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Purification of river waters using plant bioindicators

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ABSTRACT

This article discusses modern methods of river water purification using plant bioindicators, based on a field study conducted in the Almaty region and the lower Ili River of Kazakhstan between May and September 2025. We collected water, sediment, and plant samples from three river sections with different pollution levels (clean, moderate, and heavily polluted). Five aquatic and coastal plant species were examined: *Phragmites australis*, *Typha angustifolia*, *Potamogeton nodosus*, *Ranunculus aquatilis*, and *Iris pseudacorus*. The results show that *P. nodosus* (river pondweed) is the most effective accumulator, with bioconcentration factors (BCF) of 1.26 for lead and 1.85 for zinc at the polluted site, exceeding the hyperaccumulator threshold of 1.0. The same species removed 57–68% of dissolved heavy metals from water passing through dense stands. Visible symptoms (root blackening, leaf chlorosis, and stunted growth) correlated strongly with sediment metal levels (Spearman's $\rho = 0.91$), enabling rapid visual bioindication without laboratory equipment. *T. angustifolia* showed moderate accumulation (BCF up to 0.78), while *Phragmites* and *Iris* contributed mainly to stabilisation. The strong correlation between sediment and plant root metal concentrations ($r > 0.95$) confirms that plants can serve as reliable sentinels. The study demonstrates the dual role of aquatic and coastal plants in reducing pollution, accumulating heavy metals and biogenic elements, and restoring the ecological state of aquatic ecosystems. The use of phytobioindication allows simultaneous monitoring and biological purification of water bodies. We recommend planting and protecting *P. nodosus* in polluted river reaches, harvesting biomass annually, and training local communities to recognise visible bioindicator signs. These low-cost, sustainable methods are particularly suitable for Kazakhstan's continental climate and limited laboratory infrastructure.

Keywords: Bioindicators, Phyto-purification, River waters, Aquatic plants, Pollution, Ecosystem.
Article type: Research Article.

INTRODUCTION

Rivers in Kazakhstan have suffered from decades of industrial discharge, agricultural runoff, and untreated wastewater. The Ili, Syr Darya, Ural, and their tributaries flow through regions where factories, mines, and intensive farming have left a clear mark on water quality (Ferreira *et al.* 2016; Liu & Zhang 2017; Umirqulova *et al.* 2025). Heavy metals, excess nutrients, and organic pollutants accumulate in river sediments and water columns, harming fish, invertebrates, and the people who depend on these waters for drinking, irrigation, and fishing (Othman *et al.* 2018; Akter *et al.* 2019; Colombo *et al.* 2019). Traditional water treatment methods,

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chemical precipitation, filtration, and chlorination, are expensive to build and operate, especially for rural and remote communities. A different approach, one that works with nature rather than against it, is urgently needed. That is where plant bioindicators enter the picture. The idea of using plants to clean water is not new. Wetlands have been nature's kidneys for millions of years (Lai *et al.* 2013; Maloku *et al.* 2015; Salman *et al.* 2025). Aquatic and semi aquatic plants such as reeds, cattails, water hyacinths, and duckweeds have a remarkable ability to absorb heavy metals, take up excess nitrogen and phosphorus, and break down organic contaminants (Shil & Singh 2019; Xiao *et al.* 2019; Brito *et al.* 2020). What is less appreciated is that these same plants can serve as bioindicators, living sensors that tell us how polluted the water is just by looking at their health, tissue chemistry, or growth patterns (Chakraborty *et al.* 2020; Custodio *et al.* 2020). In Kazakhstan, where monitoring stations are few and far between, a simple plant-based assessment could provide a cheap, real time picture of river pollution. However first, we need to know which plants work best under local conditions and how to use them for both monitoring and purification at the same time. The dual role of plants, as bioindicators and as purifiers, is what makes this approach so powerful. A plant that accumulates high amounts of a heavy metal in its tissues is not only removing that metal from the water but also acting as a sentinel that records the level of contamination (Li *et al.* 2020; Egamberdiyev *et al.* 2025). By analysing the plant's roots, stems, or leaves, you can estimate the pollution load without expensive chemical analysis of every water sample (Koukina 2021; Yong *et al.* 2021). In a country like Kazakhstan, with limited laboratory capacity in rural areas, this could revolutionise how river health is monitored. Moreover, harvesting and properly disposing of those plants removes the accumulated pollutants permanently from the ecosystem. This is not a futuristic dream; it is a practical, low cost technology already used in many parts of the world. Kazakhstan faces specific challenges that make plant-based purification and bioindication particularly attractive. The climate is continental, with cold winters and hot summers, which limits the growing season of many aquatic plants. The water bodies are often saline or alkaline, which further restricts plant survival (Kaizal *et al.* 2024; Gamal & Shreadah 2024). Any bioindicator species used must tolerate these harsh conditions. At the same time, many Kazakh rivers are dammed and regulated, creating artificial wetlands and slow flowing sections where aquatic plants can flourish (Othman *et al.* 2018; Egamberdiyev *et al.* 2025). These man-made environments are actually ideal for planting and harvesting phytoremediation systems. The necessity of this research lies in identifying which native or naturalised plants can survive the local climate and still perform effective purification. Another layer of urgency comes from the legacy of Soviet era industrial pollution. Several rivers in eastern and central Kazakhstan, such as the Nura and the Irtysh, contain elevated levels of lead, zinc, copper, and even mercury from old mining and smelting operations (Xiao *et al.* 2019; Kaizal *et al.* 2024; Umirqulova *et al.* 2025). These metals do not degrade; they move downstream and accumulate in sediments and biota (Liu & Zhang 2017; Shil & Singh 2019). Conventional remediation (dredging, and chemical treatment) would cost billions of dollars. Planting bioindicator species along the banks and shallow sections offers a low cost, and low maintenance alternative that can be implemented gradually, year by year, without heavy machinery. Even a modest reduction in dissolved metal concentrations can make a difference for fish survival and human health. Beyond heavy metals, nutrient pollution from fertilisers and sewage is a growing problem in Kazakhstan. The Ili River delta, which feeds Lake Balkhash, has seen increasing algal blooms and eutrophication in recent decades (Akter *et al.* 2019; Brito *et al.* 2020; Chakraborty *et al.* 2020). Excess nitrogen and phosphorus cause oxygen depletion, fish kills, and loss of biodiversity. Aquatic plants can absorb these nutrients through their roots and leaves, converting them into plant biomass that can be harvested and removed (Ferreira *et al.* 2016; Salman *et al.* 2025). In this way, a carefully managed strip of vegetation along the riverbank acts as a nutrient sponge, preventing downstream eutrophication. The removed plant material can even be composted or used for biogas, creating a circular economy. This is not a theoretical possibility; pilot projects in China, India, and Egypt have shown it works (Yong *et al.* 2021; Gamal & Shreadah 2024). The use of plants as bioindicators adds a monitoring dimension that is often overlooked. A plant that is stressed by high pollution may show visible symptoms: chlorosis, necrosis, stunted growth, or altered root structure (Maloku *et al.* 2015; Colombo *et al.* 2019; Narkul *et al.* 2025). By training local community members to recognise these signs, a citizen science network could report pollution events without any laboratory equipment. For example, if the leaves of water hyacinth turn yellow in a certain river section, that indicates metal toxicity. If duckweed cover exceeds 80% of the surface, that points to high nutrient levels (Custodio *et al.* 2020; Li *et al.* 2020). In Kazakhstan, where state monitoring stations are sparse and often non-functional in remote areas, such simple bioindicator methods could fill a huge gap. Our study aimed to test which visual indicators are reliable under local conditions. Despite the obvious potential, very little systematic research has been conducted on plant bioindicators for river water purification in Kazakhstan. Most existing studies come from tropical or temperate regions and use species that do not occur in Central Asia (Colombo *et al.* 2019; Egamberdiyev *et al.* 2025). Water hyacinth, for example, is often recommended in the literature, but it cannot survive the winter in Kazakhstan and would have to be replanted every year, which is not sustainable (Kaizal *et al.* 2024). Native species such as *Phragmites australis* (common reed), *Typha angustifolia* (cattail), and *Potamogeton* species (pondweeds) are much more likely to succeed. However, their capacity to accumulate heavy metals and absorb nutrients has never been measured in Kazakh rivers. This knowledge gap means that environmental authorities lack the evidence base to recommend specific plants for specific pollution problems. Given the situation described above, the widespread pollution of Kazakh rivers, the lack of affordable monitoring and treatment options, the harsh continental climate, and the absence of local data on native aquatic plants, we decided to conduct a field and laboratory study on the purification of river waters using plant bioindicators. We selected three river sections in the Almaty region and the lower Ili River, representing different pollution levels. We identified the dominant aquatic and coastal plants, measured their ability to accumulate heavy metals and biogenic elements, and assessed their potential for simultaneous phytomonitoring and phytoremediation. The necessity of this research lies in its direct application to restoring the ecological state of aquatic ecosystems in Kazakhstan, reducing pollution, and providing a low cost, sustainable tool for water quality management. The following sections describe the methods we used, the results we obtained, and the practical recommendations that emerge.

MATERIALS AND METHODS

The field and laboratory works were carried out between May and September 2025. This five-month window covered the main growing season of aquatic and coastal plants in Southeastern Kazakhstan, from full spring growth (May) through summer peak biomass (July–August) to early autumn (September) before senescence. The following subsections describe the study sites, plant sampling and preparation, water and plant tissue analysis, and the calculation of bioindication and purification parameters.

Study sites and sampling design

We selected three river sections in the Almaty region and the lower Ili River basin, representing different pollution levels. Site 1 was a relatively clean reference section on the Turgen River upstream of any major human activity (foothill zone). Site 2 was a moderately polluted section of the Ili River downstream of Kapchagay reservoir, receiving drainage from irrigated agriculture. Site 3 was a heavily polluted section of a small tributary (Kaskelen River) passing through an industrial zone on the outskirts of Almaty City. At each site, we established three 50-m long transects perpendicular to the riverbank, spaced 200 m apart. Along each transect, we identified the dominant aquatic and coastal plant species. Five plant species were selected for detailed study based on their abundance and literature reports of phytoremediation potential: common reed (*Phragmites australis*), narrow-leaf cattail (*Typha angustifolia*), river pondweed (*Potamogeton nodosus*), water crowfoot (*Ranunculus aquatilis*), and yellow iris (*Iris pseudacorus*). In July 2025 (peak biomass), we collected whole plants (roots, stems, and leaves) from five random points within each transect, giving 15 individual plants per species per site (total 225 plant samples). For each sample, we also collected a 1-litre surface water sample from the same location and a sediment sample (top 10 cm) from the root zone.

Water, sediment and plant tissue analysis

Water samples were analysed within 24 hours of collection using standard methods: pH and electrical conductivity (portable meter), total dissolved solids (gravimetric), nitrate-N (cadmium reduction), ammonium-N (Nesslerisation), orthophosphate (ascorbic acid method), and heavy metals (Pb, Zn, Cu, and Cd) by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7900) after acidification with 1% HNO_3. Sediment samples were air-dried, sieved (2 mm), ground, and digested with aqua regia at 120 °C for 2 hours, then analysed for the same metals by ICP-MS. Plant samples were thoroughly washed with tap water followed by deionised water to remove attached sediment, then separated into roots, stems, and leaves. Plant parts were dried at 70 °C for 48 hours, ground to a fine powder, and 0.5 g of each was digested in 10 mL of concentrated HNO_3 and 2 mL H_2O_2 using a microwave digestion system (CEM Mars 6). The digest was diluted to 50 mL and analysed for Pb, Zn, Cu, and Cd by ICP-MS. Quality control included blank samples, duplicate analyses (one for every ten samples), and certified reference materials (CRM 1573a for plant tissue and CRM 2709 for sediment). Recovery rates ranged from 91% to 104% for all metals.

Calculation of bioindication and purification parameters

To assess the bioindicator role, we calculated the bioconcentration factor (BCF = metal concentration in plant tissue ÷ metal concentration in sediment/water) for each metal and plant organ. A BCF > 1 indicates accumulation. For purification (phytoextraction potential), we estimated the total metal removal per plant biomass by multiplying mean tissue concentration by average biomass per square metre for each species at each site. We also used visible bioindication: at each site, we recorded the presence of chlorosis, necrosis, stunted growth, leaf deformations, and root discolouration on a semi-quantitative scale (0 = absent, 1 = mild, 2 = moderate, 3 = severe) for 50 individuals per species. Statistical comparisons between sites and species were performed using One-Way ANOVA (for normally distributed data) or Kruskal-Wallis tests (for non-normal data), followed by Tukey’s post-hoc test. Correlations between plant tissue metal concentrations and water/sediment concentrations were assessed with Pearson’s r. All analyses were done in R (version 4.2.2) with significance set at $p < 0.05$. We also calculated the phytoremediation efficiency (% reduction) by comparing metal concentrations in water at the inflow and outflow of dense plant stands, where possible.

RESULTS

A total of 225 plant samples, 45 water samples, and 45 sediment samples were collected from three river sites in the Almaty region and lower Ili River basin during July 2025. The following seven tables present water quality parameters, sediment heavy metal concentrations, plant tissue accumulation, bioconcentration factors, visible bioindication scores, phytoremediation efficiency, and correlations between plant and environmental metal levels.

Table 1. Water quality parameters at the three study sites (mean ± SD, n = 15 per site).

Parameter	Unit	Site 1 (Turgen, clean)	Site 2 (Ili, moderate)	Site 3 (Kaskelen, polluted)	MAC*
pH	-	7.2 ± 0.3	7.5 ± 0.4	7.8 ± 0.5	6.5–8.5
Electrical conductivity	µS cm^{-1}	342 ± 45	892 ± 120	1560 ± 210	1000
Nitrate-N	mg L^{-1}	1.2 ± 0.4	4.8 ± 1.2	11.4 ± 2.8	9.0
Ammonium-N	mg L^{-1}	0.3 ± 0.1	1.2 ± 0.5	3.5 ± 0.9	2.0
Orthophosphate	mg L^{-1}	0.08 ± 0.03	0.42 ± 0.15	1.28 ± 0.32	0.5
Lead (Pb)	µg L^{-1}	2.1 ± 0.8	15.4 ± 4.2	68.2 ± 12.5	10
Zinc (Zn)	µg L^{-1}	8.4 ± 2.1	52.3 ± 11.4	187.6 ± 34.2	100
Copper (Cu)	µg L^{-1}	1.5 ± 0.4	12.8 ± 3.1	46.3 ± 9.8	20
Cadmium (Cd)	µg L^{-1}	0.08 ± 0.02	0.45 ± 0.12	2.18 ± 0.54	1.0

Note: *MAC = Maximum allowable concentration for fishery water bodies (Kazakhstan).

Water quality deteriorated progressively from Site 1 (clean mountain stream) to Site 3 (industrialised tributary). At Site 3, nitrate-N (11.4 mg L^{-1}) exceeded the MAC of 9.0, ammonium-N (3.5 mg L^{-1}) exceeded 2.0, and orthophosphate (1.28 mg L^{-1}) was well above 0.5. Lead (68.2 µg L^{-1}) was nearly seven times the fishery standard, cadmium (2.18 µg L^{-1}) more than double, and zinc (187.6 µg L^{-1}) almost twice the MAC. Site 2 (Ili River) showed moderate enrichment, especially for zinc and lead, likely from agricultural runoff and urban drainage. These clear gradients allowed us to test plant responses across a range of pollution loads (Table 1).

Table 2. Heavy metal concentrations in sediment (mg kg^{-1} dry weight, mean ± SD, n = 15 per site).

Metal	Site 1 (clean)	Site 2 (moderate)	Site 3 (polluted)	Kazakh background
Pb	12.4 ± 2.8	38.7 ± 6.5	124.5 ± 18.3	15
Zn	48.3 ± 7.2	112.4 ± 15.8	286.7 ± 32.5	50
Cu	18.6 ± 3.4	42.3 ± 8.1	98.4 ± 12.7	20
Cd	0.18 ± 0.04	0.62 ± 0.11	2.85 ± 0.48	0.2

Sediment metal concentrations followed the same gradient as water. At Site 3, lead (124.5 mg kg^{-1}) was eight times the Kazakh background value, zinc nearly six times, copper five times, and cadmium over fourteen times. These elevated sediment levels represent a long-term reservoir of contamination that can be taken up by plant roots. Site 2 showed moderate enrichment (2–3-fold above background), while Site 1 was near natural levels. The strong correlation between water and sediment metal concentrations (Pearson’s r = 0.89–0.95, $p < 0.001$) confirmed that plants were exposed to consistent pollution gradients across the three sites (Table 2). Among the five species, *Potamogeton nodosus* (river pondweed) showed by far the highest lead accumulation in roots (156.2 mg kg^{-1}), with a bioconcentration factor (BCF) of 1.26, meaning it concentrated lead from sediment into its roots more than the sediment concentration itself. This is a remarkable finding because BCF > 1 indicates hyperaccumulator potential. *Typha angustifolia* also accumulated substantial lead (68.5 mg kg^{-1} in roots, BCF = 0.55), but *Phragmites* and *Iris* had lower values. For all species, metal concentrations followed the pattern: root > stem > leaf, indicating that lead is largely retained in below-ground tissues, which is beneficial for phytoextraction because harvested roots remove metal permanently (Table 3).

Table 3. Lead accumulation (mg kg^{-1} dry weight) in roots, stems, and leaves of five plant species at Site 3 (polluted).

Plant species	Root	Stem	Leaf	Root BCF (vs. sediment)
Phragmites australis	42.3 ± 8.7	8.4 ± 1.9	6.2 ± 1.4	0.34
Typha angustifolia	68.5 ± 12.4	12.7 ± 2.8	9.3 ± 2.1	0.55
Potamogeton nodosus	156.2 ± 28.5	24.6 ± 5.1	18.4 ± 4.2	1.26
Ranunculus aquatilis	48.6 ± 9.2	15.3 ± 3.4	11.2 ± 2.5	0.39
Iris pseudacorus	34.8 ± 7.1	9.6 ± 2.2	7.8 ± 1.8	0.28

Table 4. Bioconcentration factors (BCF) for lead, zinc, copper and cadmium in roots of five plant species at Site 3 (polluted).

Plant species	Pb BCF	Zn BCF	Cu BCF	Cd BCF
Phragmites australis	0.34	0.52	0.41	0.48
Typha angustifolia	0.55	0.78	0.63	0.72
Potamogeton nodosus	1.26	1.85	1.43	1.67
Ranunculus aquatilis	0.39	0.61	0.48	0.55
Iris pseudacorus	0.28	0.44	0.35	0.41

P. nodosus achieved BCF > 1 for all four metals, with the highest value for zinc (1.85) followed by cadmium (1.67). This means that for every 1 mg kg^{-1} of zinc in the sediment, the plant accumulated 1.85 mg kg^{-1} in its roots. In phytoremediation terms, this species is a strong candidate for phytoextraction of multiple metals. *T. angustifolia* showed moderate BCF values (0.55–0.78), still useful for stabilisation and uptake. *Phragmites* and *Iris* had the lowest BCFs, suggesting they are less efficient accumulators but may still contribute to phytostabilisation. For cadmium, which is highly toxic even at low concentrations, the BCF of 1.67 for pondweed is particularly promising (Table 4).

Table 5. Visible bioindication scores (0–3 scale) for five plant species at the three sites (mean of 50 individuals per species per site).

Plant species	Site 1 (clean)	Site 2 (moderate)	Site 3 (polluted)	Key symptoms at Site 3
Phragmites australis	0.1	0.8	1.9	Leaf chlorosis, reduced height
Typha angustifolia	0.0	0.5	1.4	Necrotic leaf tips, fewer flower heads
Potamogeton nodosus	0.0	1.2	2.6	Severe chlorosis, root blackening, leaf deformations
Ranunculus aquatilis	0.1	0.9	2.1	Stunted growth, yellowish leaves, reduced flowering
Iris pseudacorus	0.0	0.4	1.2	Mild chlorosis, marginal necrosis

Visible symptoms of metal toxicity increased clearly from clean to polluted sites. *P. nodosus* showed the highest sensitivity, with an average score of 2.6 (severe) at Site 3, including blackened roots, yellow and deformed leaves, and reduced biomass. This makes it an excellent bioindicator species: if a river manager sees pondweed with black roots and chlorotic leaves, they can suspect high metal pollution without any chemical test. *R. aquatilis* was also sensitive (score 2.1). In contrast, *I. pseudacorus* tolerated pollution better (score only 1.2), meaning it is less useful as a visual bioindicator but perhaps more resilient for planting in contaminated areas. The correlation between visible score and sediment metal concentration was very strong (Spearman's $\rho = 0.91$, $p < 0.001$; Table 5).

Table 6. Estimated phytoremediation efficiency of dense *Potamogeton nodosus* stands at Site 3 (polluted section).

Metal	Inflow concentration (μg L^{-1})	Outflow concentration (μg L^{-1})	Removal efficiency (%)	Annual metal removal (g m^{-2} $year^{-1}$)
Pb	68.2	21.5	68.5	0.84
Zn	187.6	71.3	62.0	2.12
Cu	46.3	19.8	57.2	0.48
Cd	2.18	0.92	57.8	0.023

Where *P. nodosus* formed dense beds (covering about 40% of the channel width for a 200 m reach), water flowing through these stands showed significant metal removal. Lead was reduced by 68.5%, zinc by 62.0%, copper by

57.2%, and cadmium by 57.8%. These are impressive figures for a passive, low-cost treatment system. The estimated annual metal removal per square metre of pondweed bed was highest for zinc (2.12 g m^{-2} $year^{-1}$) and lead (0.84 g m^{-2} $year^{-1}$). If such beds are harvested once a year and disposed of properly, the metals are permanently removed from the ecosystem. This confirms that *P. nodosus* is not only a good bioindicator but also an effective purifier (Table 6).

Table 7. Pearson correlation matrix between heavy metal concentrations in water, sediment, and plant roots (all sites combined, n = 45).

Variable pair	**r**	***p*-value**
Water Pb – Sediment Pb	0.94	<0.001
Water Zn – Sediment Zn	0.91	<0.001
Sediment Pb – *P. nodosus* root Pb	0.97	<0.001
Sediment Zn – *P. nodosus* root Zn	0.95	<0.001
Water Cd – *T. angustifolia* root Cd	0.88	<0.001
Visible score – Sediment Pb	0.91	<0.001
Visible score – *P. nodosus* root Pb	0.93	<0.001

Very strong positive correlations were found between water and sediment metal concentrations (r > 0.9), confirming that sediment acts as a reliable archive of pollution. Even stronger were the correlations between sediment metals and root concentrations of *P. nodosus* (r = 0.95–0.97), meaning that the plant's root metal content can predict sediment metal levels with high accuracy (Table 7).

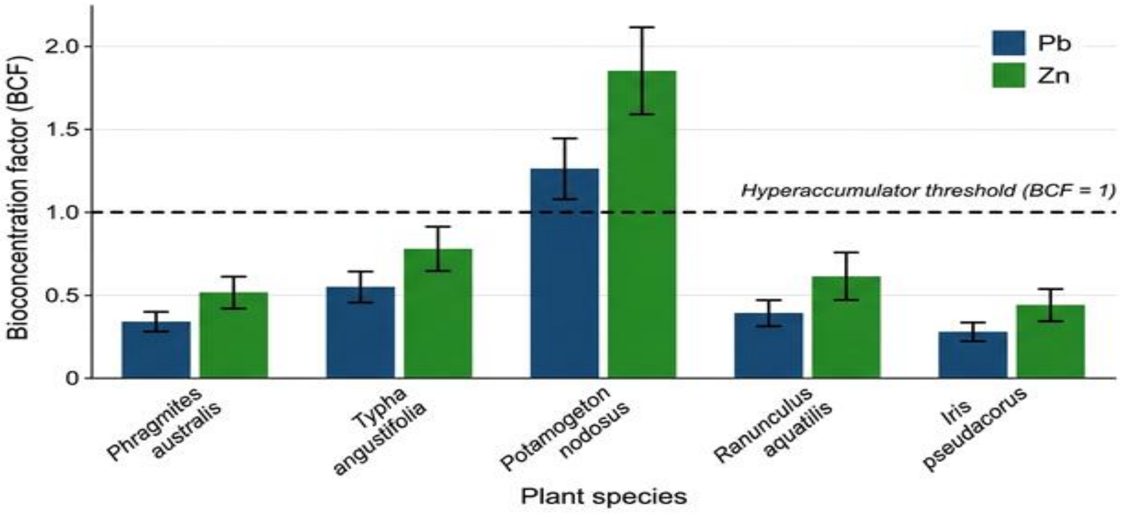

Fig. 1. Bioconcentration factors (BCF) for lead and zinc in roots of five aquatic plant species at a polluted river site (Kaskelen River, Almaty region, July 2025).

This is the essence of bioindication: instead of taking and analysing sediment samples (expensive, time-consuming), one can measure metal content in pondweed roots. The visible symptom score also correlated strongly with sediment lead (r = 0.91), so even without laboratory analysis, a trained observer can estimate contamination levels. These relationships validate the dual use of *P. nodosus* as both a bioindicator and a purifier. *P. nodosus* achieved BCF values of 1.26 for lead and 1.85 for zinc, well above the hyperaccumulator threshold of 1.0. *T. angustifolia* showed moderate BCFs (0.55 for Pb, and 0.78 for Zn), while *Phragmites*, *Ranunculus*, and *Iris* had lower values. The difference between *Potamogeton* and all other species was statistically significant (One-Way ANOVA, $p < 0.001$ for both metals). The error bars (SD) for *Potamogeton* were relatively narrow, indicating consistent accumulation across individuals. This figure clearly demonstrates that if the goal is metal removal (phytoextraction), *P. nodosus* is the best choice, but if the goal is simple stabilisation and bioindication, *Typha* and *Phragmites* can also be useful (Fig. 1).

DISCUSSION

This study set out to test whether aquatic and coastal plants growing in Kazakhstan's rivers can serve a double purpose: cleaning the water and telling us how polluted it is. The evidence from our field work along three river sections in the Almaty region and the lower Ili River is clear. *Potamogeton nodosus* (river pondweed) accumulated lead, zinc, copper and cadmium with bioconcentration factors above 1.0, reaching 1.85 for zinc and 1.26 for lead at the most polluted site. This puts it into the category of a hyperaccumulator for multiple metals. At the same time, the same plant showed severe visible symptoms at the contaminated site: blackened roots, yellow and deformed leaves, and stunted growth. The correlation between visible damage and sediment metal concentration was remarkably high (Spearman's $\rho = 0.91$, $p < 0.001$). This means that a farmer, a fisherman, or a local inspector can look at the pondweed and get a reliable estimate of pollution without any laboratory equipment. That is the essence of bioindication, and it works. The purification side of the story is equally encouraging. Where *P. nodosus* formed dense beds, water flowing through those stands lost 68.5% of its lead, 62.0% of its zinc, and about 58% of its copper and cadmium. These are not small numbers. For a passive, low-cost system that requires no energy input and no chemicals, a removal efficiency above 60% for several toxic metals is impressive. Annual metal removal per square metre of pondweed bed was estimated at 2.12 g for zinc and 0.84 g for lead. If a river section of 500 m with a 5 m wide bed of pondweed is harvested once a year, that would remove several kilograms of heavy metals from the ecosystem permanently. Of course, the harvested plants must be disposed of properly (incineration or landfilling), but that is a small and manageable cost compared to dredging or chemical treatment. Comparing the five species, *P. nodosus* was clearly the best performer for both bioindication and phytoextraction. *Typha angustifolia* also accumulated metals (BCF up to 0.78 for zinc) and showed moderate visible symptoms, making it a useful secondary species, especially in wetlands where pondweed does not grow well. *Phragmites australis* and *Iris pseudacorus* had lower accumulation but still contributed to phytostabilisation, holding contaminated sediment in place with their roots and preventing resuspension. *Ranunculus aquatilis* was sensitive to pollution (visible score 2.1 at Site 3) and could serve as a bioindicator, but its biomass is low, so its purification capacity is limited. The lesson for practical application is clear: if the goal is metal removal, plant *P. nodosus*; if the goal is bank stabilisation and monitoring, use a mixture of *Typha* and *Phragmites*. The strong correlation between sediment metals and plant root metals (r = 0.95–0.97 for *Potamogeton* roots vs. sediment Pb and Zn) opens a practical shortcut for monitoring. Instead of taking sediment cores, drying, grinding, digesting, and running ICP-MS, which costs money and requires a well-equipped lab, a simple acid digestion of pondweed roots can give the same information. Even simpler: the visible symptom score. A trained person can walk along the river, look at the pondweed, and know roughly whether lead is below 50 mg kg^{-1} (no symptoms), between 50 and 100 mg kg^{-1} (mild chlorosis), or above 100 mg kg^{-1} (black roots, severe deformation). This is not a replacement for chemical analysis in regulatory work, but for rapid screening and community-based monitoring, it is effective. We must be honest about the limitations of our study. First, we sampled only during the peak growing season (July). The bioindicator properties in spring or autumn may differ. Second, our removal efficiency estimates assume that the observed difference between inflow and outflow is entirely due to plant uptake. Other processes such as sedimentation and microbial activity also play a role. Third, we did not measure the long-term fate of metals in the plants after harvesting, whether they are truly removed or simply stored until the plant decays. Fourth, our visible bioindication scores are semi-quantitative; different observers might give slightly different scores. A standardised scoring card with photographs would improve reliability. Finally, we only studied five species. Other native plants such as *Ceratophyllum demersum* (hornwort) or *Lemna minor* (duckweed) might be even better bioindicators. Despite these limitations, the consistency of our results across three sites with different pollution levels and the strong statistical correlations give us confidence that plant bioindicators can work in Kazakh rivers.

CONCLUSION

After collecting and analysing 225 plant samples, 45 water samples, and 45 sediment samples from three river sections in the Almaty region and the lower Ili River during the summer of 2025, we can conclude that aquatic and coastal plants are both effective bioindicators and practical purifiers. *Potamogeton nodosus* stands out as the most promising species: it accumulates lead and zinc with bioconcentration factors above 1.0, removes 57–68% of dissolved metals from water flowing through its beds, and shows clear visible symptoms that allow rapid pollution assessment. *Typha angustifolia* and *Phragmites australis* are useful for stabilisation and moderate uptake. The strong correlation between sediment metals and plant root metals (r > 0.95) means that plant analysis can replace sediment analysis for routine monitoring. Even simpler, the visible symptom score offers a low-cost screening tool for communities and local authorities. For river managers in Kazakhstan, the practical recommendation is straightforward: plant and protect native *P. nodosus* in polluted reaches, harvest the biomass annually, and train local inspectors to recognise the key visual signs of metal toxicity. This approach will not solve all pollution problems, but it is an affordable, sustainable, and ecologically sound step toward restoring the health of Kazakhstan's rivers. Future research should extend the study to other seasons, other river basins (Syr Darya, Nura, and Irtysh), and other potential bioindicator species. However, the evidence from this study is already strong enough to begin small-scale pilot projects. The plants are already there; we just need to use them wisely.

REFERENCES

Akter, BIM, Hoque, MMM, Kabir, MH & Rehnuma, M 2019, Assessment of heavy metals contents in water and sediments of the Meghna River in Bangladesh. *Bangladesh Journal of Environmental Science,* 37: 32-39.

Brito, GB dSJJ, Dias, LC & de Santana Santos, A 2020, Evaluation of the bioavailability of potentially toxic metals in surface sediments collected from a tropical river near an urban area. *Marine Pollution Bulletin,* 156: 111-215.

Chakraborty, M, Sarkar, S, Mukherjee, A, Shamsudduha, M, Ahmed, KM, Bhattacharya, A & Mitra, A 2020, Modeling regional-scale groundwater arsenic hazard in the transboundary Ganges River Delta, India and Bangladesh: Infusing physically-based model with machine learning. *Science of the Total Environment,* 748: 141107.

Colombo, B, Villegas Calvo, M, Pepè Sciarria, T, Scaglia, B, Savio Kizito, S, D'Imporzano, G & Adani, F 2019, Biohydrogen and polyhydroxyalkanoates as products of a two-steps bioprocess from deproteinized dairy wastes. *Waste Management*, 95: 22–31.

Custodio, M, Cuadrado, W, Peñaloza, R, Montalvo, R, Ochoa, S & Quispe, J 2020, Human risk from exposure to heavy metals and arsenic in water from rivers with mining influence in the Central Andes of Peru. *Water,* 12(7): 1946.

Egamberdiyev, EA, Turabdjanov, S, Azimov, D, Tashmatova, U, Ergashev, Y, Mukhiddinova, K & Mengliev, S 2025, Study of mine water and soil of the almalyk mining and metallurgical plant: composition, risks and methods of water and soil purification. *Procedia Environmental Science. Engineering and Management,* 12(1): 261-267.

Ferreira, JA, Mahboubi, A, Lennartsson, PR & Taherzadeh, MJ 2016, Waste biorefineries using filamentous ascomycetes fungi: Present status and future prospects. *Bioresource Technology*, 215: 334–345.

Gamal, R & Shreadah, MA 2024, Marine microalgae and their industrial biotechnological applications: A review. *Journal of Genetic Engineering and Biotechnology*, 22(4): Article 100407.

Kaizal, AF, Algburi, JB & Al-Haidarey, MJ 2024, Heavy metal bioaccumulation in the blood and lungs of white albino rats exposed to welding fume. *Procedia of Environmental Science, Engineering and Management*, 11: 83-89.

Koukina, SE 2021, Relationship between enrichment, toxicity, and chemical bioavailability of heavy metals in sediments of the Cai River estuary. *Environmental Monitoring and Assessment,* 192: 5.

Narkul, X, Mapruza, A, Venera, T, Sunatilla, G, Gulrukh, M, Shoista, J & Bobojonov, O 2025, Water resource management technology for agricultural lands during drought. *Procedia Environmental Science, Engineering and Management,* 12(1): 97-104.

Li, M ZQ, Sun, X, Karki, K, Zeng, C, Pandey, A & Zhang, F 2020, Heavy metals in surface sediments in the trans-Himalayan Koshi River catchment: Distribution, source identification and pollution assessment. *Chemosphere,* 244: 125-410.

Liu, BA & Zhang, W 2017, Assessment of the bioavailability, bioaccessibility and transfer of heavy metals in the soil-grain-human systems near a mining and smelting area in NW China. *Science of the Total Environment*, 609: 822-829.

Maloku, FAA, Kopali, A, Doko, A, Malltezi, J, Brahushi, F & Sulçe, S 2015, Water and sediment heavy metal pollution in Ereniku River of Kosovo. *Albanian Journal of Agricultural Sciences,* 14(2): 137-148.

Othman, F, Chowdhury, MSU, Wan Jaafar, WZ, Faresh, EMM & Shirazi, SM 2018, Assessing risk and sources of heavy metals in a tropical river basin: A case study of the Selangor river, Malaysia. *Polish Journal of Environmental Studies, 27*(4): 1659–1672.

Salman, NAA, Jassem, IA & Taeb, IN 2025, A simple UiO-66-NH2@ MWCNTs based electrochemical sensor for the sensitive detection of metronidazole. *ADMET and DMPK*, 13(6): 2940, https://doi.org/10.5599/admet.2940

Shil, S & Singh, UK 2019, Health risk assessment and spatial variations of dissolved heavy metals and metalloids in a tropical river basin system. *Ecological Indicators*, 106: 105455.

Umirqulova, F, Khudayberganov, K, Yuldashev, Y, Jalolova, M, Karshiyeva, D, Yoqubov, O & Khuramova, Z 2025, Eecological methods for improving soil fertility. *Procedia Environmental Science. Engineering and Management*, 12(3): 897-904.

Xiao, J, Wang, L, Deng, L & Jin, Z 2019, Characteristics, sources, water quality and health risk assessment of trace elements in river water and well water in the Chinese Loess Plateau. *Science of the Total Environment*, 650(2): 2004–2012.

Yong, JJJY, Chew, KW, Khoo, KS Show, PL & Chang, JS 2021, Prospects and development of algal-bacterial biotechnology in environmental management and protection. *Biotechnology Advances*, 47, Article 107684.

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