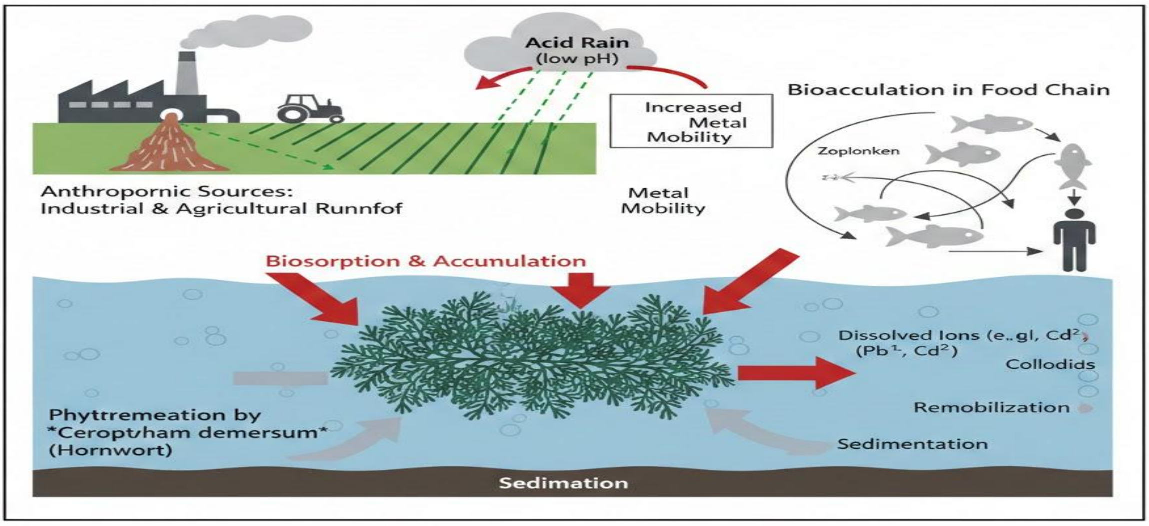

Figure 1. Pathways of Heavy Metal Migration in the Biosphere [11].

Standards for Heavy Metal Content in Water

To assess water safety, the maximum permissible concentration (MPC) indicators are used. These standards are established based on toxicological, organoleptic, general sanitary, and fishery criteria.

Exceeding MPC values may have adverse effects on public health, the natural self-purification processes of water bodies, and the overall condition of aquatic ecosystems..

Table 1 — Maximum Permissible Concentrations of Selected Metals in Water Bodies [12].

Metal	MPC (mg/dm³)	Type of Impact
Mercury (Hg)	0.0005	High toxicity
Cadmium (Cd)	0.001	High toxicity
Lead (Pb)	0.003–0.03	Sanitary-toxicological
Chromium (Cr VI)	0.05	Carcinogenic
Manganese (Mn)	0.1	Organoleptic

Biosorption as a Water Treatment Method

Biosorption is based on the ability of biological materials to bind metal ions through functional groups located on cell walls. Bacteria, fungi, algae, and higher plants are widely used as biosorbents. This method is effective at metal concentrations of 1–100 mg/L and is characterized by low cost and environmental safety [13].

Phytoremediation of Water Bodies

The phytoremediation method enables in situ (on-site) purification of water bodies. In addition to Ceratophyllum demersum, excellent results have been demonstrated by Eichhornia crassipes (water hyacinth).

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During ten-day experimental trials, it reduced copper concentrations by 8.5 times and cadmium concentrations by 6 times.

Macrophytes are also effective in removing strontium, which is chemically similar to calcium and poses a threat to human bone tissue due to its ability to accumulate in skeletal structures [14].

Removal of Strontium Ions from Water

Strontium belongs to hazard class II and enters water bodies primarily from celestine deposits. Due to its chemical similarity to calcium, strontium can replace calcium in bone tissue, leading to skeletal damage when accumulated in the body.

Studies show that aquatic macrophytes are capable of effectively accumulating strontium ions, making phytoremediation a promising alternative to conventional water treatment methods [15].

CONCLUSION AND PROSPECTS

Heavy metal contamination of water bodies in Uzbekistan, particularly within irrigation systems, represents a serious environmental and public health concern. The accumulation of Pb, Cd, Cu, Zn, Mn, Cr, Fe, and Sr creates risks of metal transfer through the "water–soil–plant–human" system, increasing the potential for long-term ecological and toxicological consequences.

It has been established that biological treatment methods provide high metal removal efficiency: lead extraction reaches 95–96%, cadmium concentration decreases by up to sixfold, copper by 8.5-fold, and zinc by more than fivefold. The adsorption capacity reaches up to 6.17 mg/g for Cu and 13.98 mg/g for Zn, while the cadmium accumulation factor exceeds 3000.

The practical significance of this research lies in the feasibility of implementing biosorption and phytoremediation technologies for the purification of irrigation waters in Uzbekistan, achieving concentrations close to maximum permissible levels (MPC) with low operational costs. A promising direction involves the development of regionally adapted biological treatment systems with integrated monitoring to prevent secondary contamination.

REFERENCES

1. Vestnik PNIPU. Applied Ecology. Urban Studies. Malygin, A. V., & Kirsanov, V. V. (2011). *Pollution of water bodies with heavy metals and methods of their purification*. No. 4. Available at: https://cyberleninka.ru/article/n/zagryaznenie-vodnyh-obektov-tyazhelymi-metallami-i-metody-ih-ochistki.
2. Bagrov, V. V., & Glybina, A. P. *Wastewater treatment from heavy metal ions*. eLIBRARY.RU. Available at: https://www.elibrary.ru/item.asp?id=18833957.
3. Ekologiya i kontrol sostoyaniya prirodnoy sredy. Izrael, Yu. A. (1984). *Ecology and Environmental Monitoring*. 2nd ed., revised. Moscow: Gidrometeoizdat, 560 p.
4. Melioratsiya zemel. Golovanov, A. I., Aidarov, I. P., & Grigorov, M. S. (2011). *Land Reclamation: University Textbook*. 2nd ed., revised and supplemented. Moscow: KolosS, 824 p.
5. Prandzhishvili, D. A. (2018). *Biosorption of heavy metals: mechanisms and prospects for biomass application*. Biotekhnologiya, Vol. 34, No. 2, pp. 15–28.
6. Vestnik Natsionalnogo universiteta Uzbekistana. Khaydarova, G. D., & Toshmatov, B. A. (2021). *The role of macrophytes in the self-purification processes of irrigation canals*. No. 2, pp. 45–50.
7. Tyazhelye metally i rasteniya. Titov, A. F., Talanova, V. V., Kaznina, N. M., & Laidinen, G. F. (2014). Petrozavodsk: Karelian Research Centre of the Russian Academy of Sciences, 194 p.
8. Soedineniya tyazhelykh metallov v pochvakh. Motuzova, G. V. (2013). *Heavy Metal Compounds in Soils: System Organization, Ecological Significance, Monitoring*. Moscow: MSU Publishing House, 208 p.
9. Gidrokhimiya. Nikanorov, A. M. (2001). *Hydrochemistry*. 2nd ed., revised and supplemented. Saint Petersburg: Gidrometeoizdat, 444 p.
10. Zakislienie vod. Moiseenko, T. I. (2003). *Water Acidification: Factors, Mechanisms, and Environmental Consequences*. Moscow: Nauka, 276 p.
11. Vestnik Permskogo natsionalnogo issledovatelskogo politekhnicheskogo universiteta. Prikladnaya ekologiya. Urbanistika. Malygin, A. V., & Kirsanov, V. V. (2011). *Pollution of water bodies with heavy metals and methods of their purification*. No. 4, pp. 86–100.
12. SanPiN RUz No. 0318-15 (2015). *Hygienic standards for maximum permissible concentrations (MPC) of chemical substances in water bodies for drinking and domestic use*. Tashkent.
13. Vestnik MGTU im. N. E. Baumana. Seriya Mashinostroenie. Bagrov, V. V., & Glybina, A. P. (2012). *Wastewater treatment from heavy metal ions*. Special Issue No. 2, pp. 195–201.
14. Izvestiya NAN RK. Seriya biologicheskaya i meditsinskaya. Shoraeva, K. A. (2018). *Application of water hyacinth (Eichhornia*

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Available Online at: https://www.scholarexpress.net
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crassipes) in phytoremediation of technogenically polluted waters.
15. Vestnik Permskogo natsionalnogo issledovatelskogo politekhnicheskogo universiteta. Prikladnaya ekologiya. Urbanistika. Gladkikh, A. A., & Pyankova, S. V. (2021). *Study of macrophytes for application in purification of natural waters from strontium ions*. No. 1 (41), pp. 106–120.