Application of advanced phytoremediation techniques in soils and waters contaminated with heavy metals (Case study: Eshtehard Industrial Town)

Setayesh Zandi Babaei [1,*] - Mohammad Mahdi Poorhasan Mehrzanjani [2]
[1] M.Sc. Graduate, Department of Horticultural Science and Landscape Architecture, Faculty of Agriculture, University of Tehran. Email: setayeshzandi80@ut.ac.ir

[2] M.Sc. Graduate, Department of Reclamation of Arid and Mountainous Regions, Faculty of Natural Resources, University of Tehran .Email: m.poorhasan@ut.ac.ir

ABSTRACT

Heavy metal contamination in soil and water represents one of the most critical environmental challenges, with far-reaching consequences for human health and ecosystem sustainability. Due to the high concentration of polluting industries, the Eshtehard Industrial Town is recognized as a major hotspot for the release of such metals. This study was conducted with the overarching aim of improving environmental quality and enhancing the resilience of the industrial network in Eshtehard. The primary focus was placed on employing phytoremediation techniques to mitigate soil and water pollution, while simultaneously creating suitable green spaces to improve the working environment for industrial employees. The research adopted a descriptive–analytical approach. Data and imagery from the Google Earth Engine platform were utilized to identify areas contaminated with copper, zinc, and iron, and an analytical pollution map was generated. The findings revealed that certain sites exhibit higher levels of contamination and therefore require targeted management strategies. To integrate technical results with managerial insights, the SWOT framework was applied to identify strengths, weaknesses, opportunities, and threats associated with environmental management in the industrial town. Based on this analysis, practical strategies and plant-based recommendations were proposed, demonstrating that the use of selected species can provide a sustainable and cost-effective approach to reducing pollution and improving environmental quality in industrial areas.

Keywords: *Phytoremediation, Heavy metals, Soil pollution, Water pollution, Google Earth Engine(GEE), Eshtehard*

1. *INTRODUCTION*

Recent concerns about environmental pollution have highlighted the urgent need for advanced technologies to assess the presence and mobility of metals in soil, water, and wastewater. Since the Industrial Revolution, heavy metal contamination has increased substantially, becoming one of the most critical environmental challenges. Such pollutants pose significant threats to soil and water resources as well as to human health [1]. The major sources of contamination include anthropogenic activities such as polluting industries, smelting and mining operations, military activities, fuel production, and the extensive use of agricultural chemicals. Unlike organic compounds, heavy metals are not degraded by microorganisms and, due to their long half-life, persist in the environment. Studies have classified 53 elements as heavy metals, characterized by a density greater than 5 g/cm³, which are recognized as global pollutants in industrial regions [2].

The accumulation of heavy metals in soil reduces its quality and capacity to support plant growth. Moreover, these metals can penetrate plant roots and enter the food chain, thereby affecting both humans and animals. Soil contamination with heavy metals leads to biodiversity loss and degradation of natural ecosystems. In addition, infiltration of heavy metals into surface and groundwater severely diminishes water quality and poses serious health risks. According to the World Health Organization (WHO), approximately 2.2 billion people worldwide rely on untreated and non-potable water. Research has demonstrated that heavy *metal contamination of water can result in severe diseases, including cancer. Ensuring universal access to safe and clean water therefore requires appropriate infrastructure and sustainable management, although many developing countries lack such services. Within this context, phytoremediation has emerged as an effective and cost-efficient technological approach for extracting or removing inactive metals and metallic pollutants from contaminated soil and water [3].*

2. *PROBLEM STATEMENT AND OBJECTIVES*

Heavy metal contamination in soil and water is among the most serious environmental threats of the present era, with extensive impacts on human health, the quality of natural resources, and the sustainability of ecosystems. The Eshtehard Industrial Town, due to its high concentration of metallurgical, chemical, and polymer industries, is recognized as one of the primary centers of pollutant release. The long-term persistence of heavy metals in the environment and their transfer through the food chain highlight the urgent need for thorough investigation and sustainable management of this contamination. Accordingly, this study aims at a macro-level goal of improving environmental quality and enhancing the resilience of the Eshtehard Industrial Town, while pursuing a micro-level goal of applying phytoremediation techniques to contaminated soil and water in order to reduce pollution and establish green spaces that improve the working environment for industrial employees. Achieving these objectives can pave the way for practical strategies and effective policies to mitigate contamination and strengthen environmental sustainability in similar industrial towns.

3. *LITERATURE REVIEW AND THEORETICAL FRAMEWORK*

3.1 Heavy Metals in Soil Environments

Soil contamination with heavy metals originates from both natural and anthropogenic sources. Natural sources include the weathering of mineral deposits, while anthropogenic sources are primarily associated with industrial and mining activities. Heavy metals, characterized by high density, conductivity, and stability, are typically present in the environment in the form of cations. Such contamination occurs in soil, water, living organisms, and sediments, and has significantly increased since the late nineteenth and early twentieth centuries. Metals such as cadmium, copper, chromium, zinc, nickel, iron, mercury, and lead exert adverse environmental effects and, due to their long half-lives, become toxic at elevated concentrations [2].

In soils, heavy metals may exist in various forms: free metal ions, exchangeable adsorbed ions, precipitated mineral compounds, metals complexed with organic matter, and metals bound to silicates [4]. Traditional remediation methods for contaminated soil and water, such as excavation, landfill disposal, and physicochemical treatment, are costly, time-consuming, and unsuitable for large-scale areas. Bioremediation using microorganisms has been developed, but has shown limited success in addressing metallic pollutants. In contrast, phytoremediation is considered an effective approach for detoxifying contaminated sites [2].

3.1.1 Phytoremediation of Heavy Metals in Soil

Phytoremediation, as an emerging and cost-effective technology, offers economic and environmental advantages compared to conventional methods. Nevertheless, it faces limitations such as the need for further scientific research and risk assessment [4]. The use of resistant plant species in abandoned mining areas can contribute to the stabilization of toxic substances and the restoration of soil fertility. Native species, due to their adaptation to local climatic conditions, are considered suitable candidates for phytoremediation. Modern approaches include the application of nanoparticles and compost to enhance plant efficiency [5].

Phytoremediation of heavy metals relies on a set of core strategies, each playing a significant role in reducing soil contamination. First, phytoextraction, in which plants accumulate large amounts of toxic elements in their aerial tissues, enabling their harvest and removal from the environment. Second, rhizofiltration, where extensive and regenerating root systems absorb and sometimes precipitate pollutants from contaminated water; this method is particularly effective in wastewater with low pollutant concentrations. Third, phytostabilization, which immobilizes contaminants in the rhizosphere and increases plant tolerance to polluted conditions, thereby preventing the migration of heavy metals; soil amendments can further improve its efficiency. Fourth, phytovolatilization, in which contaminants absorbed by plants are translocated to leaves and released into the atmosphere; this process not only reduces pollutant concentrations but also contributes to soil stabilization and the preservation of microbial communities. Finally, hydraulic control (phytohydraulics), which employs deep-rooted, high-transpiration trees to regulate groundwater flow and *contaminant movement, preventing their entry into aquifers.The integration of these strategies demonstrates that phytoremediation can serve as a sustainable and multidimensional approach for managing heavy metal contamination in soils [1], [4], [6].*

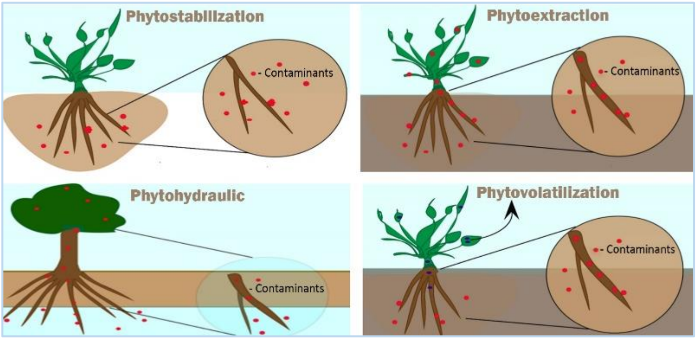

Fig. 1. *Strategies of Phytoremediation of Heavy Metals in Soil [6].*

Plants, through extensive root systems and the production of chelating molecules, possess the ability to absorb and accumulate heavy metals. Certain metals, such as lead, tend to accumulate primarily in the roots, whereas cadmium can easily translocate throughout the plant [2], [4]. The efficiency of this process is influenced by multiple factors, including the selection of appropriate plant species, environmental characteristics such as soil pH and organic matter content, the bioavailability of metals, and the addition of chelating agents [7]. Among these, the criteria for selecting plant species for phytoremediation are of particular importance. Selected species should be adapted to the local climate, capable of extracting pollutants, exhibit rapid growth, and require minimal maintenance. Furthermore, the introduction of non-native species into new areas is not recommended, as it may lead to environmental problems [6].

3.2 Heavy Metals in Water Environments

Sources of water pollution include pathogens, inorganic compounds, and organic substances, while heavy metals such as mercury, cadmium, arsenic, chromium, and lead pose severe risks to human health. Conventional methods such as soil washing and adsorption have limitations in reducing these contaminants, whereas phytoremediation has emerged as an effective alternative for the removal of water pollutants [3]. Natural and constructed wetlands provide suitable conditions for water phytoremediation, where plants, through the uptake of nitrogen and phosphorus, not only improve water quality but also demonstrate the ability to remove heavy metals [5]. Aquatic plants such as water hyacinth (Eichhornia crassipes) and duckweed (Lemna minor), owing to their extensive root systems, exhibit high capacity for absorbing and accumulating pollutants in their roots and stems, making them efficient candidates for the remediation of contaminated waters [8].

3.2.1 Phytoremediation of Heavy Metals in Water

Phytoremediation of heavy metals in aquatic environments is based on a set of core strategies, each playing a distinct role in reducing pollution. First, phytoextraction, in which plants, through their high capacity for separating and translocating metals into root cells and aerial organs, accumulate significant amounts of contaminants; this process is enhanced by symbiotic microorganisms in the rhizosphere. Second, rhizofiltration, where pollutants are adsorbed and precipitated on the root surface, enabling the removal of metals from contaminated water. Third, phytodegradation, in which pollutants are transformed into mineral compounds or less toxic intermediates, with plant enzymes and plant–microbe interactions playing a key role in this process. Fourth, phytostabilization, which immobilizes contaminants in the rhizosphere and prevents their migration, thereby reducing environmental risks; physiological traits of plants, such as nutrient uptake and biomass production, contribute to the efficiency of this method. Finally, phytovolatilization, a process in which certain pollutants such as selenium and volatile organic compounds (VOCs) are absorbed by plants, translocated to leaves, and released into the atmosphere; although this method is less commonly applied compared to other strategies [3]. The integration of these approaches demonstrates that phytoremediation in water can serve as a sustainable and multidimensional solution for managing heavy metal contamination.

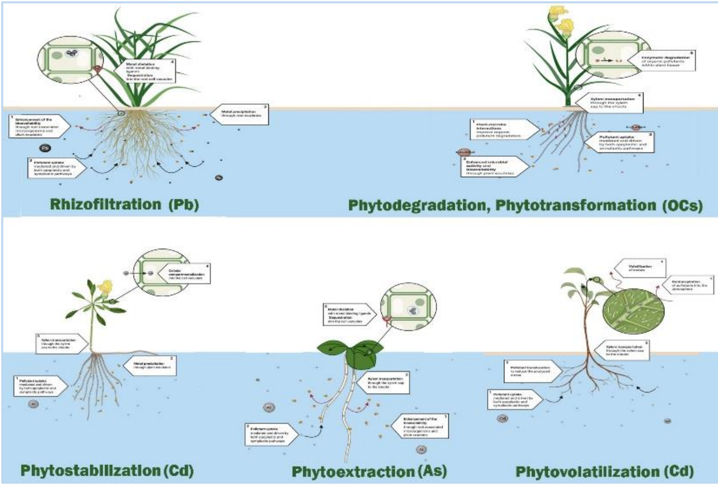

Fig. 2. *Strategies of Phytoremediation of Heavy Metals in Water [3].*

The efficiency of phytoremediation in aquatic systems is influenced by multiple environmental conditions. Factors such as temperature, salinity, pH, and the bioavailability of nutrients can alter the rate and effectiveness of remediation processes and, in some cases, reduce system performance. Alongside these conditions, the selection of appropriate plant species is of particular importance and should be based on biodiversity, ecological adaptability, and pollutant uptake capacity. Plant families such as Salviniaceae, Araceae, and Cyperaceae have demonstrated high potential in absorbing and remediating heavy metals in aquatic environments, making them effective candidates for the design of phytoremediation systems [3].

A review of the literature indicates that heavy metal contamination in soil and water is among the most critical environmental challenges, while conventional remediation methods lack sufficient efficiency due to high costs and operational limitations. In contrast, phytoremediation has emerged as a novel and sustainable approach, providing a viable alternative for reducing and managing metallic pollution across diverse environments. Findings from studies in both soil and water highlight that the core strategies of phytoremediation include phytoextraction, rhizofiltration, phytostabilization, phytodegradation, phytovolatilization, and hydraulic control, each demonstrating varying levels of efficiency depending on environmental conditions and the selected plant species.In summary, as presented in Table 1, all phytoremediation methods and their characteristics have been compiled, offering a comprehensive reference for selecting and designing appropriate strategies to manage heavy metal contamination in soil and water.

Table 1. *Different Techniques of Phytoremediation*

Application and Objectives	Phytoremediation Technique
Use of plant roots to absorb heavy metals and radionuclides from surface and groundwater; the main objective is the removal of metallic pollutants.	Rhizofiltration
Application of plants to immobilize heavy metals in soil, sediments, and sludge; prevents the migration of contaminants.	Phytostabilization
Uptake of heavy metals and radionuclides by roots and their translocation to aerial organs; enables harvesting and removal of contaminants.	Phytoextraction
Certain metals such as mercury, selenium, and arsenic are absorbed by plants and released into the atmosphere; applicable in soil, sediments, and water.	Phytovolatilization
Organic pollutants in soil and water are degraded by plant enzymes and converted into less hazardous compounds.	Phytodegradation
Stimulation of rhizosphere microorganisms to degrade organic pollutants; plant–microbe interactions play a key role.	Rhizodegradation
Use of deep-rooted, high-transpiration trees to regulate groundwater flow and limit the movement of dissolved contaminants.	Phytohydraulic

4. *MATERIALS AND METHODS*

In this study, the research method is descriptive–analytical. Data were collected from library sources including books, scientific articles, and research reports related to phytoremediation and heavy metal contamination in soil and water, as well as from reputable scientific databases. Extracted data from reliable laboratory reports were utilized through the Google Earth Engine platform to generate heavy metal contamination maps and identify highly polluted areas.

Google Earth Engine, launched in 2010 by Google, is a powerful cloud-based computational platform that enables the analysis of geospatial data and satellite imagery. It contains a vast database of global information and imagery, allowing rapid data visualization, spatial navigation across any location on Earth, and examination of temporal changes [10]. In this research, time-series satellite images from Sentinel-2 were employed to prepare contamination maps for the Eshtehard Industrial Town, focusing on heavy metals including copper, iron, and zinc. Sentinel-2 imagery, due to its wide spectral coverage and short revisit intervals, provides high potential for estimating heavy metal concentrations in soil [11].

Finally, to integrate technical results with managerial analysis and propose practical strategies, the SWOT framework was applied as a strategic analysis tool. This enabled the identification of strengths, weaknesses, opportunities, and threats related to environmental management in the industrial town, linking them to actionable objectives and operational solutions.

4.1 Study Area

The case study in this research is the Eshtehard Industrial Town, located in Eshtehard County, Alborz Province. The purpose of selecting this area is to identify and examine heavy metal contamination (copper, zinc, and iron) in the soil and to propose appropriate strategies for reducing pollution through the application of modern phytoremediation techniques.

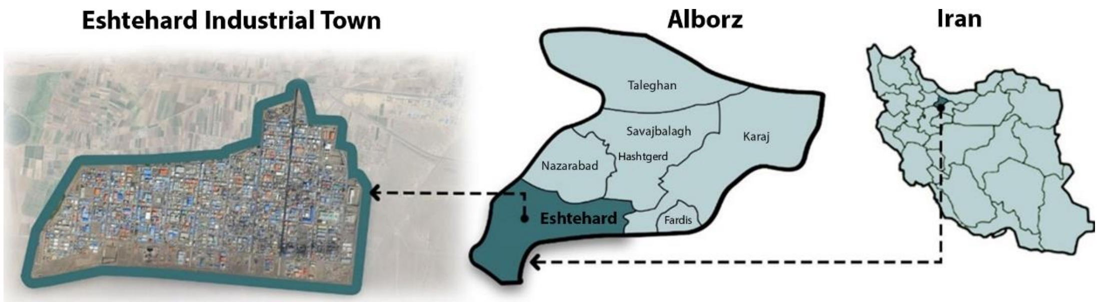

Fig. 3. *Geographical location of Eshtehard Industrial Town*

4.2 Soil Reports of the Study Area

According to previous studies, the background reference values for heavy metals iron, zinc, and copper are defined as 2.6, 2.1, and 1.2 mg/kg, respectively [12]. Reports from 2011 indicate that the concentrations of these metals in soil samples collected from the southern belt of Eshtehard County (approximately 2 kilometers and 70 meters from the industrial town) were 2.9, 1.07, and 0.5 mg/kg, respectively [13]. Given the short distance from the industrial zone, it can be inferred that the level of heavy metal contamination within the Eshtehard Industrial Town itself is significantly higher, due to the density of industrial land uses and manufacturing activities.

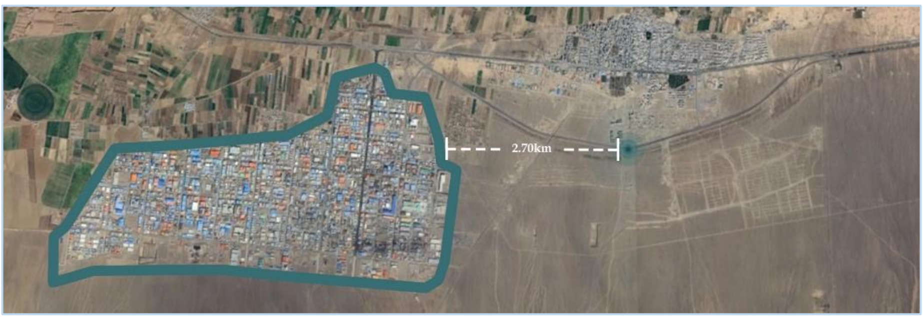

Fig. 4. *Location of the Soil Sampling Site Relative to Eshtehard Industrial Town*

4.3 Soil Reports of the Study Area

In this study, Sentinel-2 satellite imagery from the period 2011 to 2025 was employed to calculate and analyze heavy metal contamination indices (iron, zinc, and copper). The primary index applied is the Heavy Metal Pollution Index (PI), which is calculated as follows:

$$PI = C_i / C_{ri} \tag{1}$$

where represents the current concentration of the heavy metal in soil (mg/kg), and denotes the reference or background concentration of the heavy metal. This index reflects the level of heavy metal contamination and enables the assessment of pollution status as well as the identification of necessary management actions [14].

5. *RESULTS AND DISCUSSION*

Ultimately, a spatial layer representing the accumulation of heavy metals, including copper, zinc, and iron, was extracted from the Google Earth Engine platform based on the Pollution Index (PI) formula for each metal. All indices were integrated and displayed as a single composite layer. Map zooming was applied to highlight spatial variations of the indices. The map was presented using a color palette of blue, green, yellow, orange, and red, where red indicates the highest level of contamination and represents critical conditions.

The results of the heavy metal pollution indices, calculated as averages, were compared with the internal land-use map of the Eshtehard Industrial Town. Findings revealed that metal, mineral and non-metal, polymer, and chemical industries contribute the most to severe contamination of zinc, copper, and iron. Active factories in these sectors include those producing metal pipes, paints and coatings, ceramics and tiles, polyester, and polymeric and chemical materials.

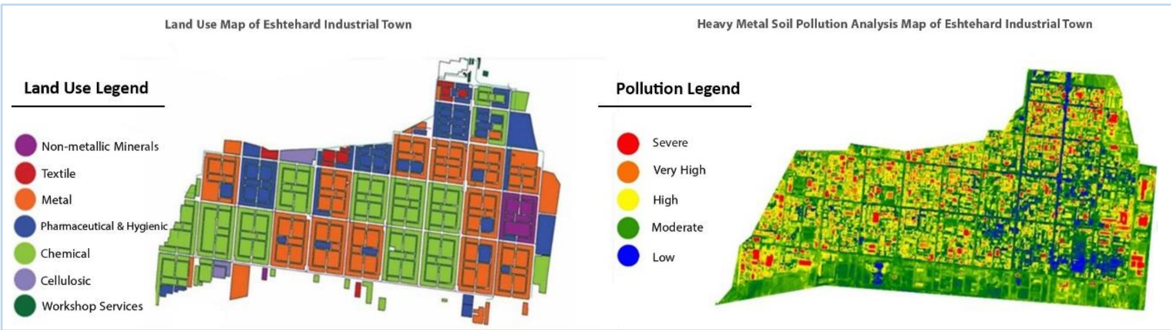

Fig. 5. *Comparison of Land Use Map and Heavy Metal Pollution in the Soil of Eshtehard Industrial Town*

In addition, a time-series chart of pollution indices from 2019 to 2025 was extracted, illustrating changes in the composite index of iron (Fe), zinc (Zn), and copper (Cu) throughout the study period. This time frame was selected due to the noticeable increase in contamination beginning in 2019. In the chart, the horizontal axis represents time, while the vertical axis shows the values of the pollution index. Data points indicate PI values at specific dates, and the red line depicts the overall trend of changes, assisting in the identification of long-term patterns of contamination.

As shown in Figure 6, in certain years the data points shift upward, reflecting an increase in contamination levels over time, whereas in other years the downward movement of index values indicates a reduction in pollution. Despite these fluctuations, the overall trend line demonstrates that heavy metal contamination patterns are increasing linearly. Based on these findings, the implementation of environmental management and preventive measures can play a significant role in mitigating the upward trend of pollution.

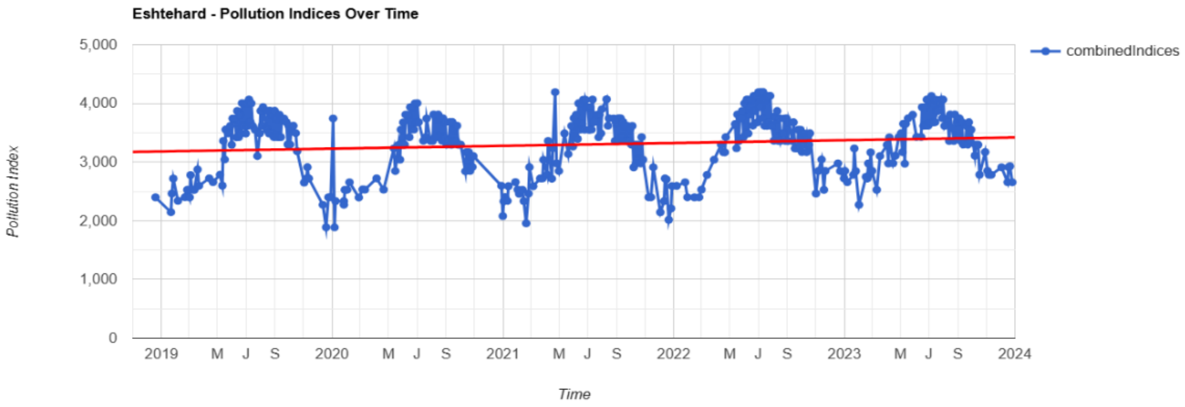

Fig. 6. *Time-Series Chart of Heavy Metal Pollution Indices (Zinc, Copper, Iron)*

Based on the review of existing studies related to Eshtehard Industrial Town, including physical and environmental analyses as well as the assessment of heavy metal contamination in soil and water, a SWOT table has been prepared. This table highlights the strengths, weaknesses, opportunities, and threats associated with the environmental management of the industrial town. As a strategic tool, the SWOT framework enables the formulation of appropriate objectives and practical solutions aimed at reducing pollution and enhancing environmental sustainability.

Table 2. *SWOT Analysis (Strengths) in Environmental Management of Eshtehard Industrial Town*

Strengths (S)	Component
• Easy access to Iran's highways and major transportation routes (such as the Abyek–Charmshahr beltway). • Availability of complete infrastructure facilities (water, electricity, gas, etc.). • Affordable pricing of existing factories for transfer or acquisition. • Presence of an extensive network of routes with suitable longitudinal and transverse accessibility within the site. • Layout of industrial units aligned with a uniform access network.	Physical & Landscape
• Presence of native and suitable vegetation around the area. • Existence of drought-resistant species adapted to xeriscaping principles. • Availability of refuges and planting sites suitable for the development of green spaces and phytoremediation. • Flat roofs with potential for creating green roofs and phytoremediation to reduce air pollution.	Ecological & Environmental
• Creation of job opportunities and reduction of unemployment rates. • Government financial facilities and support for investors. • Access to skilled and unskilled labor in nearby areas. • Diversity of industries within one area, leading to synergy and cost reduction. • Lack of dependence on a few specific industries, which reduces risk.	Cultural–Social & Economic

Table 3. *SWOT Analysis (Weaknesses) in Environmental Management of Eshtehard Industrial Town*

Weaknesses (W)	Component
• Shortage of essential infrastructure in certain areas, along with poor lighting and urban furniture. • Lack of proper views and landscape due to lowland location and absence of spatial identity. • Deficiency of identity-forming elements and urban signage (boards and markers). • Presence of lifeless and inactive spaces, shortage of parking, and inadequate traffic infrastructure. • Deterioration of certain facilities (such as fire station and health center) and absence of protective fencing for the industrial town.	Physical & Landscape
• Pollution of water, soil, and air caused by industrial activities. • Lack of planning for stormwater collection, leading to infiltration of pollutants into groundwater resources. • Improper disposal of industrial wastewater and emission of unpleasant odors from the treatment plant. • Non-compliance with environmental standards in some units. • Shortage of dedicated green spaces and absence of plant species resistant to salinity and drought. • Neglect of the water–energy–industry nexus in planning and operations.	Ecological & Environmental
• Shortage of auxiliary services such as educational, medical, and banking centers. • Power outages and weak provision of sustainable energy. • Migration of workforce to other regions due to lack of welfare facilities. • Weakness in management and planning of industrial towns. • Drinking water supplied from saline and hard wells, causing machinery damage and increased costs. • Presence of stray animals, leading to disorder and a sense of insecurity.	Cultural–Social & Economic

The SWOT analysis revealed that Eshtehard Industrial Town possesses significant strengths in terms of communication infrastructure, access to basic facilities, industrial diversity, and the potential for developing green spaces. These strengths can serve as a foundation for sustainable development and the implementation of phytoremediation strategies.

Conversely, weaknesses such as the shortage of auxiliary services, deterioration of certain facilities, environmental pollution caused by industrial activities, lack of dedicated green spaces, and deficiencies in management and planning present serious challenges to improving environmental quality and enhancing urban resilience.

This synthesis indicates that leveraging strengths while addressing weaknesses can provide effective and sustainable strategies for reducing pollution and improving the environmental conditions of the industrial town.

In continuation, and with the aim of completing the SWOT framework, opportunities and threats will be examined, with the results presented in Tables 4 and 5.

Table 4. *SWOT Analysis (Opportunities) in Environmental Management of Eshtehard Industrial Town*

Opportunities (O)	Component
• Development of required infrastructure, including waste disposal systems, improvement of public transportation, and reduction of traffic. • Availability of vertical surfaces (walls and roofs) suitable for creating green walls and green roofs. • Density of orchards and agricultural lands surrounding the area, with their positive ecological impacts on the site. • Location on a suitable slope (1%) that enables stormwater control. • Potential for creating gathering spaces and small parks from unused land uses.	Physical & Landscape
• Possibility of implementing environmental projects and reducing pollution through phytoremediation techniques. • Capacity to utilize clean technologies and renewable energy sources. • Preservation of biodiversity and protection of native species. • Focus on sustainable production aligned with environmental needs.	Ecological & Environmental
• Growth of domestic and international markets for industrial products. • Expansion of industrial exports and presence in regional markets. • Attraction of domestic and foreign investors. • Increasing public awareness through education on environmental protection. • Existence of small-scale workshops near Eshtehard, supporting the prosperity of large-scale industrial activities. • Mitigation of challenges and provision of employment and income opportunities for rural communities.	Cultural–Social & Economic

Table 5. *SWOT Analysis (Threats) in Environmental Management of Eshtehard Industrial Town*

Threats (T)	Component
• Occurrence of natural disasters such as earthquakes, floods, and the impacts of climate change. • Visual degradation of the industrial landscape due to waste accumulation and unbalanced development. • Conversion of agricultural lands as a result of industrial expansion. • Destruction of rangelands and orchards due to future development of the industrial town. • Increase in noise pollution and its spread to adjacent land uses.	Physical & Landscape
• Decline in biodiversity and destruction of natural habitats. • Reduction of agricultural water resources and contamination of groundwater. • Improper disposal of industrial waste, intensifying environmental pollution.	Ecological & Environmental
• Cultural changes resulting from migration and population growth, accompanied by greater pressure on natural resources. • Competition with foreign industries and cheap imports threatening domestic production. • Economic fluctuations and political instability negatively affecting investment and development. • Sudden changes in industrial laws and regulations. • Shortage of suitable raw materials for industrial production due to economic sanctions.	Cultural–Social & Economic

The analysis of opportunities and threats showed that Eshtehard Industrial Town has significant capacities for sustainable development, including the potential use of clean technologies, renewable energies, implementation of phytoremediation and bioremediation projects, and preservation of biodiversity. These opportunities can contribute to reducing heavy metal pollution and improving environmental quality. In contrast, threats such as industrial expansion over agricultural lands, reduction of water resources, environmental pollution, and economic and regulatory fluctuations pose serious challenges to sustainable management. Therefore, the intelligent utilization of opportunities and mitigation of threats are the key conditions for the success of phytoremediation strategies in this region.

6. *CONCLUSION AND RECOMMENDATIONS*

In this study, using analytical maps, the status of heavy metal pollution in Eshtehard Industrial Town was examined, and critical areas with high concentrations of copper, zinc, and iron were identified. These findings revealed that certain parts of the town require immediate and sustainable intervention. Accordingly, a SWOT analysis was conducted to evaluate the strengths, weaknesses, opportunities, and threats related to the town's environmental management. The results of this analysis indicated that leveraging existing capacities and mitigating challenges can pave the way for implementing sustainable strategies.The overarching goal of the research is to improve environmental quality and enhance the resilience of Eshtehard Industrial Town, while the specific objective is to employ phytoremediation techniques to reduce pollution and create efficient green spaces for employees. Within this framework, two main strategies were developed:

First Strategy – Phytoremediation as the Core Approach to Pollution Reduction: The operational measures of this strategy include planting pollutant-absorbing species in rain gardens to capture runoff contaminants, using phytoremediating species in green gardens to purify rainwater and reduce soil and groundwater pollution, establishing green belts around industrial units to stabilize soil pollutants, and planting phytoremediating species along canals and drainage paths to direct polluted water into artificial wetlands. These measures were designed in response to identified weaknesses and threats, particularly water and soil pollution, while simultaneously capitalizing on existing strengths and opportunities such as the capacity of resistant species and managerial support.

Second Strategy – Creation of Green and Recreational Spaces: This strategy aims to increase social resilience and improve the quality of the working environment for employees. Its measures include developing green pedestrian pathways with climbing plants around industrial units and designing gathering spaces with rain gardens in various urban locations. These actions not only enhance the landscape and reduce employee stress but also contribute to reducing runoff pollution, thereby linking environmental and social objectives.

Overall Synthesis, The present study pursued phytoremediation through two main axes:

- *Water phytoremediation via rain gardens, planting pollutant-absorbing species along canals, and directing contaminated runoff into artificial wetlands.*
- *Soil phytoremediation through planting hyperaccumulator species (plants capable of storing very high concentrations of heavy metals in their leaves, stems, or roots without suffering serious damage) in green gardens and peripheral belts around industrial units to absorb and stabilize heavy metals.*

Thus, phytoremediation is proposed as the principal solution for pollution reduction and environmental quality enhancement in Eshtehard Industrial Town.

Fig. 7. *Strategic Design and Planning of Eshtehard Industrial Town through Phytoremediation Approaches*

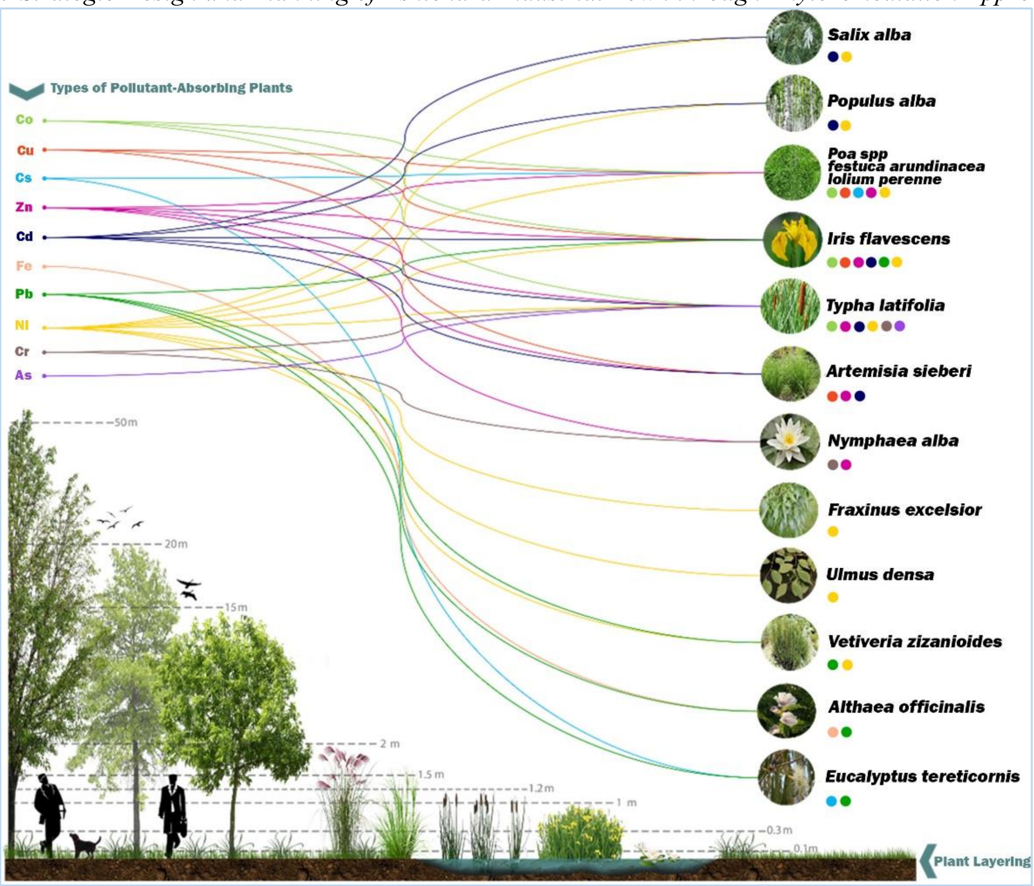

Fig. 8 *Planting Design and Layering of Pollutant-Absorbing Species in Eshtehard Industrial Town*

Finally, in line with the research objectives and the formulated management actions, plant species resistant and adapted to the climatic and environmental conditions of the region have been selected so that they can play an effective role in the process of heavy metal remediation. These species are presented in Table 6 and will be used as a practical solution in environmental management and in enhancing environmental quality.

Table 6. *Proposed Plant Species for Phytoremediation of Heavy Metals in Water & Soil*

Contaminated Medium	Target Heavy Metals	Phytoremediation Technique	Scientific Name
Soil	Zn	phytoextraction	*Euphorbia cheiradenia*
Soil	Zn	phytoextraction	*Sedum alfredii*
Soil	Cu,Zn, Cd, Pb	Phytostabilization, phytoextraction	*Salix L.*
Soil	Zn, Fe	phytostabilization	*Jatropha curcas*
Soil	Fe	phytostabilization	*Clerodendrum indicum L.*
Soil	Zn	phytostabilization	*Scirpus mucronatus*
Soil	Zn, Cd, Pb, Cu	phytovolatilization	*Lolium perenne*
Soil	Cu	phytovolatilization	*Festuca rubraL.*
Soil	Zn, Pb	phytovolatilization	*Artemisia roxburghiana*
Soil	Cu, Pb, Zn	phytovolatilization	*Agrostis castellana*
Soil	Cu, Fe, Zn, Mn	phytoextraction	*Helianthus annuus*
Soil	Cu, Pb, Zn, As, Co	Phytoextraction. phytostabilization	*Pupolus L.*
Soil	Cu, Cd, Zn	Phytoextraction, phytostabilization	*Vetiveria zizanioides*
Soil & Water	Fe, Zn, Cu , Hg	phytostabilization	*Myriophylhum aquaticum,*
Soil & Water	Cd, Se , Cu	phytostabilization	*Lemna minor L.*
Soil & Water	Zn	phytostabilization	*Lemna gibba L..*
Water	Zn, Mn, Co, Cd, Cr, Ni, As	phytovolatilization	*Typha latifolia L*
Water	Cd, Zn	phytoextraction	*Arabis paniculata*
Water	Cr, Pb, Cu, Ni	phytoextraction	*Azolla caroliniana*
Water	Cr, Zn	Rhizofiltration	*Iris pseuda-corus*
Water	Cd, Co, Cu, Ni, Pb, Zn	Phytoextraction	*Nelumbo nucifera*
Water	Cd, Cu, Fe, Hg	Phytoextraction, Rhizofiltration	*Pistia stratiotes*
Water	Zn, Cu, Cd, Pb	Rhizofiltration	*Potamogeton natans*
Water	Zn, Cu, Ni, Cr	Phytoextraction	*Salvinia natans*

REFERENCES

[1] *Tangahu, B. V., Sheikh Abdullah, S. R., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011), "A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation". International journal of chemical engineering, 2011(1), 939161.*

[2] *Ahmadpour, P., Ahmadpour, F., Mahmud, T. M. M., Abdu, A., Soleimani, M., & Tayefeh, F. H. (2012), "Phytoremediation of heavy metals: A green technology". African Journal of Biotechnology, 11(76), 14036-14043.*

[3] *Delgado-González, C. R., Madariaga-Navarrete, A., Fernández-Cortés, J. M., Islas-Pelcastre, M., Oza, G., Iqbal, H. M., & Sharma, A. (2021), "Advances and applications of water phytoremediation: A potential biotechnological approach for the treatment of heavy metals from contaminated water". International Journal of Environmental Research and Public Health, 18(10), 5215.*

[4] *McIntyre, T. (2003), "Phytoremediation of heavy metals from soils". Phytoremediation, 97-123.*

[5] *Wei, Z., Van Le, Q., Peng, W., Yang, Y., Yang, H., Gu, H., ... & Sonne, C. (2021), "A review on phytoremediation of contaminants in air, water and soil". Journal of hazardous materials, 403, 123658.*

[6] *Muthusaravanan, S., Sivarajasekar, N., Vivek, J. S., Paramasivan, T., Naushad, M., Prakashmaran, J., ... & Al-Duaij, O. K. (2018), "Phytoremediation of heavy metals: mechanisms, methods and enhancements". Environmental chemistry letters, 16, 1339-1359.*

[7] *Awa, S. H., & Hadibarata, T. (2020), "Removal of heavy metals in contaminated soil by phytoremediation mechanism: a review". Water, Air, & Soil Pollution, 231(2), 47.*

[8] *Ali, S., Abbas, Z., Rizwan, M., Zaheer, I. E., Yavaş, İ., Ünay, A., ... & Kalderis, D. (2020), "Application of floating aquatic plants in phytoremediation of heavy metals polluted water: A review". Sustainability, 12(5), 1927.*

[9] *Salehi, A., & Matinizadeh, M. (2017). "The effect of symbiosis with arbuscular mycorrhizal fungi on the phytoremediation process of soils contaminated with heavy metals." Iranian Journal of Biology, 1(1), 57–66. Available at: https://www.ijbio.ir/article_1783.html [In Persian]*

[10] *Rezaie, H. (2022). Introducing of Google Earth Engine. Zist Sepehr Student Magazine, 14(4), 8-10. Available at: https://biosepehrsj.ut.ac.ir/article_87026.html?lang=en [In Persian]*

[11] *Bakhshi Rad, O. , Askari, M. S. , Vaezi, A. R. and Afshari, A. (2023). Quantitative Estimation of Zn and Pb in Soil Using Multivariate Analysis and Remote Sensing Technique. Water and Soil Science, 33(1), 79-92. doi: 10.22034/ws.2021.43111.2393 [In Persian]*

[12] *Yazdaninejad, F., Torabi Golsafidi, H., & Dovatgar, N. (2013). Mapping of available Fe, Zn, Cu and Mn in soils of southern Tehran lands by geostatistical and GIS techniques. Iranian Journal of Soil and Water Research, 44(4), 383–395. SID. Available at: https://sid.ir/paper/225374/en [In Persian]*

[13] *Eshtehard Municipality. (2011). "Phase I studies – Report on soil and water of green spaces, design of water supply and irrigation network for green spaces in Eshtehard City." Eshtehard Municipality, Alborz Province Governorate. [In Persian]*

[14] *Hamzehnezhad, R., & Khodaverdilou, H. (2020). Quantitative assessment of heavy metal pollution in soil. Applied Soil Research, 8(2), 37–52. SID. Available at: https://sid.ir/paper/390897/fa [In Persian]*