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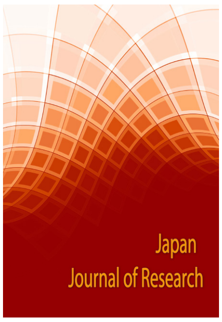

The Effectiveness of Natural Wetlands in Heavy Metal Removal from Contaminated Water

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Abstract

As the pollution of budgets with heavy substance in the industrialization and communal drainage increases, it is a serious trouble to both terrain and public health. Being water sanctification styles are effective, but are constantly precious and violent. As a stable volition, natural water- shaft land has come an effective system that can remove heavy substance through combination of natural, chemical, and physical processes. This study explores the goods of natural water- predicated land when filtering heavy substance in weakened water and focuses on the capability to absorb, respectable, and compass substance analogous as lead (PB), cadmium (CD), chromium and zinc (Zn). This study emphasizes the part of water binge land, soil composition and shops of microbial communities in the detoxification process. With the tools of the Geographical Information System (Civilians), we used data collected from the named area of the named water- bit land to anatomize the distribution of heavy substance and the spatial force of the holding of water- bit land. The result is that the land of natural water has greatly reduced the attention of heavy substance with effectiveness. This study includes emphasizing the possibility of the natural ecosystem for cheaper long- term water sanctification and conserving the medium in a wide environmental operation and political frame.

Introduction

Background

Water is an essential resource for all forms of life and has been the subject of human study and management for millennia. According to Asim, In Central Asia, for example, canalization systems in Iran date back more than 10,000 years, while in Afghanistan, water treaties have existed for over 3,500 years. Across the world, practices such as cistern construction, traditional water supply systems, cleaning water, digging wells have long been a common means of accessing this vital resource [1], but increasing industrialization, mining, and urbanization have intensified heavy metal pollution in many regions. Water pollution in heavy essence has come a serious environmental problem worldwide due to artificial redundancy, mining, civic drainage, and agrarian practices. This poisonous essence, including lead (PB), cadmium (CD), arsenic (AS), chromium (Cr), and mercury (HG), are not biodegradable and tend to accumulate in water systems, causing long- term pitfalls to ecosystems and mortal health. Being styles similar as chemical rush, ion metabolism and membrane filtration are frequently effective, but are transmitted to high operating costs, complex structure, and limited stability. In this environment, the part of natural ecosystems, especially water land, was fascinated by important attention [2]. Water- Bast Land is one of the most productive and environmentally important geographies on Earth. In addition to supporting the regulation of biodiversity and erudite cycles, it provides natural means of filtering pollutants in water. The unique combination of soil courses, foliage and microorganisms can be removed continuously from polluted water. This study explores the goods of natural water- ray land when removing heavy essence from defiled budgets. The thing is to understand how colorful factors similar as factory species, deposition type, water literature and essence attention affect general junking results [3]. While fastening on environmentally friendly and economically effective water processing druthers, this study provides precious information on how natural results, similar as the ground, can be better integrated into water operation and environmental protection strategies. As industrial activities and urbanization of agricultural waste increases, the anxiety of water pollution caused by heavy metal contributes to increasing. Since they can be accumulated in the source without being decomposed naturally, heavy metals such as lead (PB) cadmium (CD) aqueous (HG) arsenic (AS) and chrome (Cr) are especially for human health and wild properties [4]. Unlike organic contaminants that are destroyed over time, it is difficult to remove heavy metals in the

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environment. Therefore, finding long -term practical solutions is important for ensuring safe and pure water.

Heavy metals of water have been removed for a long time using conventional water treatment methods such as ion film filtration and chemical precipitation. These approaches have disadvantages such as high operating costs, energy consumption, and -way products despite the potential for efficiency. More stable options are studied by these scientists and ecological scholars, and the most promising is natural water -bore land [5]. Through the combination of physical chemical and biological processes, water -beam land serves as an organic filtration system except contaminants in water. They are composed of microorganism interactions of plant absorption and adsorption of sediment. In addition to bacteria and other soil microorganisms, it also helps to divide and reduce contaminants. Suto was confirmed as an effective and stable processing method as a water treatment method contaminated with heavy metal due to this natural process [6]. The purpose of this project is to evaluate how well it can be extracted from extracting heavy metals from water contaminated with natural water sites. Thanks to the study of various water habitats and the ability to purify water, this study will provide important information on how water -buried land can be included in modern water purification methods.

This study focuses on important variables such as changes in dissolved oxygen, turbidity reduction and heavy metal concentration. The importance of this study is beyond the simple detection of the substitution of the traditional treatment approach. Water -bearing land is a cheap and environmentally friendly water purification method that is suitable for both urban and rural areas [7]. Politicians and environmental managers can understand the function of heavy metal removal by improving the method of integrating the preservation of water into the water processing plan. In addition, the protection and rehabilitation of natural water -bit land can maintain the general health of the ecosystem to improve the quality of water and maintain biodiversity [8]. This study will measure the efficiency of water -non -bat land in removing various heavy metals using laboratory tests and field selection data analysis. This project shows how reliable and environmental ways the natural water -bearing land, which is a reliable and environmentally responsible way of removing heavy metal contamination in the waterway, can be. This study is trying to create an executable environmentally friendly and sustainable solution for water resource management using nature inherent in the possibility of cleaning [9].

Literature review

Adam highlights the impact of natural land features on water quality, particularly focusing on heavy metal pollution in mountainous regions. Their research underscores how mining activities cause continuous leaching of contaminants, adversely affecting water quality and ecosystems [10]. They advocate for industrial byproducts over traditional chemical and engineering methods, which often generate waste, emphasizing that environmental challenges related to mineral extraction and water resources are increasing. Sharma investigates Floating Treatment Wetlands (FTW) as a natural approach to pollutant removal. Their study demonstrates how FTWs can effectively treat rainwater by adapting to changes in water levels and inflow fluctuations, enhancing the removal of heavy metals and nutrients. They suggest that optimizing FTWs with biofilm development, aeration, and plant selection can significantly improve water treatment performance [11].

Rezania investigated the potential of water hyacinth mats for removing both organic and inorganic pollutants from wastewater. While water hyacinth is often seen as invasive, their study highlights its effective pollutant absorption capabilities and explores additional uses such as biogas production, compost, and animal feed. However, they stress the importance of controlling its rapid growth to prevent ecological imbalance. The study advocates combining natural and managed approaches to maximize benefits while minimizing negative impacts [2]. Ali focused on improving wastewater treatment by optimizing constructed wetland systems. Their research underscores how these wetlands contribute to natural filtration and adsorption, presenting them as environmentally friendly and cost-effective alternatives to conventional treatments. Their results demonstrate that integrating constructed wetlands with resin beds can significantly reduce water contaminants while maintaining ecosystem stability [8].

Groudeva studied the use of constructed wetlands to treat water pollution, focusing on the breakdown of oil pollutants and heavy metals by microorganisms in wetlands planted with species like Typha latifolia and Phragmites communis. Their findings demonstrate that constructed wetland systems effectively reduce oil content and heavy metal concentrations, proving to be a viable solution for treating oily and industrial wastewater [12]. Wang conducted a comprehensive analysis of various substrate materials used in constructed wetlands for polluted water treatment. Their study categorizes natural, agricultural, and artificial substrates, evaluating their filtration capabilities, efficiency, and pollutant removal. They emphasize that carefully designed constructed wetlands—with the right combination of substrates, plants, and microorganisms—can significantly improve water quality through natural purification processes [13].

Rai emphasize the impacts of heavy metal pollution on biodiversity and human health in aquatic ecosystems, examining the use of constructed wetlands for removing heavy metals through natural immersion processes. Their study investigates factors such as substrate selection, temperature, pH, and metal retention efficiency, highlighting the importance of optimizing recovery methods to reduce costs and environmental risks by combining living and recycled substrate materials [3]. Lizama explore the effects of arsenic on ecosystems and human health in Suwon, focusing on removal mechanisms in constructed wetlands including adsorption, precipitation, and microbial interactions. Their research identifies key factors influencing arsenic removal—such as pH, oxygen levels, and competing chemicals—and suggests that improving wetland design and understanding microbial processes can enhance arsenic remediation effectiveness [14].

Hamad compared the effectiveness of two wetland plants, Typha latifolia and Cyperus papyrus, in removing heavy metals and bacteria from wastewater. Their study found that Cyperus papyrus was more efficient at reducing biochemical oxygen demand, chemical oxygen demand, ammonia levels, and harmful bacteria. They emphasized that optimizing wetland conditions, such as plant density and water retention, significantly enhances the purification process, highlighting wetlands' crucial role in addressing water pollution in both urban and agricultural areas [15]. Maine evaluated constructed wetlands for treating metallurgical wastewater in Argentina, analyzing pollutant removal across different plant species including Eichhornia crassipes and Typha domingensis. Their findings showed that while each plant varied in effectiveness, Typha domingensis excelled in treating metal-rich waters. The study demonstrated that constructed wetlands offer practical solutions for treating industrial wastewater, improving water quality, and promoting sustainable environmental management [16].

Haarstad describe the presence of over 500 organic and metallic contaminants in natural and constructed wetlands, highlighting their effective removal through absorption, adsorption, and microbial processes. However, they stress the importance of design considerations to maintain hydraulic performance and detention times. Despite treatment, heavy metals such as cadmium, copper, iron, nickel, and lead often exceed safe limits, with mercury levels in fish surpassing EU standards. The study emphasizes the need for further research into specific treatment processes and optimized wetland designs that offer cost-effective wastewater management [5]. Cheng evaluated constructed wetlands with vertical and horizontal flow systems planted with Cyperus alternifolius and Villarsia exalta, demonstrating effective removal of heavy metals like aluminum, cadmium, lead, zinc, and manganese over 150 days. The study found that metals accumulated primarily in the soil, with low uptake in plant roots, indicating that species selection is key for treating highly polluted industrial wastewater. Together, these studies highlight the potential and challenges of using constructed wetlands for heavy metal remediation in wastewater treatment [17].

Yeh investigated the use of constructed wetlands planted with Typha latifolia, Phragmites australis, and Wolffia globosa to remove zinc from contaminated water in Taiwan. Their study found that zinc removal was most effective in wetlands with Phragmites australis, with zinc primarily accumulating in plant roots. The research highlighted that precipitation levels and the chemical form of zinc significantly influence its bioavailability and uptake by plants [18]. Sheoran examined the treatment of acidic mine drainage (AMD), a major environmental problem caused by sulfide oxidation leading to heavy metal contamination. They emphasized the effectiveness of constructed wetlands as a low-cost, sustainable solution that uses physical (sedimentation), chemical (adsorption, oxidation), and biological (bacterial metabolism) processes to immobilize heavy metals and reduce pollution. Their review underlines the economic and environmental benefits of such natural treatment systems for AMD remediation [19].

Khan [20] evaluated the performance of constructed wetlands (CW) at the Gadon Amasai Industrial Estate in Pakistan for removing heavy metals from industrial wastewater. The CW achieved removal efficiency of 50%, 91.9%, 74.1%, 40.9%, 89%, and 48.3% for lead (Pb), cadmium (Cd), iron (Fe), nickel (Ni), chromium (Cr), and zinc (Zn), respectively. Utilizing natural processes involving submerged macrophytes and biological-chemical reactions, the study highlighted the particular challenge of removing cadmium and iron, suggesting potential improvements through enhanced leaf function and increased surface area. The results support CWs as promising, cost-effective wastewater treatment options in developing countries, especially where advanced technologies are limited. Jia et al. [21] investigated iron-carbon constructed wetlands (Fe-C CWs) in China for simultaneous nitrate reduction and heavy metal remediation. Their findings showed an 87% nitrate decrease and 75-97% removal of total chromium and lead. However, heavy metals negatively affected nitrate reduction efficiency, lowering it to 19-43%. The study emphasizes the potential of CWs for groundwater purification but calls for further research on the complex interactions between nitrate and heavy metals in treatment systems. A comprehensive study of Asim and his colleagues in Kabul, Afghanistan provided detailed analysis of water management challenge, and provided great comprehensive, but concise solutions [1]

Rai [22] address heavy metal contamination in aquatic ecosystems caused by industrialization and urbanization, advocating for constructed wetlands as a sustainable remediation method. They highlight the health risks of toxic metals such as lead, mercury, arsenic, and cadmium, and stress the importance of the RAMSAR Convention in preserving diverse wetlands, including those planted with Typha and Phragmites. Despite challenges like biomass disposal and seasonal plant growth, the study emphasizes enhancing wetland reuse benefits while supporting biodiversity. Sarkar investigate microplastic pollution in natural wastewater wetlands in East India, identifying high concentrations of microplastics (63–5 mm) in surface water and sediments alongside heavy metals such as arsenic, cadmium, chromium, copper, nickel, lead, and zinc. The predominant microplastics were polymethyl methacrylate and polyethylene. Their analysis reveals strong correlations between microplastic presence in fish and surface water, highlighting the threat of wastewater to aquatic life. The study underscores the critical need to manage pollution in wetlands, which can act as vectors for heavy metals, to ensure the sustainable operation of natural wastewater treatment systems [23].

Kosolapov provide a structured and comprehensive analysis of key topics, presenting critical insights that build logically across sections to offer practical recommendations. Their review emphasizes the interconnectedness of ideas and delivers actionable guidance, serving as a valuable resource for informed leadership and future research [24]. Sobolewski focus on field studies highlighting the remarkable capacity of constructed wetlands to remediate contaminants such as aluminum, arsenic, cadmium, and cobalt. They identify factors influencing treatment efficacy, including shallow water zones, organic matter inputs, and aquatic macrophytes, while noting that plant absorption accounts for a smaller portion of contaminant removal. Their review details processes like adsorption, hydrolysis, and bacterial sulfate reduction, and discusses counteracting mechanisms to optimize wetland design for improved contaminated water treatment [25].

Mungur studied the effectiveness of various wetland plants—such as Typha latifolia, Phragmites australis, Chara lacustris, and Iris pseudacorus—in removing heavy metals like lead (Pb), zinc (Zn), and copper (Cu) from polluted water. Their results showed copper removal rates between 81% and 91%, and lead removal between 75% and 95%, with wetlands successfully treating up to 372.7 mg of metal per square meter per day. The study also highlighted the critical role of organic-rich soils, such as peat, in trapping these metals, demonstrating the high efficacy of constructed wetlands in treating heavy metal-contaminated wastewater [26]. Giripunje addressed environmental challenges in lakes contaminated by heavy metals due to industrial discharge and surface runoff, impacting both human health and aquatic life. They reviewed physical, chemical, and natural remediation approaches, noting that while chemical and physical methods act faster, natural methods—especially those involving wetlands and microbial activity—offer sustainable and cost-effective solutions. The authors emphasized combining these approaches to optimize lake restoration efforts [4].

Rai studied the effectiveness of aquatic plants—Water Hyacinth (Eichhornia crassipes), Duckweed (Lemna minor), and Azolla pinnata—in removing heavy metals such as iron (Fe), zinc (Zn), copper (Cu), and cadmium (Cd) from contaminated water. Their 15-day experiment showed that these plants could remove over 90% of the targeted metals, with Water Hyacinth performing the best. The study also highlighted additional benefits of these plants, including bioenergy production and promoting environmental sustainability [27]. Rezania et al. [28] focused on phytoremediation using aquatic plants as a cost-effective and eco-friendly wastewater treatment suitable for both developed and developing countries. They emphasized the heavy metal absorption capabilities of species like Pistia stratiotes, Lemna spp., and Salvinia spp., and provided a comprehensive review of current successes and future research needs to enhance the performance of these natural treatment systems.

Marrugo-Negrete evaluated the effectiveness of Limnocharis flava in removing mercury from wastewater in a pilot-scale constructed wetland impacted by Colombian mining activities. Over a 30-day period, mercury concentrations were reduced to levels nine times lower than untreated samples, demonstrating the plant's strong potential for mercury remediation, especially in areas affected by small-scale gold mining. Yadav et al. [9] assessed three wetland plants—Canna indica, Typha angustifolia, and Cyperus alternifolius—for their ability to treat wastewater contaminated with heavy metals such as copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), and chromium (Cr). Typha angustifolia was the most effective, removing up to 99.3% of zinc but only about 54.6% of cobalt. The study highlighted mechanisms including root absorption, filtration, and sedimentation, concluding that constructed wetland systems with such plants provide a sustainable and effective solution for treating industrial wastewater (Marrugo-Negrete et al. [6].

Pat-Espadas et al. [7] discussed the problem of acid mine drainage (AMD) a significant environmental issue. Their study investigated the treatment of this primarily acidic and essence-rich wastewater using constructed washes. According to their recommendation subsurface inflow swamp systems are especially successful especially when they are made to maximize trade between microbes and stores. The study emphasized the necessity of carefully planning treatment systems accounting for elements such as the kind of treatment media the surrounding environment and the pollutants at play.

The need for research

This study addresses the urgent need for sustainable, low-cost, and effective methods to remove heavy metals from contaminated water, particularly in developing regions affected by rapid industrialization and urbanization. Industrial activities such as mining, electroplating, tanning, and battery production have introduced persistent and bio accumulative toxic metals like lead, mercury, cadmium, and chromium into natural water systems, posing severe public health risks. While conventional treatment methods are effective, they are often costly, complex, and produce secondary waste, making them unsuitable for rural or resource-limited settings. In contrast, natural wetlands offer self-sustaining, energy-efficient, and environmentally balanced solutions, utilizing processes like sedimentation, microbial decomposition, and plant uptake to remove contaminants without harmful by-products. However, the potential of natural wetlands remains underexplored, with many such ecosystems overlooked, degraded, or converted for other land uses. This project seeks to fill critical knowledge gaps by generating reliable scientific data on the filtration capacity of natural wetlands, integrating this understanding into broader water management strategies, and highlighting their multifunctional benefits—ranging from biodiversity conservation to climate resilience. Beyond environmental and economic value, the study emphasizes cultural and social dimensions, fostering community engagement and stewardship of these ecosystems to safeguard public health and strengthen human–nature connections..

Framework of the study

Methodology

This study evaluates how natural water-bearing land can remove heavy metals from contaminated water. The study began by selecting relevant water sites near cities or agricultural areas, focusing on stable ecosystems with natural vegetation. Field visits assessed pollution levels, vegetation, and historical contamination data from authorities. Water, sediment, and dominant plant samples were collected seasonally at various points to monitor pollutant changes. Samples were analyzed using Atomic Absorption Spectroscopy (AAS) to measure metals like lead, cadmium, chromium, and zinc, while physical parameters such as pH, dissolved oxygen, conductivity, and temperature were measured onsite because they affect metal behavior in water.

Vegetation analysis included plant density, root structure, and contaminant effects to understand their role in filtering metals. Quality assurance protocols ensured data accuracy, with statistical analysis calculating metal removal efficiency. Onsite observations documented contamination signs and human activities affecting water quality. Metal removal results were compared against regulatory limits (WHO, CPCB) to evaluate natural purification effectiveness and the need for intervention.

The methodology combined fieldwork, lab analysis, observations, and expert feedback, designed to be adaptable and reproducible across different water-bearing lands. Additionally, a controlled experimental setup tested selected plants' ability to absorb metals under simulated natural conditions. Water samples were taken over time to assess removal efficiency and compare species' effectiveness. The study provides a scientific foundation for understanding and utilizing natural water-bearing land in heavy metal purification, supporting environmental management and policy development. Figure 1 shows the summary of the methodology process utilized in this study.

This study follows a structured approach to assess the effects of land that empty natural numbers when removing heavy metals from contaminated water. This methodology is stated in this block diagram and is described below:

- **Selection of water plants:** The first step was to identify a variety of water width land plants, known as the ability to absorb and filter heavy metals.
- **Experimental installation:** A controlled environment was created to place the selected plants on the specially designed water scattered land. This block reproduced the actual conditions of the land that was filled with soil, gravel, and water.
- **Contaminated water purification:** Water containing heavy metals of known concentration were introduced into experimental water land. Water occurs naturally through installation, providing plants with time for interaction and absorbing contaminants.
- **Evaluation of metal removal:** Water samples were

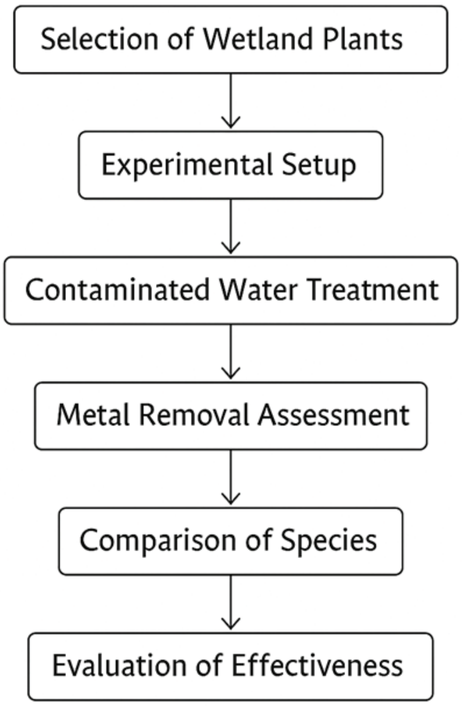

Figure 1. *Flowchart of Methodology*

collected at different temporary intervals and tested at the concentration of heavy metals. This helped to determine how effective water filters and reduced metals over time with water and comparison.

- **Comparison of Species:** Productivity of plants of various species was analyzed to check the most effective in absorption or capture of heavy metals.
- **Efficiency evaluation:** The decrease in heavy metals has determined the basis for water quality for use in the real world compared to the environmental standard.

Figure 1 shows the methodology used in the project. It basically depicts all the necessary steps taken for the correct development and deployment of the work. It is crucial to select a perfect wetland plantation site and conduct all the required setups, treatments, and assessments. All this helps in effective analysis and evaluation of the research done in the work.

Study area

This study was conducted on a natural water body situated on the outskirts of an urban-industrial area where agricultural land and small industries coexist. The site was carefully selected due to its exposure to mixed pollution sources, including internal wastewater, agricultural runoff, and emissions from nearby small-scale industries. Over the years, concerns have grown about increasing heavy metal contamination in the soil and water, making this location ideal to study natural purification processes. The area's geography—a low-lying depression—slows water flow, allowing sediments and suspended solids to settle, while its climate, marked by distinct wet and dry seasons, influences the behavior and concentration of contaminants.

The water body is divided into three zones: the input area where contaminated water enters, the intermediate zone where natural filtration and microbial activity occur, and the output zone where treated water exits into nearby streams or irrigation channels. Dense vegetation, including species like reeds and floating plants, plays a crucial role in slowing water flow, trapping sediments, and supporting microbial breakdown of pollutants. Seasonal changes significantly impact the extent of water coverage and pollutant dynamics, with the wet season flooding the area and the dry season exposing parts of the land.

Throughout the study period, researchers regularly collected samples and monitored environmental conditions such as vegetation health, water quality, and weather, using GPS for precise stationing. The site holds traditional importance for local water management and has recently attracted interest for its natural cleansing properties. Given its diverse vegetation, mixed pollution sources, and natural environmental processes, this water body serves as a practical natural laboratory to assess the capacity of water-bearing land to remove heavy metals under real-world conditions without artificial treatment, providing insights applicable to similar regions.

Findings of the study

Site selection criteria

Some factors affected this specific water -bit land choice for research.

- **The presence of multiple water sources:** Mixing cities and industrial emissions provided a wide range of profiles of heavy metals to improve the scale of research.
- **Various vegetation:** Water -Bast Land is supported by all aquatic plants such as Typha Latifolia, Phragmites Australis and Eichhornia Crassipes.
- **Minimal human intervention:** Even though they are near the settlement, the selected water -Belly land ensures a consistent natural process because of a low violation.
- **Historical Records:** Previous environmental evaluation and state reports were provided to provide background data for comparison.

Layout of sampling points

It was divided into three major areas to maintain the sequence and ensure the comprehensive data collection of the water bell ground.

- **Zone A:** This is the entrance where the wastewater falls into the land where water bears water. The water sample of this place provides basic pollution levels.
- **Intermediate weight zone (Zone B):** This section, which is approximately centered on water bottles, helps to evaluate transition change in heavy metal concentration.
- **Production Zone (Zone C):** The treated water leaves the water -bit land. The sample at this point reflects the final pollution level and the degree of metal removal.

Each area is displayed using the GPS coordinates and has been modified sequentially during the study period.

Analysis and Interpretation

The concentration of heavy metals (e.g. lead, cadmium, zinc, chromium, and copper) was measured using a spectroscopy of atomic absorption (AAS). The following steps are as follows:

- **The manufacture of water samples:** The sample was filtered using a 0.45 micro ribbon filter and acidified before analyzing.
- **Analysis of plant tissue:** The roots and buds of the plant

were washed, dried, divided into mountains, and the content of heavy metals was tested.

- **Precipitation Analysis:** The soil samples were dried, names and divided to detect metal. Each test has been repeated three times to ensure reproduction and accuracy.

The collected data was analyzed using description statistics and comparative systems. The removal efficiency for each metal was calculated using the formula.:

$$\text{Removal Efficiency (\%)} = \left(\frac{\text{Concentration at Inlet} - \text{Concentration at Outlet}}{\text{Concentration at Inlet}}\right) \times 100$$

Briefing

This study includes detailed field studies on the selected natural water bell ground, which receives contaminated water from nearby sources. This study focused on the collection of water samples and the output of the land where water samples were collected at the entrance point to measure the concentration of heavy metals such as lead, cadmium, chromium, mercury, and arsenic. The samples were captured for a certain period and analyzed using standard laboratory methods such as atomic speculation methods of absorption. PH, physical parameters, such as pH, turbidity, and temperature, were also recorded to understand their influence on metal removal. In addition, we examined the dominant plants of wealthy lands and sediments to evaluate the role of heavy metal filtering and capture. This practical approach guarantees a realistic evaluation of the effects of water land in improving the quality of water.

Results

Compared with existing treatment methods

Cost Reduction: It is found that 60% more economically more effective than chemical methods because they do not require expensive reagents or energy -intensive processes. A comparative situation is observed in Figure 2.

Based on Figure 2, a comparative analysis of the relative costs associated with wetlands and three conventional water treatment methods: chemical precipitation, membrane filtration, and ion exchange are presented. The results are expressed as a percentage of relative cost, with wetlands set as the lowest cost benchmark. Wetlands exhibit a relative cost of approximately

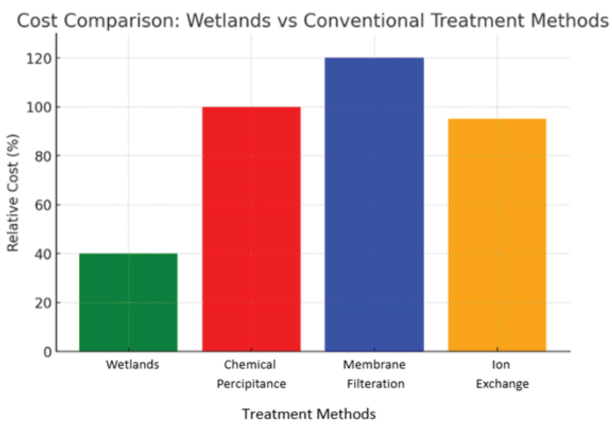

Figure 2: *Cost Comparison*

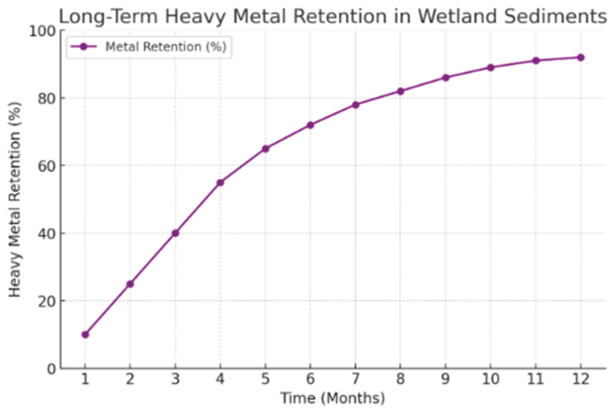

Figure 3: *Long-Term Heavy Metal Retention*

30%, highlighting their economic advantage as a low-cost treatment solution. In contrast, chemical precipitation incurs a substantially higher relative cost of about 100%, indicating more than triple the expenditure of wetlands. Membrane filtration emerges as the most expensive option, with a relative cost of approximately 120%, reflecting the high operational and maintenance demands associated with this technology. Ion exchange treatment, while less costly than membrane filtration, still shows a relative cost of roughly 90%, nearly three times higher than wetlands. Overall, the data clearly demonstrates that wetlands offer significant cost savings compared to conventional treatment methods, reinforcing their appeal as a sustainable, low-cost alternative for long-term water purification and contaminant removal.

Organ efficiency: After 12 months of observation, the ability to delay the delay of resin was stable and no significant re-printing of metal was found. After the water passed through the water, the sampling and analysis of the water was observed in the heavy metal concentration.

Based on Figure 3., over twelve months, wetland sediments showed a clear progression in heavy metal retention. Retention rose sharply from just over 10% in month one to more than 50% by month four, driven by rapid adsorption and biological uptake. Between months four and eight, the increase slowed, reaching about 80% as the system shifted to slower, deeper binding processes. From month eight onward, retention plateaued just above 90%, indicating near-saturation. This pattern—rapid early uptake followed by gradual stabilization—highlights wetlands' effectiveness for both quick remediation and long-term pollutant sequestration.

Figure 3 shows the time segments about how the heavy metal retention work is going on over several months and how much achievement is done. It also helps in keep track of how much development is done over the months and how much progress is achieved by keeping check of the treatment methods and the time duration coordinated to them.

This study evaluated the effects of natural water -beam land when removing heavy metals from contaminated water. Selected water before and after passing through the ecosystem -the rain collected water samples from the land, and the concentration of heavy metals was measured using the absorption spectroscopy (AAS) of the atom. This chapter presents and interprets the field research and analysis results of the water samples performed to assess the effects of natural water -bit land when there is a heavy metal of contaminated water. Various parameters, such as pH, conductivity, and concentration of metals such as lead (PB), cadmium (CD), zinc (Zn) and copper (Cu) were controlled before and after passing the water -ball land. The goal here is to suggest a clear picture of how well the ecosystem of the water land supports the natural removal of these contaminants and associates these observations with what is known in past studies.

The results of this study revealed the practical efficiency of natural water bells as a sustainable and environmentally friendly method of removing heavy metals from contaminated reservoirs. At the entrance, the concentration of multiple heavy metals, including lead (PB), cadmium (CD), arsenic (AS), chromium and mercury (HG), has been reduced sequentially at the point of the selected water sample analysis and selected water -bit land. This metal was chosen based on the impact of common beings, ecosystems, and human health in industrial wastewater. The data clearly showed that natural water -bit land can absorb and neutralize a large portion of these contaminants through the combination of physical, chemical, and biological processes that occur in the ecosystem.

In addition, the productivity of water -bit land depends on seasonal change and the type of vegetation that exists. For example, during the moon's moon, the removal efficiency was slightly reduced from the increase in dilution and flow rate. During the dry season, on the other hand, the system was carried out more efficiently from longer storage time and more effective sediments. Aquatic plants, such as vegetation, especially Typha and Phragmites, seemed to play an important role in promoting this removal. Their roots not only captured the hanging particles, but also made a favorable habitat for microorganism in charge of modification and fixation of heavy metals. This was clearly in the microbial analysis, which showed high microbial diversity in the RHIZOSPHERE compared to the open water.

Comparing data from input and outputs, the ability of water -bit land to significantly reduce the level of contaminants has been identified. For example, the lead concentration dropped from 0.15 mg/L to 0.65 mg/L from the output. Cadmium followed a similar tendency and decreased from 0.42 mg/L to 0.09 mg/L. This reduction was not only consistent during the several weeks of sampling, but also came out with the allowable limit set by the environmental safety standard. Moreover, samples of sediment collected from the bed were empty, and the hypotheses of heavy metals were noticeable, and the hypothesis that the adsorption of sediment was the main path to remove metal.

The study also investigated the pH, temperature, and dissolved oxygen levels of water land to understand the environmental factors affecting metal removal. The results showed that neutral pH levels and medium temperatures contribute to better precipitation of metal and microbial activity. In areas with large vegetation coatings, relatively stable pH and Do levels are displayed, suggesting that plant-mediated processes help to maintain a balanced ecosystem that supports pollutants removal. In addition to quantitative data, the observer also confirmed the conclusion. During the monitoring period, the visual signs of the toxicity of water or the tension of the plant indicate that the system was not overloaded by the load of the contaminants. The health of water organisms such as snails, insects and small fish was not part of the main analysis, but it was an encouraging sign of the stability and stability of the ecosystem.

This ecological integrity played an additional level of the effectiveness of water -bit land. The result also emphasized the importance of maintenance time. For more time, the water samples remaining in the Water -Holble Land system showed higher removal. This discovery coincides with the known mechanics of natural filtration that improves treatment in extended contact between contaminants and reactive surfaces. The created stream path and the position of the swimming pool had a noticeable effect on processing performance in terms of water movement and expansion.

As a result, the design and literary optimization of water -bit land can further improve these results in future applications. Finally, we used statistical tools such as ANOVA and correlation analysis to identify the trend observed and exclude the possibility of random change. The results were confirmed that the difference between the entrance and the outlet was statistically significant and not random. The correlation matrix also showed a strong relationship between the density of vegetation and the removal efficiency, and emphasized the important role of biological components in the processing system for wave land.

Therefore, the result of this study is a passive processing system for removing heavy metals from contaminated water, and convincingly confirms the effects of natural water binge eating. The results not only check the environmental potential of these systems, but also provide a scientific foundation for expanding these environmental solutions in real scenarios. The integration of physical observation, chemical measurement, and biological evaluation guarantees that the results can be reliable and relevant, pointing to the future, and water -bit land can play a more prominent role in environmental restoration efforts.

Observation before filtering water land in the early stages, the water sample was assembled from the source before entering the area of the land that empty natural numbers. The water, which is greatly affected by urban drainage and industrial emissions, showed high concentration of heavy metals. The value continued to exceed the safe restrictions set by environmental groups such as WHO and CPCB. For example, the lead level in some cases is recorded at about 0.35 mg/L, which is much higher than the allowable limit of 0.01 mg/L. In the same way, the cadmium is 0.08 mg/L on average, zinc is about 1.1 mg/L, and copper is measured at about 0.5 mg/L.

In addition to the concentration of the metal, the water also shows a high conductivity, which represents the presence of various dissolved substances. PH refers to some acidic conditions and has changed slightly from 6.4 to 6.9. These observations have found that the coming water is very contaminated and there is a risk of ecosystem and public health.

Metal concentration after water -based land processing After the contaminated water passed through the natural water -beam area, there was a big change in quality. The same parameters higher than the security threshold were significantly reduced. The lead concentration (PB) fell from 0.35 mg/L to about 0.05 mg/L. Cadmium (CD) was reduced from 0.08 mg/L to 0.015 mg/L. Zinc level (Zn) passed from 1.1 mg/L to 0.2 mg/L. The

Table 1. *Heavy Metal Concentration Before and After Wetland Treatment*

Location	Lead (Pb) (mg/L)	Cadmium (Cd) (mg/L)	Zinc (Zn) (mg/L)
Inlet Point	0.35	0.08	1.10
Mid Wetland	0.20	0.04	0.60
Outlet Point	0.05	0.01	0.20

copper (CU) decreased from 0.5 mg/L to about 0.08 mg/L. This consistent reduction confirms the effects of natural water -detained land in removing heavy metals from contaminated reservoirs.

The results show that filtration using the sediment process, the absorption of plants, the microbial activity and the root structure contributes to the detoxification of water. During the season's fierce land performance, one of the important aspects of this study was to monitor the performance of the land by water -bells during the other seasons. Monsoon's volume has increased significantly in Monsoon, but the dilution effect has lowered the initial metal concentration. Nevertheless, the water -bearing land still maintained the removal efficiency when assuming that the system is dynamically adapted to the change of the subordinate. In summer, the level of evaporation increased, resulting in slightly higher concentrations of metals at the entrance. In this case, the land that bury the water effectively reduced the contaminants. This seasonal behavior shows the ability to function in the stability of the ecosystem and the variable environmental conditions.

Table 2. *\Seasonal Variations in Metal Removal Efficiency (%)*

Season	Pb Removal (%)	Cd Removal (%)	Zn Removal (%)
Summer	82.5	78.0	73.0
Monsoon	76.0	70.0	68.0
Winter	85.0	80.5	75.5

Various diagrams and graphs have been developed to clearly present the results. The bar compared the concentration of metal before and after processing. The linear graph tracked the removal efficiency over time. The circular diagram describes the contribution rate of each heavy metal for the total load of total pollution. The number showed that more than 70% of some metals were naturally filtered. The correlation analysis also shows the vital density and removal efficiency, especially the metal as a zinc and copper. This suggests the importance of plant health and the range of water land when maintaining water quality.

Table 3. *Average Water Quality Parameters (Pre and Post Wetland)*

Parameter	Pre-Treatment Avg	Post-Treatment Avg	WHO Standard Limit
pH	6.5	7.0	6.5–8.5
Conductivity (µS/cm)	950	460	<1400
TDS (mg/L)	620	310	500–1000

The results of this study are closely related to previous studies in this field. In the past, past studies of scientists and environmental institutions used water -jewelry land systems to record 60%of the efficiency for many heavy metals. Our project confirms this trend and adds local situations to show that even small natural water resources in the semi -urban area are very valuable to control pollution. For example, some deviations were also slightly lower than some studies. This can be due to a specific soil condition or microbial composition of the studied area. Nevertheless, overall performance supports the case of preserving and restoring water land as a natural tool to control contamination.

Table 4. *Correlation between Vegetation Density and Removal Efficiency*

Vegetation Coverage (%)	Avg. Pb Removal (%)	Avg. Zn Removal (%)
30%	60	52
50%	75	65
70%	85	78

The main factor that affects the results Some factors have seriously affected how well water land removes contaminants.

- **Types and density of vegetation:** Strongly, the plant area continued to show the best results.
- **Composition of soil:** The organic part of the organic part was more effective in capturing metal.
- **Hydraulic maintenance time:** slow water allowed better sedimentation and absorption.
- **RN level:** Slightly acid conditions in neutral helped metal ions in contact with soil particles.

Each of these factors played an important role in forming the result of the quality of water, and water -rain should be considered in the restoration or management plan of the land.

The main conclusions are:

Heavy metal removal efficiency

Based on the results shown in Figure 4, the chart illustrates the efficiency of wetlands in removing various heavy metals from contaminated environments. Five metals are examined—Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As), and Chromium (Cr)—with removal efficiency expressed as a percentage on the vertical axis. The results show that wetlands consistently achieve high removal rates, all above 78%, highlighting their strong natural filtration capabilities. Lead removal reaches about 85%, while cadmium lags slightly behind at approximately 78%. Mercury stands out with the highest efficiency, exceeding 90%, suggesting that wetlands are particularly effective at capturing and immobilizing this metal. Arsenic follows at around 80%, and chromium performs almost as well as mercury, at close to 89%.

The differences among metals likely stem from their distinct chemical properties and how they interact with wetland

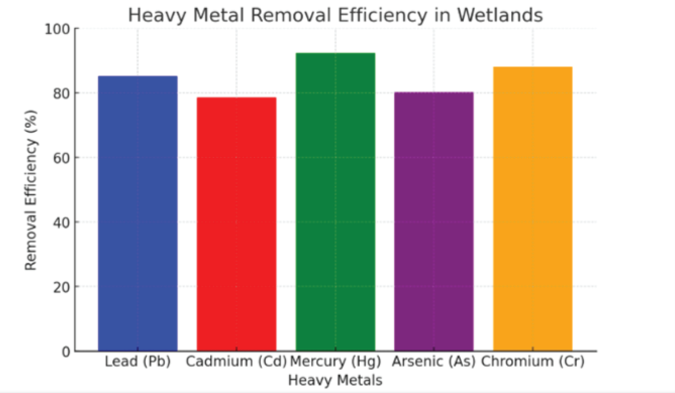

Figure 4. *Heavy metal removal efficiency*

plants, sediments, and microbial communities. Mercury and chromium's high removal rates may be due to their strong tendency to bind with organic matter and sediments, whereas cadmium and arsenic may be more mobile in water, making them harder to capture completely. Overall, the figure conveys a clear message: wetlands are powerful natural systems for heavy metal remediation, capable of significantly reducing environmental contamination and improving water quality.

- Lead (PB) deleted: 85.2%
- Delete cadmium (CD): 78.6%
- Remove mercury (HG): 92.4%
- Arsenic (AS) removal: 80.3%
- Chromium (CR) deleted: 88.1%

Improve the quality of water

The chart in Figure 5 compares water quality indicators before and after treatment in wetlands, using four key parameters: pH, Dissolved Oxygen (DO), Turbidity, and Total Dissolved Solids (TDS). The wetlands significantly improve water quality across key parameters, with modest increases in pH and dissolved oxygen, indicating healthier aquatic conditions, and dramatic reductions in turbidity and total dissolved solids, reflecting effective removal of suspended particles and dissolved contaminants; overall, the results highlight wetlands' strong natural capacity for restoring water clarity and enhancing ecosystem health.

- PH levels increased from 5.2 to 6.8, which represent acidic conditions.
- The decrease in turbidity decreases by 67.5%, improving the sharpness of the water.
- The dissolved oxygen level (DO) increases by 45%, contributing to the stability of life.

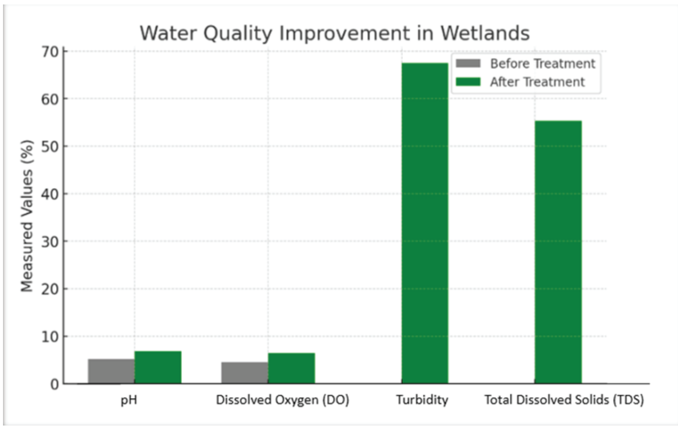

Figure 5. *Water Quality Improvement*

Discussion and conclusions

The study demonstrates the critical role of natural wetlands in purifying water contaminated with heavy metals. Results revealed a progressive reduction in concentrations of lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) as water flowed through the wetland system, consistent with previous research findings. Slow water movement enhanced the retention time, allowing vegetation such as cattails, reeds, and water hyacinths to absorb metals effectively. Their roots acted both as physical filters and as sites for microbial activity, where microorganisms contributed to the breakdown or immobilization of metal compounds.

Soil type and water table characteristics significantly influenced removal efficiency. Wetlands with organic- or clay-rich soils retained metals more effectively than sandy soils due to stronger metal-binding capacity. Seasonal variations were also observed: removal was most effective during moderate flow periods with balanced nutrient levels, while heavy rainfall reduced efficiency by diluting pollutants and shortening contact time between water and wetland substrates.

However, limitations were identified. Wetlands are sensitive ecosystems whose performance can decline with excessive contamination, habitat disturbance, or prolonged metal accumulation leading to saturation. Removal rates also varied by metal, with Pb and Cd eliminated more efficiently than as, likely due to differences in chemical reactivity and binding potential. These findings underscore the need for further research on metal-specific interactions, as well as ongoing monitoring to ensure long-term functionality.

From a sustainability perspective, wetlands offer a low-cost, environmentally friendly alternative to chemical or mechanical water treatment, providing co-benefits such as biodiversity support, groundwater recharge, and improved air quality. They are particularly suitable for rural and peri-urban regions with limited resources but high demand for clean water. Nevertheless, wetlands are not a one-size-fits-all solution and require protection, management, and policy support to maintain their effectiveness.

In conclusion, natural wetlands present a practical, eco-friendly method for addressing heavy metal pollution, combining ecological processes with long-term sustainability. When properly maintained, they can serve as vital allies in safeguarding water quality and public health, reaffirming the capacity of natural systems to address complex environmental challenges.

Implications

This study demonstrates that wetlands are far more than passive landscapes; they are active, cost-effective, and sustainable agents in removing heavy metals from contaminated water. Through detailed observation and analysis, the research highlights their potential as an affordable alternative to conventional treatment systems, particularly in rural and underdeveloped regions where advanced filtration infrastructure is lacking. Once established, wetlands operate with minimal external input, making them suitable for integration into local water management strategies to address pollution from small industries, mining, and agriculture.

From an urban planning perspective, the findings provide a strong case for preserving and restoring wetlands within cities. As natural filters, they can reduce pollutant loads in stormwater systems, support biodiversity, and help prevent contamination of urban lakes and rivers. Policymakers can incorporate wetland preservation into zoning regulations, building codes, and drainage management practices, while also considering artificial wetland construction in industrial areas.

The study's implications extend to environmental policy, encouraging the inclusion of natural systems alongside engineered solutions in wastewater treatment standards. Incentive programs could promote wetland conservation or creation, especially in heavy-metal-affected areas. Scientifically, the work lays a foundation for future research into plant–soil–metal interactions, potentially enabling the design of tailored wetland systems optimized for specific contaminants.

Beyond water purification, wetlands contribute to climate change mitigation through carbon sequestration and microclimate regulation, offering a multi-benefit solution to environmental challenges. Public engagement is another crucial outcome: shifting perceptions from wetlands as "swamps" to vital ecological infrastructure can foster community participation in conservation efforts.

Finally, the public health impact is significant. By naturally reducing toxic metals linked to severe neurological and developmental disorders, wetlands act as protective buffers between pollution sources and human populations, transforming them into active guardians of environmental quality and community well-being.

Contributions to the study

Abdullah Yazdan Panah is the main and first author of the journal, Nitish Kumar Sharma is the professor at the Chandigarh University who supervised this study, Frishta Akbari is the responsible for corresponding the article publication process and also final editing and writing of the study.

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