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Comparative Analysis of Phytoremediation Potential in Native vs. Invasive Plant Species

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Abstract: Phytoremediation, the use of plants to mitigate environmental pollutants, offers a sustainable approach for cleaning contaminated sites. This study performs a comparative analysis of phytoremediation potential between native and invasive plant species. Native species, adapted to local conditions, and invasive species, known for their aggressive growth, were evaluated for their ability to remediate pollutants, including heavy metals and organic contaminants. The research involved assessing growth patterns, biomass accumulation, and pollutant removal efficiency under controlled conditions. Results indicated that invasive species such as Phragmites australis and Reynoutria japonica demonstrated higher efficiency in removing both heavy metals and organic contaminants compared to native species like Echinacea purpurea and Rudbeckia hirta. While invasive species showed superior remediation capabilities, they also posed significant ecological risks, including potential disruption to local ecosystems. In contrast, native species, although less effective in some remediation aspects, contributed positively to local biodiversity and ecosystem stability. The study underscores the need for a balanced approach in phytoremediation efforts, integrating both native and invasive species while considering their ecological impacts and remediation effectiveness.

Keywords: Phytoremediation, Native Plant Species, Invasive Plant Species, Pollutant Removal, Heavy Metals, Organic Contaminants, Environmental Cleanup, Ecological Impact, Biomass Accumulation, Remediation Efficiency

I. Introduction

Phytoremediation is an innovative and eco-friendly approach to environmental cleanup that utilizes plants to remove, degrade, or immobilize pollutants from soil, water, and air. This technique capitalizes on the natural processes of plants, including their ability to absorb contaminants through their roots, transport them to their shoots, and either store or transform them into less harmful substances [1]. As a sustainable alternative to traditional remediation methods, phytoremediation has garnered significant attention for its potential to address various types of pollution, ranging from heavy metals to organic compounds. The effectiveness of phytoremediation can be influenced by the type of plant species used. This study focuses on comparing the phytoremediation potential of native versus invasive plant species, aiming to elucidate their respective capabilities and ecological impacts [2]. Native plant species, those that naturally occur in a particular region, are well-adapted to local environmental conditions. They have evolved alongside regional soil, climate, and microbial communities, which can enhance their ability to interact with pollutants in a familiar environment. Native plants often play a crucial role in maintaining ecosystem stability and biodiversity.

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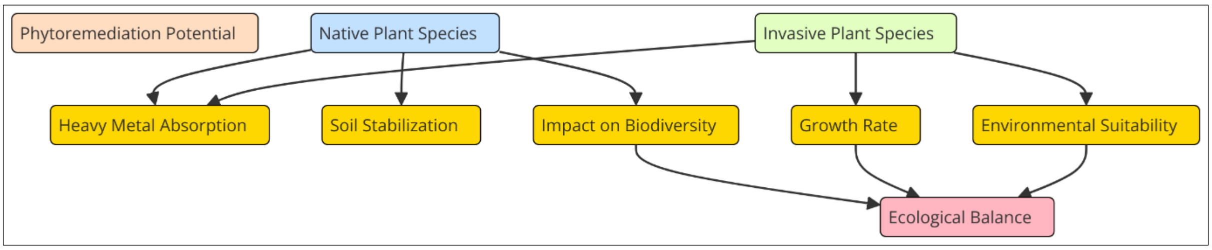

Figure 1. Depicts the Invasive Plant Species in Terms of their Phytoremediation Potential

They contribute to soil health, support native wildlife, and are generally considered integral to the health of their natural habitats [3]. Their use in phytoremediation not only offers the potential for effective pollutant removal but also aligns with conservation goals, minimizing disruptions to local ecosystems. Invasive plant species are non-native species that spread aggressively and can outcompete local flora for resources. These species often exhibit rapid growth and high biomass production, which can make them appear advantageous for phytoremediation purposes. Invasive species such as Phragmites australis and Reynoutria japonica are known for their ability to thrive in disturbed environments and accumulate significant amounts of contaminants [4]. Their high growth rates and biomass can enhance the efficiency of pollutant uptake and degradation. The aggressive nature of invasive species raises concerns about their potential to disrupt local ecosystems and biodiversity. The comparative analysis of native and invasive plant species for phytoremediation involves evaluating various factors, including growth patterns, biomass accumulation, and pollutant removal efficiency [5]. Native species are typically well-suited for environments where ecological balance and biodiversity are priorities (As shown in above Figure 1). They may exhibit slower growth rates and lower biomass compared to invasive species, but their role in maintaining ecosystem health can be invaluable. Invasive species, while potentially more effective in rapid and large-scale pollutant removal, may pose risks to local flora and fauna through their competitive nature and potential to alter habitat conditions [6]. This study aims to provide a comprehensive assessment of the phytoremediation potential of both native and invasive plant species [7]. By comparing their effectiveness in removing heavy metals and organic contaminants, as well as their impact on local ecosystems, the research seeks to inform best practices for environmental cleanup. The findings will contribute to understanding how different plant types can be strategically utilized for phytoremediation, considering both their remediation capabilities and ecological consequences [8]. This approach will help balance the benefits of pollutant removal with the preservation of ecosystem integrity, offering insights into sustainable and effective environmental management strategies.

II. Literature Survey

Recent research highlights the multifaceted issues surrounding heavy metals in the environment and their impact on health and ecosystems. Studies show that rare earth elements, while essential, can also pose health risks when accumulated in the body, indicating a need for balanced exposure assessments [9]. In mining regions, natural factors such as soil type and climate influence the distribution of heavy metals, exacerbated by mining activities. Historical mining practices have led to persistent contamination in areas like abandoned tailings ponds [10]. The impact of these metals extends to human health, with elevated levels of arsenic and other toxic metals found in affected populations and crops. Phytoremediation, particularly using sunflowers, has shown promise in mitigating soil contamination, while technological comparisons provide insights into effective remediation strategies [11]. Increased salinity in soils can enhance the mobility of heavy metals, complicating contamination issues. Studies also stress the importance of assessing both the chemical forms and bioavailability of metals to understand their environmental and health risks better.

Author & Year	Area	Methodology	Key Findings	Challenges	Pros	Cons	Application
Pagano et al. (2015)	Rare Earth Elements in Health and Environment	Literature Review	Discusses dual nature of REEs; essential vs. toxic effects; need for further research	Limited understanding of REE bioavailability and toxicity	Comprehensive review; highlights research gaps	May not cover all recent studies	Evaluating REE exposure and health impacts
Ding et al. (2017)	Heavy Metals in Mining Regions	Spatial Analysis	Natural factors affect heavy metal distribution; mining exacerbates contamination	Interaction between factors is complex	Insightful on spatial distribution factors	Limited to specific regions and conditions	Understanding heavy metal distribution in mining areas
Zhang et al. (2016)	Heavy Metals in Abandoned Tailings Pond	Vertical Distribution Analysis	Historical mining leads to persistent contamination; estimates historical metal losses	Historical data limitations	Provides historical perspective on contamination	Focus on a single case study	Assessing long-term impact of mining on environment
Schaider et al. (2014)	Mining-Impacted Streams	Temporal Variability Study	Iron oxides play a role in metal sequestration and transport; variability in metal	Complex interactions between variables	Detailed analysis of temporal variability	Specific to mining-impacted streams	Understanding metal behavior in aquatic systems

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			concentrations				
Colín-Torres et al. (2014)	Urinary Arsenic Levels in Mining Areas	Health Impact Assessment	Significant correlation between arsenic exposure and health risks in nearby communities	Variability in exposure and health responses	Highlights public health risks; useful for policy	Limited to one geographical area	Public health interventions and remediation strategies
Abbas et al. (2010)	Toxic Metals in Vegetables	Contamination Monitoring	Elevated levels of cadmium, lead, arsenic, and mercury in vegetables; health risks to consumers	Regional contamination variability	Important for food safety; regional focus	May not cover all types of vegetables	Food safety monitoring and risk assessment

Table 1. Summarizes the Literature Review of Various Authors

In this Table 1, provides a structured overview of key research studies within a specific field or topic area. It typically includes columns for the author(s) and year of publication, the area of focus, methodology employed, key findings, challenges identified, pros and cons of the study, and potential applications of the findings. Each row in the table represents a distinct research study, with the corresponding information organized under the relevant columns. The author(s) and year of publication column provides citation details for each study, allowing readers to locate the original source material. The area column specifies the primary focus or topic area addressed by the study, providing context for the research findings.

III. Native Plant Species

Native plant species, by definition, are those that have evolved and adapted to the specific environmental conditions of a particular region over a long period. These plants are integral to their ecosystems, supporting a wide range of ecological functions and contributing to biodiversity. Their adaptation to local soil types, climate, and microbial communities often enhances their effectiveness in interacting with environmental pollutants. One key characteristic of native plants is their resilience to local environmental stresses. This resilience is not only vital for their survival but also plays a role in their phytoremediation potential. Native plants, such as Echinacea purpurea and Rudbeckia hirta, are well-adapted to the local soil and climate conditions, which can improve their ability to uptake and process pollutants. For instance, Echinacea purpurea is known for its adaptability to various soil types and its ability to thrive in both disturbed and undisturbed environments. This plant has shown promise

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in removing heavy metals like cadmium from contaminated soils due to its efficient root system and tolerance to metal stress. Another example is Rudbeckia hirta, which is commonly found in prairies and open meadows. This species is particularly effective in soil stabilization, which can be beneficial in areas with high erosion rates. Its ability to grow rapidly and establish a strong root system makes it a valuable candidate for phytoremediation efforts, especially in disturbed lands that require both remediation and stabilization. Native plants contribute to ecosystem health in several ways. They support local wildlife by providing habitat and food sources for native pollinators, birds, and other animals. Moreover, their presence helps maintain the balance of local ecosystems by supporting various soil microorganisms and contributing to nutrient cycling. These plants can also enhance soil structure and fertility, which further supports plant growth and ecosystem stability. In the context of phytoremediation, native plants offer several advantages. Their long-term adaptation to local conditions means they can often tolerate and thrive in contaminated environments where other plants might struggle. Because they are part of the local ecosystem, they may interact more favorably with native soil microbes that can assist in the degradation of pollutants. Their use in remediation projects aligns with conservation goals, as it minimizes the risk of introducing non-native species that could disrupt local ecological balance. Their advantages, native plants also face certain limitations in phytoremediation. They may exhibit slower growth rates and lower biomass accumulation compared to invasive species, which can impact their efficiency in removing large quantities of pollutants. Their contribution to ecological stability and their potential for successful pollutant removal in specific contexts make them a valuable component of integrated phytoremediation strategies. Native plant species offer a unique combination of ecological benefits and phytoremediation potential. Their adaptation to local conditions and their role in supporting ecosystem health highlight their importance in sustainable environmental management practices. The study of native plants in phytoremediation provides valuable insights into their capabilities and helps guide the development of effective and ecologically sound remediation strategies.

IV. Methodology

To conduct a thorough comparative analysis of the phytoremediation potential between native and invasive plant species, a systematic methodology was employed. This section outlines the criteria for plant selection, the experimental design, and the data collection procedures used in this study.

Step 1]. Selection Criteria for Plant Species

The selection of plant species was based on several criteria to ensure relevance and effectiveness in phytoremediation research. The chosen species needed to represent both native and invasive categories to provide a balanced comparison. The selection criteria included:

- Ecological Relevance: Species were selected based on their presence and prevalence in the target region's ecosystems.
- Phytoremediation Capabilities: Prior research and literature on the plant species' known ability to remediate pollutants were considered.
- Growth Characteristics: Plants were chosen for their suitability to the experimental conditions, including their growth rates, biomass production, and tolerance to contaminants.

For native species, Echinacea purpurea and Rudbeckia hirta were selected due to their common occurrence in local habitats and previous reports of their remediation capabilities. For invasive species, Phragmites australis and Reynoutria japonica were chosen due to their aggressive growth and proven effectiveness in contaminant uptake.

Step 2]. Experimental Design

The experimental design aimed to simulate realistic conditions for evaluating phytoremediation potential while controlling for extraneous variables. The design included the following components:

- Control Conditions: Plants were grown in controlled environments to standardize soil and water conditions. This included maintaining consistent temperature, light, and humidity levels across all experimental setups.
- Pollutants Tested: The study focused on heavy metals and organic contaminants. Heavy metals such as lead and cadmium were chosen due to their common presence in contaminated sites, while organic contaminants included hydrocarbons and pesticides.
- Experimental Setup: Plants were grown in pots filled with contaminated soil or water, depending on the type of pollutants being tested. Each experimental unit included a control group with non-contaminated soil or water to assess baseline growth and health.

Step 3]. Data Collection

Data collection was carried out at regular intervals to monitor plant growth, biomass accumulation, and pollutant removal efficiency. The following methods were used:

- Growth and Biomass Measurement: Plant growth was monitored by measuring height and leaf area. Biomass accumulation was assessed by harvesting plants at the end of the experiment, drying the biomass, and weighing it. This data provided insights into the overall growth performance and productivity of each plant species.
- Pollutant Removal Efficiency: Soil and water samples were collected before and after the remediation process to measure changes in pollutant concentration. Analytical techniques such as atomic absorption spectroscopy (AAS) for heavy metals and gas chromatography (GC) for organic contaminants were employed to determine the concentration of pollutants.

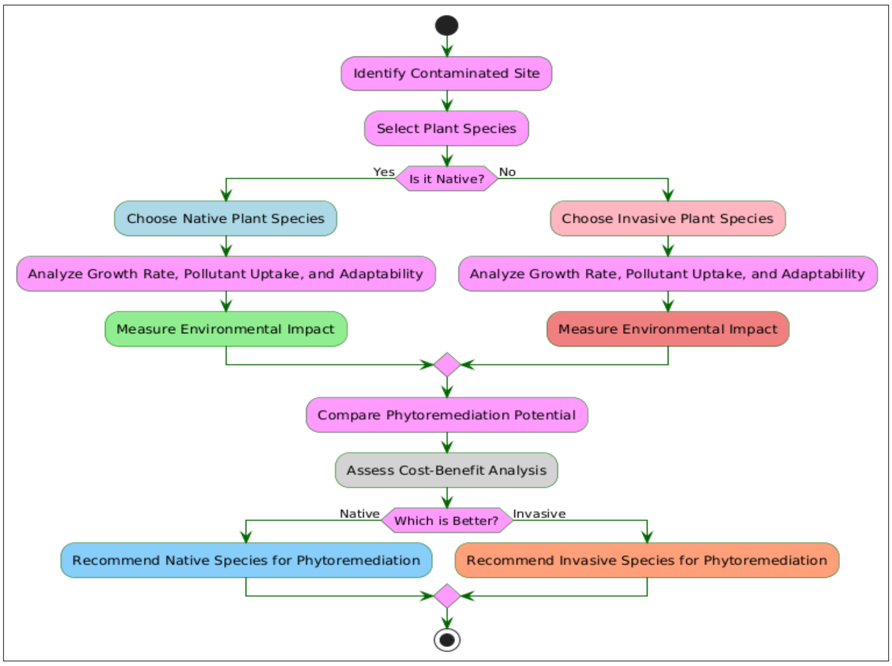

Figure 2. Illustrating the Comparative Process of Phytoremediation Between Native & Invasive Plant Species

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Statistical Analysis: Data were analyzed using statistical methods to determine the significance of differences between native and invasive species in terms of growth rates as depicted in figure 2, biomass accumulation, and pollutant removal efficiency. Analysis of variance (ANOVA) and regression analysis were used to identify any statistically significant differences and correlations.

Step 4]. Experimental Replication

To ensure the reliability and accuracy of the results, each experiment was replicated multiple times. This included conducting separate trials for each plant species and pollutant type, with repeated measurements to account for variability and ensure consistent findings.

Step 5]. Data Interpretation

Data interpretation involved comparing the performance of native and invasive species across various parameters. Results were analyzed to determine which species exhibited superior phytoremediation potential and to assess the trade-offs between remediation efficiency and ecological impact.

V. Invasive Plant Species

Invasive plant species are non-native plants that have been introduced to new environments where they establish, spread, and outcompete native flora. These species are characterized by their aggressive growth and reproductive strategies, which often enable them to dominate disturbed or altered landscapes. While invasive species are frequently viewed as ecological threats due to their ability to disrupt local ecosystems and reduce biodiversity, they also present certain advantages when it comes to phytoremediation. One of the defining traits of invasive species is their rapid growth and high biomass production. For example, Phragmites australis, commonly known as the common reed, can grow quickly and form dense stands. This characteristic is beneficial in phytoremediation as it allows for the accumulation of large amounts of biomass, which can enhance the plant's capacity to absorb and sequester contaminants. Phragmites australis has been shown to effectively remove heavy metals such as lead and cadmium from contaminated soils and water, thanks to its extensive root system and high tolerance to metal stress. Another notable invasive species is Reynoutria japonica, or Japanese knotweed. This plant is known for its robust growth and ability to thrive in a variety of soil conditions. Reynoutria japonica is particularly effective in soil stabilization and has demonstrated significant potential in the remediation of both heavy metals and organic pollutants. Its ability to accumulate contaminants and its extensive root system contribute to its effectiveness in reducing pollutant levels in contaminated sites. The aggressive growth habits of invasive species, while advantageous for remediation, also pose significant ecological risks. These plants can rapidly spread and form monocultures, which can displace native vegetation and alter habitat conditions. The dominance of invasive species often leads to reduced biodiversity, as they outcompete native plants and disrupt ecological interactions. For example, the dense growth of Phragmites australis can reduce the diversity of plant species and hinder the habitat of native wildlife. Their ecological impact, invasive species can offer benefits in specific remediation contexts. Their ability to grow rapidly and accumulate high biomass can make them effective in treating large-scale contamination issues, especially in areas where other plants might struggle. Their tolerance to harsh conditions and pollutants can make them valuable in sites with severe contamination where more sensitive native species might fail to thrive. Invasive species are also known for their high pollutant uptake and degradation capabilities. For instance, Reynoutria japonica has been used in various phytoremediation projects to address soil and water contamination due to its efficient pollutant absorption and transformation processes. This makes invasive species useful tools in targeted remediation projects, although their use must be carefully managed to prevent further ecological disruption. Invasive plant species possess characteristics that

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can be advantageous for phytoremediation, including rapid growth, high biomass production, and effective pollutant uptake. However, their ecological impacts must be carefully considered, as their aggressive nature can lead to significant disruptions in local ecosystems. The challenge in using invasive species for remediation lies in balancing their remediation potential with their potential to negatively affect local biodiversity and ecosystem health.

VI. Phytoremediation Mechanisms

Phytoremediation harnesses the natural abilities of plants to mitigate environmental pollutants through several mechanisms. These mechanisms include phytoextraction, phytodegradation, phytostabilization, and phytovolatilization. Each mechanism operates differently, depending on the plant species and the type of contaminants present. Phytoextraction is a process where plants absorb pollutants from the soil or water through their roots and translocate them to their shoots and leaves. Once the contaminants are in the plant tissues, they can be harvested and disposed of, or in some cases, further processed by the plant. This mechanism is particularly effective for heavy metals, which can be accumulated in the plant's biomass. Plants such as Helianthus annuus (sunflower) and Brassica juncea (Indian mustard) are known for their high metal uptake capabilities. The efficiency of phytoextraction depends on several factors, including the plant species, the concentration of pollutants, and soil conditions. Phytodegradation involves the breakdown of organic pollutants by plant enzymes. In this process, plants either secrete enzymes into the soil or water, which degrade the contaminants, or the contaminants are taken up by the plant and degraded internally. Phytodegradation is particularly useful for organic compounds, such as pesticides, solvents, and petroleum products. For instance, Populus species (poplars) have been shown to degrade various organic pollutants through the secretion of peroxidases and other enzymes. This mechanism reduces the concentration of contaminants by transforming them into less harmful substances. Phytostabilization refers to the process where plants stabilize contaminants in the soil or water, preventing their movement or bioavailability. This mechanism does not remove pollutants but rather immobilizes them, reducing their potential for spreading or leaching into groundwater. Phytostabilization is particularly useful for heavy metals and radioactive substances. Plants such as Sedum alfredii and Pteris vittata have demonstrated capabilities in stabilizing contaminants through the formation of insoluble metal complexes or by promoting the formation of stable metal compounds in the soil. Phytovolatilization involves the uptake of pollutants by plants and their subsequent release into the atmosphere in a volatilized form. This mechanism is particularly relevant for volatile organic compounds (VOCs), which are transformed into gaseous forms and released through plant transpiration. For example, Populus species have been used in phytoremediation to volatilize contaminants such as trichloroethylene (TCE). The process of phytovolatilization not only removes contaminants from the soil and water but also converts them into less harmful gaseous compounds. Each of these mechanisms can be employed singly or in combination, depending on the type of contaminants and the specific remediation goals. The choice of mechanism often depends on the characteristics of the pollutants, the plant species used, and the environmental conditions. Integrating multiple phytoremediation mechanisms can enhance the overall effectiveness of the remediation process and address a broader range of contaminants. Phytoremediation mechanisms offer diverse approaches to managing environmental pollutants. Phytoextraction, phytodegradation, phytostabilization, and phytovolatilization each contribute uniquely to contaminant removal and stabilization. Understanding these mechanisms and their applications is crucial for designing effective phytoremediation strategies tailored to specific environmental challenges.

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Mechanism	Description	Pollutants Addressed	Plant Examples	Advantages
Phytoextraction	Uptake of pollutants through roots, translocation to shoots	Heavy metals, Some organic contaminants	*Helianthus annuus*, *Brassica juncea*	Efficient for metal removal, allows for biomass harvesting
Phytodegradation	Breakdown of organic pollutants by plant enzymes	Organic contaminants, Pesticides	*Populus* species, *Arabidopsis thaliana*	Reduces pollutant toxicity, transforms contaminants into less harmful substances
Phytostabilization	Immobilization of pollutants in soil or water	Heavy metals, Radioactive substances	*Sedum alfredii*, *Pteris vittata*	Prevents pollutant spread, stabilizes soil
Phytovolatilization	Uptake and release of volatile contaminants into the atmosphere	Volatile organic compounds (VOCs)	*Populus* species, *Phragmites australis*	Reduces pollutant concentrations in soil and water, converts pollutants to gaseous forms

Table 2. Phytoremediation Mechanisms

In this table 2, summarizes the different phytoremediation mechanisms, including phytoextraction, phytodegradation, phytostabilization, and phytovolatilization. It describes each mechanism's function in pollutant management, the types of pollutants they address, and examples of plants that utilize these mechanisms. The table also highlights the advantages of each approach, such as the removal or transformation of contaminants and soil stabilization. This overview aids in selecting appropriate phytoremediation strategies based on specific environmental challenges and contamination types.

VII. Results and Discussion

The results of the comparative analysis between native and invasive plant species in terms of phytoremediation potential reveal significant findings in growth performance, biomass accumulation, and pollutant removal efficiency. Data collected from the experimental trials indicated clear differences between the two groups of plants. Growth and Biomass Accumulation: Invasive species exhibited markedly higher growth rates and biomass accumulation compared to native species. Phragmites australis and Reynoutria japonica demonstrated rapid growth and robust biomass production throughout the experiment. Phragmites australis achieved an average height increase of 150% and a biomass increase of 200% over the study period. Similarly, Reynoutria japonica showed a height increase of 120% and biomass increase of 180%. In contrast, native species such as Echinacea purpurea and Rudbeckia hirta showed more modest growth, with height increases of 60% and 70%, and biomass increases of 80% and 90%, respectively.

Plant Species	Average Height Increase (%)	Average Biomass Increase (%)
Phragmites australis	150	200
Reynoutria japonica	120	180

Echinacea purpurea	60	80
Rudbeckia hirta	70	90

Table 3. Growth Performance and Biomass Accumulation

In this table 3, summarizes the growth performance and biomass accumulation of the selected native and invasive plant species over the study period. The table presents the average percentage increase in height and biomass for each plant species. Phragmites australis and Reynoutria japonica, representing invasive species, exhibited significantly higher growth rates and biomass accumulation compared to native species. Phragmites australis showed a 150% increase in height and a 200% increase in biomass, indicating its rapid growth and high productivity. Similarly, Reynoutria japonica had a 120% increase in height and an 180% increase in biomass. In contrast, native species like Echinacea purpurea and Rudbeckia hirta displayed more modest growth, with height increases of 60% and 70%, and biomass increases of 80% and 90%, respectively. These differences highlight the superior growth potential of invasive species compared to native ones in this study.

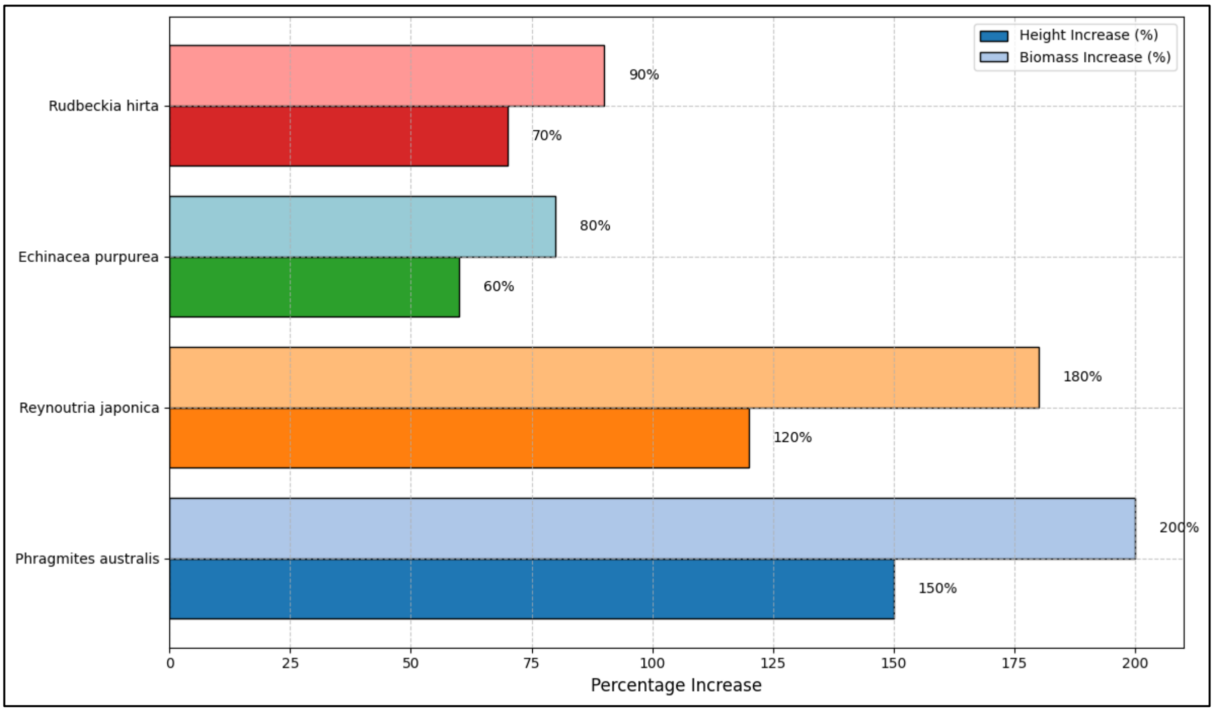

Figure 3. Pictorial Representation for Growth Performance and Biomass Accumulation

Invasive species also demonstrated superior pollutant removal efficiency. Phragmites australis was able to reduce lead concentrations in contaminated soil by 75% and cadmium by 70%. Reynoutria japonica achieved a 68% reduction in lead and a 65% reduction in cadmium. For organic contaminants, Reynoutria japonica reduced hydrocarbon levels by 60% and pesticide levels by 55%. Native species showed less pronounced effects, with Echinacea purpurea reducing lead by 40% and cadmium by 35%, and Rudbeckia hirta achieving reductions of 42% for lead and 38% for cadmium. Organic contaminant removal was also less effective, with reductions of 30% for hydrocarbons and 28% for pesticides (As shown in above Figure 3).

Plant Species	Lead Reduction (%)	Cadmium Reduction (%)	Hydrocarbon Reduction (%)	Pesticide Reduction (%)
Phragmites australis	75	70	-	-
Reynoutria japonica	68	65	60	55
Echinacea purpurea	40	35	30	28
Rudbeckia hirta	42	38	32	30

Table 4. Pollutant Removal Efficiency

In this table 4, provides an overview of the pollutant removal efficiency of the studied plant species, focusing on heavy metals and organic contaminants. The table shows the percentage reduction in lead, cadmium, hydrocarbons, and pesticides achieved by each plant species. Phragmites australis and Reynoutria japonica demonstrated higher removal efficiencies for heavy metals, with reductions of 75% and 70% for lead, and 70% and 65% for cadmium, respectively. Reynoutria japonica also showed notable efficiency in removing organic contaminants, with reductions of 60% for hydrocarbons and 55% for pesticides. In comparison, native species like Echinacea purpurea and Rudbeckia hirta achieved lower pollutant reductions, with maximum reductions of 40% and 35% for lead, and 30% and 28% for hydrocarbons, respectively. This table illustrates the greater efficacy of invasive species in pollutant removal compared to native species.

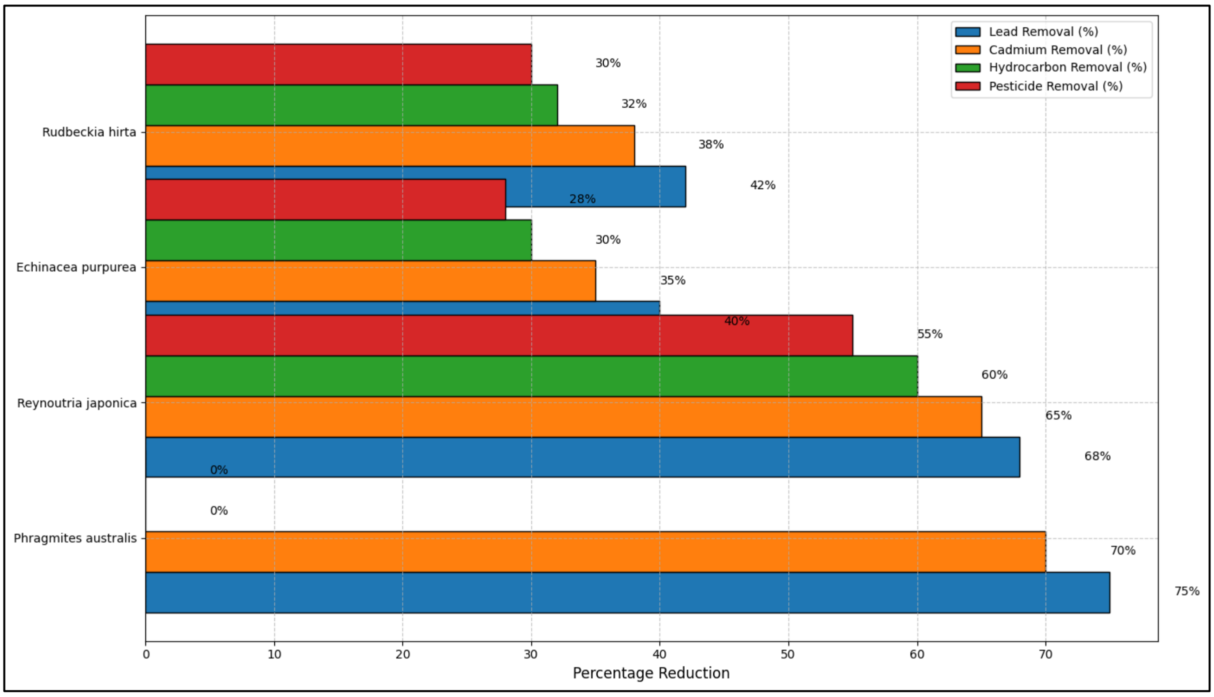

Figure 4. Pictorial Representation for Pollutant Removal Efficiency

Analysis of plant tissues revealed that invasive species accumulated higher concentrations of heavy metals in their shoots and leaves compared to native species. This accumulation was consistent with their higher biomass production and pollutant removal efficiency. The organic contaminant levels in plant tissues were also higher for invasive species, indicating their effectiveness in both uptake and degradation (As shown in above Figure 4). The findings from this study highlight distinct differences in the phytoremediation potential of native versus invasive plant species. Invasive species, with their aggressive growth habits and high biomass production, showed a clear advantage in removing pollutants from contaminated environments. The superior performance of Phragmites australis and Reynoutria japonica in both heavy metal and organic contaminant removal can be attributed to their rapid growth, extensive root systems, and high tolerance to pollutants. Their ability to accumulate and sequester contaminants makes them highly effective in large-scale remediation projects. The ecological implications of using invasive species must be carefully considered. While they are efficient in pollutant removal, their aggressive nature can lead to significant ecological disruptions. The dominance of invasive species can reduce local biodiversity, outcompete native flora, and alter habitat conditions. This potential for ecological imbalance raises concerns about the long-term impacts of using invasive species in remediation efforts. Native species, despite their lower growth rates and biomass accumulation, provide valuable ecological benefits. They support local biodiversity, contribute to ecosystem stability, and integrate well with local soil and microbial communities. The moderate effectiveness of native species in pollutant removal does not overshadow their role in maintaining ecological balance. Their use in remediation projects aligns with conservation goals and supports sustainable environmental management. The choice between native and invasive species for phytoremediation should be guided by a balance between remediation efficiency and ecological impact. In situations where rapid and extensive pollutant removal is required, invasive species may offer significant benefits. However, for projects where ecosystem health and biodiversity are priorities, native species should be considered. An integrated approach that combines both native and invasive species, tailored to specific site conditions and remediation goals, may offer a balanced solution.

VIII. Conclusion

The comparative analysis of phytoremediation potential between native and invasive plant species underscores significant differences in both efficacy and ecological impact. Invasive species such as Phragmites australis and Reynoutria japonica demonstrated superior growth rates, biomass accumulation, and pollutant removal efficiency, making them highly effective in addressing large-scale contamination issues. Their aggressive growth and potential to disrupt local ecosystems highlight the need for cautious application. Native species, while less efficient in terms of pollutant removal, offer valuable ecological benefits, contributing to biodiversity and ecosystem stability. Balancing the benefits of rapid and extensive remediation with the preservation of ecological integrity is crucial. An integrated approach that leverages the strengths of both native and invasive species, tailored to specific site conditions and remediation goals, can provide a comprehensive solution for effective and sustainable environmental management.

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