Role of hydrophytes as bio-indicators of water pollution

Sonum Bamania

Assistant professor in Botany, Govt. College, Karauli (Rajasthan)

sonambamaniya@gmail.com

Abstract

Hydrophytes, or aquatic plants, play a significant role as bio-indicators in assessing water pollution due to their sensitivity and adaptive responses to environmental changes. These plants, including submerged, floating, and emergent species, reflect variations in water quality through changes in growth patterns, species composition, and physiological conditions. Their ability to absorb, accumulate, and sometimes detoxify pollutants such as heavy metals, nutrients, and organic contaminants makes them reliable indicators of ecological health. In polluted water bodies, certain tolerant species proliferate, while sensitive species decline, providing measurable evidence of contamination levels. Hydrophytes also contribute to phytoremediation by removing excess nutrients and toxic substances, thereby improving water quality. Compared to conventional physico-chemical methods, they offer a cost-effective and continuous monitoring approach. Thus, hydrophytes serve as efficient, eco-friendly tools for evaluating and managing water pollution in aquatic ecosystems.

Keywords: Hydrophytes, bio-indicators, water pollution, aquatic ecosystems, phytoremediation.

Introduction

Water pollution has emerged as a critical environmental issue affecting freshwater ecosystems, biodiversity, and human health worldwide, driven by rapid industrialization, urbanization, and agricultural runoff. Contaminants such as heavy metals, excessive nutrients, pesticides, and organic wastes alter the physical, chemical, and biological properties of water bodies, thereby disrupting ecological balance. In this context, the use of biological indicators has gained prominence as a reliable and integrative approach to monitor water quality. Hydrophytes, or aquatic plants, represent an important group of bio-indicators due to their close association with aquatic environments and their ability to respond sensitively to changes in water chemistry. These plants, which include free-floating species such as Eichhornia crassipes, submerged species like Hydrilla verticillata, and emergent species such as Typha latifolia, exhibit distinct morphological, physiological, and biochemical adaptations that enable them to absorb and accumulate pollutants from water and sediments. Variations in their distribution, abundance, and health status often reflect the degree and type of pollution present in a water body. For instance, the dominance of nutrient-tolerant species may indicate eutrophication, while the presence or absence of certain sensitive species can signal contamination levels. Hydrophytes also play a dual role by not only indicating pollution but also contributing to its mitigation through phytoremediation processes such as nutrient uptake, heavy metal sequestration, and oxygenation of water. Compared to conventional physico-chemical monitoring methods, hydrophyte-based assessment provides a cost-effective, continuous, and ecologically meaningful evaluation of water quality over time. Therefore, understanding the role of hydrophytes as bio-indicators is essential for effective environmental monitoring, conservation planning, and sustainable management of aquatic ecosystems.

Scope of the Study

The present study focuses on evaluating the role of hydrophytes as effective bio-indicators of water pollution in freshwater ecosystems. It encompasses the identification, classification, and ecological significance of major aquatic plant groups, including floating, submerged, and emergent hydrophytes, in relation to varying pollution levels. The study examines how changes in hydrophyte diversity, distribution, and physiological responses can be used to assess different types of contaminants such as nutrients, heavy metals, and organic pollutants. It also explores the mechanisms of pollutant absorption and accumulation, highlighting their relevance in environmental monitoring and phytoremediation. The scope is limited to freshwater bodies such as ponds, lakes, and rivers, with emphasis on ecological assessment rather than advanced molecular analysis. Furthermore, the study aims to provide a scientific basis for using hydrophytes in sustainable water quality management and pollution control strategies.

Concept of Water Pollution and Its Global Significance

Water pollution refers to the contamination of water bodies such as rivers, lakes, wetlands, and groundwater by harmful substances that degrade water quality and render it unsuitable for ecological functions and human use. These pollutants originate from diverse sources, including industrial effluents, agricultural runoff laden with fertilizers and pesticides, domestic sewage, and urban waste discharge.

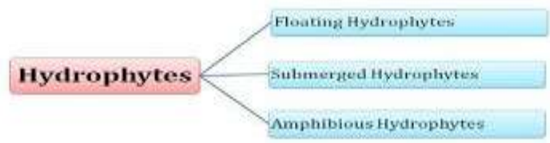
The introduction of toxic chemicals, heavy metals, pathogens, and excess nutrients alters the physical, chemical, and biological characteristics of water, leading to phenomena such as oxygen depletion, algal blooms, and loss of biodiversity. From a global perspective, water pollution poses a serious threat to environmental sustainability and public health, as millions of people depend on freshwater resources for drinking, agriculture, and livelihoods. It contributes to the spread of waterborne diseases and disrupts aquatic ecosystems, affecting food chains and ecological balance. Moreover, increasing population pressure and climate change further intensify the vulnerability of water resources, making pollution control a critical global challenge. International initiatives led by organizations such as United Nations Environment Programme and World Health Organization emphasize the urgent need for sustainable water management and pollution mitigation strategies. Therefore, understanding the concept of water pollution and its global significance is essential for developing effective conservation policies and ensuring long-term ecological and human well-being.

Importance of Aquatic Ecosystems

Aquatic ecosystems, encompassing freshwater and marine environments such as rivers, lakes, wetlands, and oceans, play a fundamental role in maintaining ecological balance and supporting life on Earth. These systems provide essential ecosystem services, including water purification, nutrient cycling, climate regulation, and habitat provision for a vast diversity of flora and fauna. They act as natural filters by removing pollutants and excess nutrients, thereby improving water quality and sustaining biodiversity. Aquatic ecosystems are also crucial for human survival, as they supply drinking water, support agriculture and fisheries, and contribute to economic activities such as tourism and transportation. Wetlands, in particular, function as buffers against floods and help in groundwater recharge, reducing the impact of natural disasters. Moreover, these ecosystems regulate global biogeochemical cycles, including carbon and nitrogen cycles, which are vital for climate stability. Despite their importance, aquatic ecosystems are increasingly threatened by pollution, overexploitation, habitat destruction, and climate change. Global initiatives like those promoted by the Ramsar Convention on Wetlands and the United Nations highlight the need for conservation and sustainable management of aquatic resources. Therefore, preserving aquatic ecosystems is essential not only for maintaining biodiversity but also for ensuring environmental sustainability and human well-being.

Definition and Classification of Hydrophytes

Hydrophytes are plants that are specially adapted to grow in aquatic environments, either wholly or partially submerged in water, and are characterized by unique morphological and physiological features that enable survival under conditions of low oxygen availability and high water saturation. These plants exhibit adaptations such as reduced mechanical tissues, well-developed air spaces (aerenchyma), thin cuticles, and flexible stems, which facilitate buoyancy, gas exchange, and efficient nutrient absorption. Hydrophytes are broadly classified based on their growth habits and ecological positioning within water bodies into three main categories: free-floating, submerged, and emergent types.



Free-floating hydrophytes, such as Pistia stratiotes and Eichhornia crassipes, float on the water surface without attachment to the substrate and absorb nutrients directly from the water. Submerged hydrophytes, including Hydrilla verticillata and Vallisneria spiralis, remain entirely or mostly underwater and play a crucial role in oxygenating aquatic systems. Emergent hydrophytes, such as Typha latifolia and Nelumbo nucifera, are rooted in the substrate but extend above the water surface, contributing to habitat structure and shoreline stabilization. This classification not only reflects their ecological roles but also their varying capacities to absorb and indicate pollutants, making hydrophytes valuable tools in aquatic environmental monitoring and management.

Rationale for Using Hydrophytes as Bio-indicators

Hydrophytes are widely utilized as bio-indicators of water pollution due to their direct and continuous interaction with aquatic environments and their capacity to reflect changes in water quality through measurable biological responses. These plants absorb nutrients, heavy metals, and other contaminants from both water and sediments, leading to their accumulation in tissues, which can be quantitatively analyzed to assess pollution levels. Their sensitivity to variations in physico-chemical parameters such as pH, dissolved oxygen, and nutrient concentration makes them reliable indicators of ecological disturbances. For instance, species like Eichhornia crassipes are known for their high tolerance to polluted conditions and often proliferate in nutrient-rich or contaminated waters, while species such as Vallisneria spiralis tend to decline under high pollution stress, thereby signaling deteriorating water quality. Additionally, hydrophytes integrate environmental conditions over time, offering a more comprehensive assessment compared to instantaneous physico-chemical measurements. Their widespread distribution, ease of sampling, and cost-effectiveness further enhance their applicability in monitoring programs. Moreover, hydrophytes contribute to pollutant removal through phytoremediation, thereby serving a dual role in both indicating and mitigating pollution. Thus, their ecological relevance, sensitivity, and functional attributes provide a strong scientific basis for their use as effective bio-indicators in aquatic ecosystem assessment and management.

Hydrophytes: Classification and Ecology

1. Types of Hydrophytes

- **Free-floating Hydrophytes**

Free-floating hydrophytes are aquatic plants that remain suspended on the water surface without being anchored to the substrate, obtaining nutrients directly from the surrounding water. Species such as Eichhornia crassipes and Pistia stratiotes are common examples that often proliferate in nutrient-rich or polluted waters, forming dense mats that can influence light penetration and oxygen levels.

- **Submerged Hydrophytes**

Submerged hydrophytes grow entirely or predominantly below the water surface and are rooted in the bottom sediments or may float freely beneath the surface. Examples include Hydrilla verticillata and Vallisneria spiralis. These plants play a crucial role in oxygenating water, stabilizing sediments, and supporting aquatic biodiversity.

- **Emergent Hydrophytes**

Emergent hydrophytes are rooted in the soil under water but extend their stems, leaves, and flowers above the water surface. Species such as Typha latifolia and Nelumbo nucifera are typical examples that contribute to shoreline protection and provide habitat for various organisms.

2. Ecological Adaptations

Hydrophytes possess reduced mechanical tissues, thin cuticles, and flexible stems, as water provides physical support, reducing the need for rigid structures. They develop specialized air-filled tissues (aerenchyma) that facilitate oxygen transport within the plant, enabling survival in oxygen-deficient aquatic environments. Many hydrophytes exhibit tolerance to high nutrient loads and pollutants, allowing them to survive and accumulate contaminants, which enhances their role as bio-indicators.

3. Distribution in Freshwater Ecosystems

Hydrophytes are distributed across ponds, lakes, rivers, and wetlands, with their occurrence influenced by water depth, light availability, and nutrient concentration. Free-floating species dominate eutrophic waters, submerged species prefer clear and well-oxygenated habitats, while emergent species are commonly found along shallow margins and wetland zones. Their distribution patterns reflect environmental conditions and pollution levels, making them essential components in assessing aquatic ecosystem health and water quality.

Literature Review

The scientific discourse on hydrophytes as bio-indicators of water pollution has evolved through extensive research emphasizing their ecological significance and functional capacity in contaminated aquatic systems. Early foundational works, such as those by Kadlec and Wallace, established the conceptual framework of treatment wetlands, demonstrating how aquatic vegetation contributes to pollutant removal through natural processes. Their work highlighted the integration of biological, chemical, and physical mechanisms in water purification systems, laying the groundwork for understanding hydrophytes as both indicators and remediators. Similarly, Gopal emphasized the ecological importance of wetlands in tropical and subtropical regions, particularly under the pressures of climate change and anthropogenic disturbances. These studies collectively underscore the critical role of aquatic plants in maintaining ecosystem stability and their sensitivity to environmental changes, which makes them suitable candidates for bio-indication. The literature also reflects a growing recognition that hydrophytes provide long-term, integrative assessments of water quality, unlike conventional physico-chemical methods that offer only instantaneous measurements.

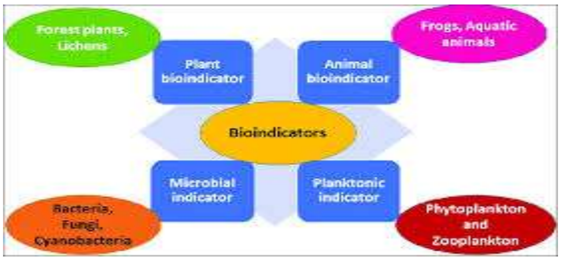
Subsequent research has focused on the mechanisms of pollutant uptake and accumulation in hydrophytes, particularly in relation to heavy metals and industrial contaminants. Bonanno and Giudice conducted detailed investigations on Eichhornia crassipes, demonstrating its remarkable capacity to accumulate heavy metals such as lead, cadmium, and chromium in its tissues. Their findings confirmed that this species not only tolerates high levels of contamination but also serves as an effective bio-indicator of metal pollution. Similarly, studies by Chandra et al. and Gupta et al. explored the phytoremediation potential of aquatic plants, including Pistia stratiotes, revealing their efficiency in removing industrial pollutants and excess nutrients from wastewater. These investigations highlight the dual functionality of hydrophytes as both indicators and agents of remediation. Furthermore, Jafari examined the ecological and socio-economic aspects of water hyacinth, noting its widespread distribution and adaptability, which enhance its applicability in pollution monitoring programs. Collectively, these studies demonstrate that hydrophytes respond predictably to pollutant stress through bioaccumulation, making them reliable tools for environmental assessment.

In addition to empirical studies, theoretical and applied research has expanded the understanding of phytoremediation processes and the role of hydrophytes in environmental management. Dhir provided a comprehensive overview of phytoremediation mechanisms, including phytoextraction, phytostabilization, and rhizofiltration, emphasizing the importance of aquatic plants in removing contaminants from water bodies. Similarly, Favas et al. examined the broader context of metal and metalloid contamination, discussing how plant-based remediation strategies can be applied across different environmental matrices. These studies highlight the biochemical and physiological adaptations of hydrophytes that enable them to tolerate and accumulate pollutants, such as the development of specialized tissues and detoxification mechanisms. The literature also emphasizes that hydrophytes exhibit species-specific responses to pollutants, which can be used to identify particular types of contamination. This specificity enhances their value as bio-indicators, as different species can signal different pollution conditions. Moreover, the integration of hydrophytes into constructed wetland systems has been widely documented as an effective and sustainable approach to wastewater treatment.

The reviewed literature provides a comprehensive understanding of the role of hydrophytes in monitoring and mitigating water pollution. The convergence of ecological, physiological, and environmental studies demonstrates that hydrophytes are not only passive indicators but active participants in maintaining water quality. Their widespread availability, ease of sampling, and cost-effectiveness make them particularly suitable for use in developing regions where advanced monitoring technologies may be limited. However, the literature also identifies certain limitations, such as seasonal variability, environmental dependency, and the need for standardized methodologies in assessing bio-indicator responses. Despite these challenges, the consistent findings across multiple studies reinforce the reliability of hydrophytes as bio-indicators. The integration of these plants into environmental monitoring frameworks and pollution control strategies represents a promising approach for sustainable water resource management. Thus, the literature strongly supports the continued use and further exploration of hydrophytes in addressing the growing global issue of water pollution.

Concept of Bio-indicators in Aquatic Systems

Bio-indicators are living organisms that provide measurable information about the quality and condition of the environment, particularly in response to pollution or ecological disturbances. In aquatic systems, organisms such as plants, animals, and microorganisms reflect changes in water quality through variations in their presence, abundance, and physiological condition. Bio-indicators typically exhibit sensitivity or tolerance to specific pollutants, have well-defined ecological requirements, and respond predictably to environmental changes.



For example, hydrophytes like Eichhornia crassipes tend to thrive in nutrient-rich or polluted waters, whereas species such as Vallisneria spiralis are more sensitive to contamination, making them useful indicators of water quality.

1. **Criteria of an Ideal Bio-indicator**

An ideal bio-indicator should respond distinctly to particular pollutants, allowing accurate identification of environmental stressors. It should be commonly found across different habitats to enable comparative analysis and monitoring. The organism should be easily recognizable and simple to collect without requiring advanced technical expertise. It must have a clear relationship with environmental conditions and play a significant role within the ecosystem.

2. **Advantages over Physico-chemical Methods**

Unlike instantaneous physico-chemical measurements, bio-indicators provide cumulative information about environmental conditions over time. Biological monitoring is relatively inexpensive as it reduces the need for continuous laboratory testing and sophisticated instruments. Bio-indicators reflect the actual biological impact of pollutants on living systems, offering a more realistic assessment of ecosystem health. They enable continuous and long-term evaluation of environmental changes, making them valuable tools for sustainable water quality management.

Mechanisms of Pollution Detection by Hydrophytes

- **Absorption and Accumulation of Pollutants**

Hydrophytes absorb dissolved contaminants through roots, leaves, and stems directly from water and sediments. Free-floating species such as Eichhornia crassipes primarily take up pollutants from the water column, whereas rooted plants accumulate substances from both sediment and water.

These plants can accumulate heavy metals like lead, cadmium, and mercury, as well as excess nutrients such as nitrogen and phosphorus, within their tissues, making them effective indicators of pollution levels.

- **Physiological and Morphological Responses**

Exposure to pollutants often results in altered photosynthesis rates, enzyme activity, and pigment concentration. Stress conditions may lead to reduced chlorophyll content and impaired metabolic processes. Hydrophytes may exhibit visible symptoms such as chlorosis (yellowing of leaves), necrosis, stunted growth, or abnormal root development. Sensitive species like Vallisneria spiralis show early signs of stress in polluted environments.

- **Biomagnification and Bioaccumulation Processes**

Hydrophytes accumulate pollutants in their tissues over time, reflecting the concentration of contaminants present in the environment. Pollutants stored in hydrophytes can enter the food chain and increase in concentration at higher trophic levels, thereby indicating long-term ecological risks.

- **Indicator Species and Their Sensitivity**

Certain hydrophytes, such as Eichhornia crassipes, thrive in highly polluted waters and indicate eutrophic or contaminated conditions. Other species, including Hydrilla verticillata, are sensitive to environmental stress and decline in polluted habitats, serving as early warning indicators of deteriorating water quality. The presence or absence of specific hydrophyte species provides valuable insights into the type and intensity of water pollution, supporting effective environmental monitoring and management.

Methodology

The study was conducted to evaluate the role of hydrophytes as bio-indicators of water pollution through systematic field sampling and laboratory analysis. Representative freshwater bodies such as ponds, lakes, and slow-flowing rivers were selected based on varying degrees of pollution (clean, moderately polluted, and highly polluted). Hydrophyte species were collected using quadrat and transect sampling methods, followed by identification with standard taxonomic keys, including species such as Eichhornia crassipes, Pistia stratiotes, Hydrilla verticillata, and Vallisneria spiralis. Water samples were simultaneously collected and analyzed for physico-chemical parameters including pH, dissolved oxygen, turbidity, nitrates, and phosphates using standard laboratory procedures. Plant samples were washed, dried, and processed for heavy metal analysis (lead, cadmium, mercury, and chromium) using atomic absorption spectrophotometry. Data on species distribution and pollutant accumulation were statistically analyzed to determine correlations between hydrophyte presence and pollution levels. Comparative analysis was performed across different sites to assess indicator efficiency and phytoremediation potential. This integrated methodological approach ensured accurate evaluation of hydrophytes as reliable indicators of water quality and environmental stress.

Result and Discussion

Table 1: Distribution of Hydrophytes in Relation to Pollution Levels

Hydrophyte Species	Type	Clean Water (%)	Moderately Polluted (%)	Highly Polluted (%)
Vallisneria spiralis	Submerged	65	30	5
Hydrilla verticillata	Submerged	55	35	10
Typha latifolia	Emergent	40	45	15
Pistia stratiotes	Free-floating	20	50	30
Eichhornia crassipes	Free-floating	10	35	55

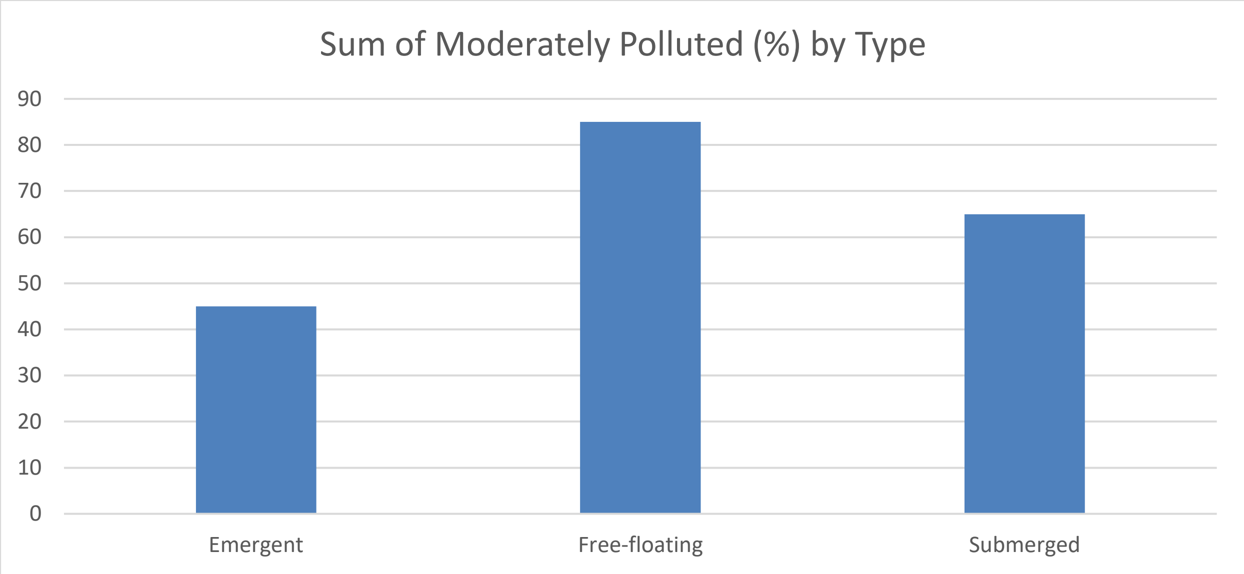


Table 1 demonstrates a clear ecological gradient in hydrophyte distribution across varying pollution levels, highlighting their indicator potential. Submerged species such as Vallisneria spiralis and Hydrilla verticillata show maximum occurrence in clean water (65% and 55%, respectively) and a sharp decline in highly polluted conditions, indicating their sensitivity to contaminants and dependence on high dissolved oxygen and low turbidity. Emergent species like Typha latifolia display moderate tolerance, occurring across all pollution levels but with higher presence in moderately polluted environments. In contrast, free-floating species such as Pistia stratiotes and Eichhornia crassipes dominate polluted waters, particularly the latter (55% in highly polluted), indicating eutrophic and contaminated conditions. Thus, species distribution effectively reflects pollution intensity.

Table 2: Accumulation of Heavy Metals in Selected Hydrophytes (mg/kg dry weight)

Hydrophyte Species	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Chromium (Cr)
Eichhornia crassipes	45	12	6	30
Pistia stratiotes	38	10	5	25
Typha latifolia	30	8	4	20
Hydrilla verticillata	22	6	3	15
Vallisneria spiralis	18	5	2	12

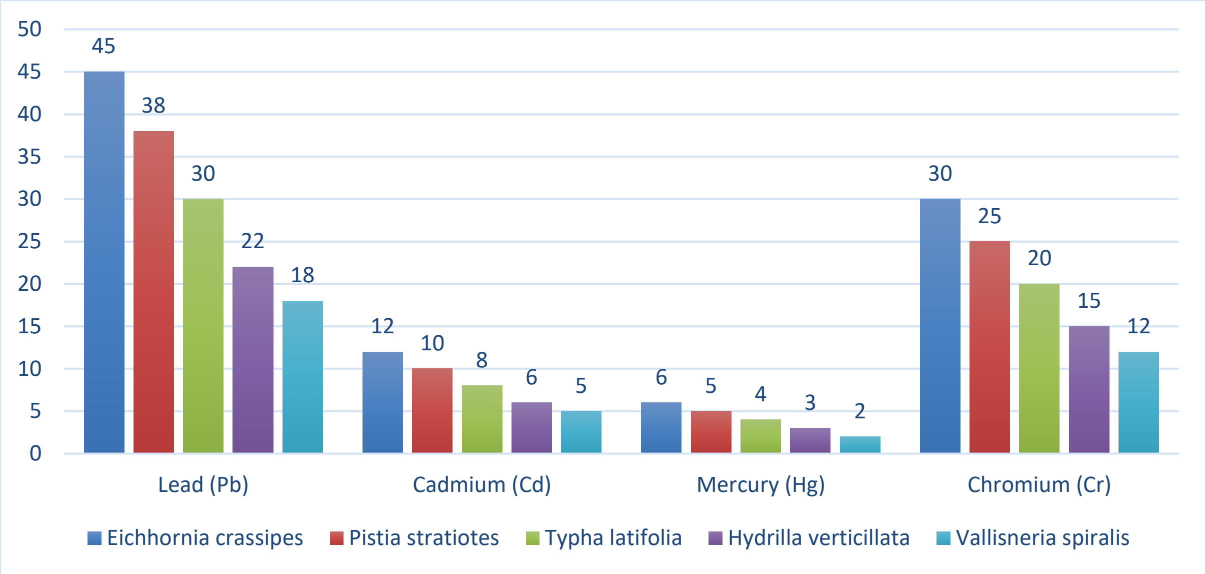


Table 2 highlights the differential capacity of hydrophytes to accumulate heavy metals, emphasizing their role in pollution monitoring and phytoremediation. Eichhornia crassipes exhibits the highest accumulation levels for all metals (Pb: 45 mg/kg, Cd: 12 mg/kg, Hg: 6 mg/kg, Cr: 30 mg/kg), demonstrating its strong bioaccumulative and tolerant nature in polluted environments. Similarly, Pistia stratiotes shows significant uptake, though slightly lower than water hyacinth. Emergent species such as Typha latifolia show moderate accumulation, reflecting their ability to absorb contaminants from both water and sediments. Submerged species like Hydrilla verticillata and Vallisneria spiralis accumulate lower concentrations, indicating sensitivity to heavy metal stress. These variations validate hydrophytes as reliable indicators of metal pollution levels.

Table 3: Physico-Chemical Parameters and Hydrophyte Response

Parameter	Clean Water	Moderately Polluted	Highly Polluted	Hydrophyte Response
pH	7.0–7.5	6.5–8.0	5.5–9.0	Variation in growth
Dissolved Oxygen (mg/L)	7–9	4–6	1–3	Reduced in sensitive species
Nitrates (mg/L)	<1	1–5	>5	Increase in floating species
Phosphates (mg/L)	<0.5	0.5–2	>2	Eutrophication
Turbidity (NTU)	<5	5–20	>20	Decline of submerged plants

Table 3 correlates key physico-chemical parameters with hydrophyte responses, illustrating how water quality influences plant distribution and health. In clean water conditions, optimal pH (7.0–7.5), high dissolved oxygen (7–9 mg/L), and low nutrient levels support the growth of sensitive submerged species. As pollution increases, dissolved oxygen declines (1–3 mg/L in highly polluted water), and nutrient concentrations such as nitrates and phosphates rise, promoting eutrophication. These conditions favor the proliferation of tolerant floating species while inhibiting submerged plants due to reduced light penetration and oxygen availability. Increased turbidity (>20 NTU) further limits photosynthesis in underwater species, leading to their decline. Variations in pH also affect metabolic processes in hydrophytes. Overall, the table demonstrates that changes in water chemistry directly influence hydrophyte composition, making them effective indicators of environmental quality.

Table 4: Phytoremediation Efficiency of Hydrophytes (%)

Hydrophyte Species	Nitrogen Removal (%)	Phosphorus Removal (%)	Heavy Metal Removal (%)
Eichhornia crassipes	75	70	80
Pistia stratiotes	70	65	75
Typha latifolia	65	60	68
Hydrilla verticillata	55	50	60
Vallisneria spiralis	50	45	55

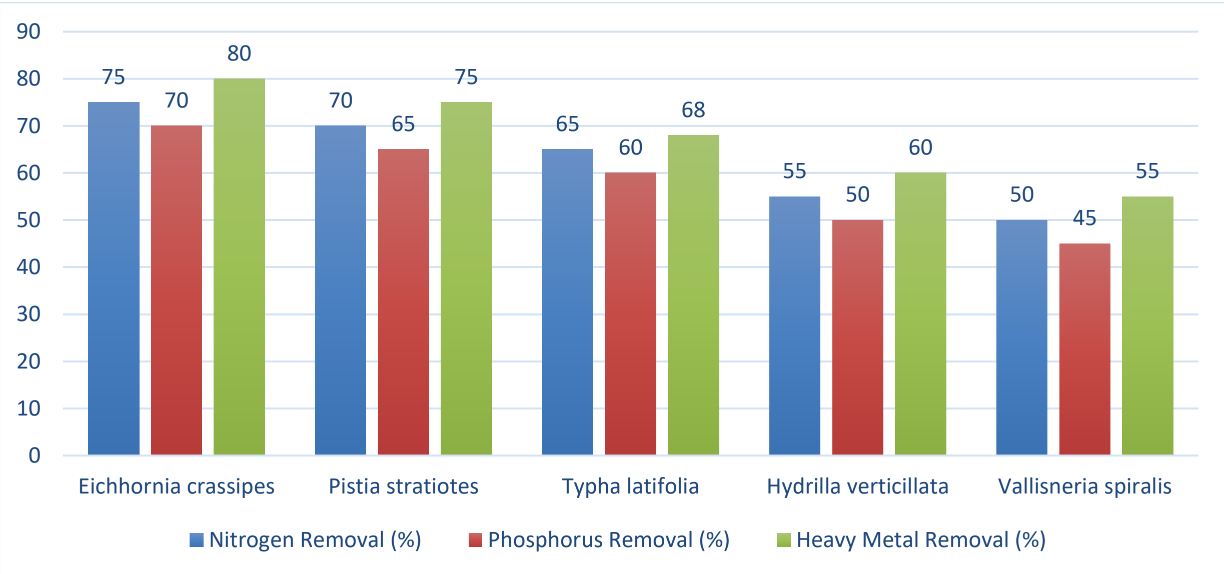


Table 4 illustrates the varying efficiency of hydrophytes in removing pollutants, reinforcing their role in water purification. Eichhornia crassipes shows the highest removal efficiency for nitrogen (75%), phosphorus (70%), and heavy metals (80%), indicating its exceptional capacity for nutrient uptake and contaminant sequestration. Pistia stratiotes also demonstrates high efficiency, making it suitable for wastewater treatment applications. Emergent species such as Typha latifolia exhibit moderate removal capacity due to their extensive root systems. Submerged species like Hydrilla verticillata and Vallisneria spiralis show comparatively lower efficiency but still contribute to nutrient cycling and water quality improvement. These findings highlight the practical significance of hydrophytes in sustainable pollution management.

Conclusion

Hydrophytes play a crucial and multifaceted role as bio-indicators of water pollution, offering a reliable, cost-effective, and ecologically meaningful approach to assessing aquatic environmental health. Their ability to absorb, accumulate, and respond to a wide range of pollutants—including nutrients, heavy metals, and organic contaminants—enables them to reflect both the intensity and nature of pollution in water bodies. The differential distribution of species such as Vallisneria spiralis and Hydrilla verticillata in clean waters, contrasted with the dominance of tolerant species like Eichhornia crassipes and Pistia stratiotes in polluted environments, clearly demonstrates their indicator value. Moreover, physiological and morphological changes observed in hydrophytes under stress conditions further strengthen their utility in monitoring ecological disturbances. In addition to their role as indicators, hydrophytes significantly contribute to phytoremediation by removing excess nutrients and toxic substances, thereby improving water quality and restoring ecological balance. Compared to conventional physico-chemical methods, hydrophyte-based assessment provides long-term, integrative insights into environmental conditions. However, factors such as seasonal variation, species specificity, and environmental fluctuations must be considered to ensure accurate interpretation. Overall, hydrophytes serve as indispensable tools in environmental monitoring, conservation planning, and sustainable water resource management, highlighting their importance in addressing the growing global challenge of water pollution.

References

1. Bonanno, G., & Giudice, R. L. (2010). Heavy metal bioaccumulation by the aquatic plant *Eichhornia crassipes* and its potential use for phytoremediation. *Ecotoxicology and Environmental Safety, 73*(7), 1374–1380.
2. Chandra, R., Yadav, S., & Yadav, S. (2012). Phytoremediation of industrial pollutants by aquatic plants. *Environmental Monitoring and Assessment, 184*(11), 7027–7038.
3. Dhir, B. (2013). Phytoremediation: Role of aquatic plants in environmental clean-up. *Springer India*.
4. Favas, P. J. C., Pratas, J., Varun, M., D'Souza, R., & Paul, M. S. (2014). Phytoremediation of soils contaminated with metals and metalloids. *Environmental Chemistry Letters, 12*(1), 123–142.
5. Gopal, B. (2013). Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. *Aquatic Sciences, 75*(1), 39–61.
6. Gupta, P., Roy, S., & Mahindrakar, A. B. (2012). Treatment of water using water hyacinth, water lettuce, and vetiver grass. *Journal of Water Resource and Protection, 4*(4), 202–209.
7. Jafari, N. (2010). Ecological and socio-economic utilization of water hyacinth (*Eichhornia crassipes* Mart Solms). *Journal of Applied Sciences and Environmental Management, 14*(2), 43–49.

8. Kadlec, R. H., & Wallace, S. D. (2009). *Treatment wetlands* (2nd ed.). CRC Press.
9. Kumar, V., Singh, J., & Kumar, P. (2017). Heavy metal uptake by aquatic plants and their role in phytoremediation. *Environmental Engineering Research, 22*(3), 247–255.
10. Mishra, V. K., & Tripathi, B. D. (2008). Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes. *Bioresource Technology, 99*(15), 7091–7097.
11. Rai, P. K. (2008). Heavy metal pollution in aquatic ecosystems and its phytoremediation using wetland plants. *Environmental Monitoring and Assessment, 152*(1–4), 89–109.
12. Rai, P. K. (2012). Role of aquatic macrophytes in heavy metal removal from wastewater. *Environmental Skeptics and Critics, 1*(1), 24–31.
13. Saha, P., & Saha, S. (2017). Assessment of aquatic macrophytes as bio-indicators of water quality. *International Journal of Environmental Sciences, 7*(2), 120–128.
14. Vymazal, J. (2011). Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia, 674*(1), 133–156.
15. Zhang, X., Liu, J., & Huang, Y. (2010). Role of aquatic plants in remediation of polluted water. *Journal of Environmental Sciences, 22*(6), 1018–1024.