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Phytotechnologies for Water Depollution in West Africa: A Review of Plant-Based Approaches

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Abstract

Emerging pollutants, including pharmaceutical residues, heavy metals, and endocrine disruptors, are increasingly found in aquatic environments, posing serious risks to human and environmental health. Phytoremediation, a green and cost-effective approach, uses plants to remove or neutralize these pollutants from water bodies. This review aims to identify and evaluate plant species, particularly those adapted to African ecosystems, that can effectively remediate contaminated water. Scientific literature was consulted using databases such as PubMed, Scopus, and Google Scholar with keywords like "phytoremediation", "emerging pollutants", and "wastewater treatment". Several plant species including *Eichhornia crassipes*, *Moringa oleifera*, *Azadiracta indica*, and *Phragmites australis* demonstrated high removal efficiency of heavy metals and organic compounds. This review highlights their mechanisms of action and potential integration into sustainable water management strategies in Africa. Further field trials and pilot-scale applications are needed to validate their large-scale feasibility.

Subject Areas

Environmental Sciences

Keywords

Phytoremediation, Emerging Pollutants, Wastewater Treatment, Purification Plants, Environmental Health, Africa

1. Introduction

Water is a vital resource, essential for the development of human societies and the sustainability of ecosystems [1]. Yet its quality is increasingly threatened by intensive human activities [2]. In West Africa, the degradation of water resources is worsened by rapid urbanization, lack of sanitation infrastructure, unsustainable agricultural practices, uncontrolled industrial effluents, and often inadequate environmental governance [3]. This multifaceted pollution affects public health, compromises water security, and exacerbates environmental poverty [4].

While conventional wastewater treatment technologies are effective, they are often not viable in developing countries due to their high cost, technical complexity, and reliance on specialized expertise [5]. Faced with these limitations, growing interest is focused on nature-based technologies, particularly the use of plants in decontamination processes [1]. Using plants through various mechanisms offers a solution adapted to local realities: low cost, availability of biological resources, community involvement, and environmental friendliness [6] [7].

Phytoremediation uses the potential of plants to extract, transform, stabilize, or degrade pollutants present in soils or aquatic environments [8]. It includes several mechanisms: phytoextraction, phytodegradation, phytostabilization, rhizofiltration, phytovolatilization, and phytocoagulation [7] [9]. Plants do not just absorb pollutants, they also mobilize enzymatic, chemical, and microbial processes via the rhizosphere to effectively decontaminate contaminated environments.

In water decontamination, many plant species [8] [10] [11] have shown remarkable ability to remove a wide variety of pollutants, ranging from heavy metals to pathogens, including pesticides, hydrocarbons, and pharmaceutical residues. In West Africa, plants such as water hyacinth (*Eichhornia crassipes*) [6], moringa (*Moringa oleifera*) [8], neem (*Azadirachta indica*), and African basil (*Ocimum gratissimum*) [9] have demonstrated interesting potential but remain underutilized scientifically at the regional scale.

This review aims to comprehensively explore the potential of several plants used for purifying contaminated water. This work seeks to contribute to better valuing indigenous knowledge and to the emergence of sustainable, contextualized, and innovative solutions to address challenges related to access to safe water in Africa.

2. Methods

This narrative review was conducted by consulting peer-reviewed literature published between 2017 and 2025. Databases searched included PubMed, Scopus, ScienceDirect, and Google Scholar. Keywords used were "phytoremediation", "emerging pollutants", "heavy metals", "wastewater treatment", and "aquatic plants". Articles were included based on their relevance, novelty, and focus on plant-based treatment in African or tropical contexts. This literature review was conducted based on clearly defined selection criteria. It focuses on plant species that are most accessible and commonly used in West African countries, particularly within the deltaic region of southern Benin. These keywords helped identify literature related to various stages of water treatment and the use of plants in the remediation of pharmaceutical-contaminated aquatic environments.

3. Results and Discussion

3.1. Emerging Pollutants: Sources and Risks

Characterizing pollutants in wastewater, as shown in Table 1, is a critical step in developing effective phytoremediation strategies, particularly in regions undergoing rapid urbanization and industrial growth. These pollutants can be broadly classified into two main categories: chemical and biological.

Table 1. Characterization of pollutants according to their effects.

Category	Type	Sources	Effects	Reference	Limitations of Conventional Treatments
Heavy Metals	Pb, Cd, Hg, Cr	Industrial, agricultural, and urban activities	Neurotoxic, carcinogenic, endocrine disruptors	[12] [13]	High costs, limited accessibility
Pharmaceutical Residues	Antibiotics, medications	Hospitals, households, livestock farming	Microbial resistance	[14] [15]	Poor removal by conventional treatments
Pesticides & Herbicides	Atrazine, glyphosate, etc.	Intensive agriculture	Biological disruptions	[20]	Low biodegradability, diffuse pollution
Hydrocarbons & VOCs	Benzene, toluene, solvents	Petrochemical industry, urban waste	High toxicity, carcinogenic	[16]	Low efficiency of biological treatments
Pathogens	Bacteria, viruses (rotavirus), protozoa (*Giardia*), helminths (*Ascaris*)	Fecal wastewater, untreated discharges	Waterborne diseases (diarrhea, parasitosis)	[17] [18]	Inadequate or absent biological treatment in some regions
Chemical: Nutrients	Nitrates, phosphates	Agricultural runoff, domestic discharges	Eutrophication, oxygen depletion	[21]	Over-enrichment not effectively treated

Chemical pollutants include heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr), which are often released through industrial, agricultural, and domestic activities. Even at trace levels, these metals are highly toxic, causing neurotoxicity, carcinogenic effects, and endocrine disruption [12] [13]. The persistent presence of pharmaceutical residues and antibiotics (primarily from hospitals, households, and livestock operations) further exacerbates the problem by promoting antimicrobial resistance [14] [15]. Additionally, pesticides and herbicides disrupt microbial communities and destabilize trophic networks, while volatile organic compounds (VOCs) and petroleum-based hydrocarbons pose carcinogenic and ecotoxic threats [16]. Excess nutrients, such as nitrates and phosphates from fertilizers and detergents, contribute to eutrophication and create anoxic conditions in aquatic ecosystems.

Biological pollutants are primarily fecal or pathogenic in origin and include bacteria such as *Escherichia coli* and *Salmonella* spp., enteric viruses, and protozoa and helminths such as *Giardia* and *Ascaris* species. These organisms are responsible for a range of acute and chronic waterborne diseases [17] [18]. Their persistence in the environment can lead to antibiotic resistance, endocrine disruption, and bioaccumulation in food chains.

The coexistence of these diverse contaminants presents a major challenge for water safety and public health, especially in low-resource settings with inadequate sanitation infrastructure. To address this multifaceted contamination, various wastewater treatment strategies (including mechanical, chemical, and biological approaches) have been employed. However, these systems are often costly, energy-intensive, and poorly adapted to decentralized or rural contexts, limiting their effectiveness in many African and low-income regions. This situation highlights the importance of pollutant characterization, which not only informs the selection of phytoremediating plants with optimal biosorption, chelation, and enzymatic degradation capacities [5] but also facilitates the development of integrated, low-cost, and eco-friendly treatment systems tailored to local pollution profiles [18] [19].

3.2. Phytoremediation Technology: An Innovative and Sustainable Alternative for African Contexts

3.2.1. Plant Technology for Water Purification

Phytoremediation has emerged as an ecological, cost-effective, and sustainable approach for treating contaminated water and soils, particularly in rural and peri-urban West African regions, where conventional wastewater infrastructure is often inadequate or absent. This nature-based solution leverages the inherent ability of certain plants to absorb, accumulate, stabilize, or transform pollutants (including heavy metals, nutrients, pesticides, and complex organic compounds) through a combination of physiological, biochemical, and microbially mediated processes [7] [22]. When applied in engineered systems such as constructed wetlands, phytoremediation is further enhanced by synergistic interactions among plant roots, microbial communities, and substrate matrices, resulting in improved pollutant removal along with additional co-benefits such as habitat creation, erosion control, and landscape restoration [23] [24].

Several plant species commonly found or widely cultivated across West Africa exhibit strong phytoremediation potential. *Eichhornia crassipes* (water hyacinth) and *Lemna minor* (duckweed), for instance, have demonstrated high efficiency in removing heavy metals and excess nutrients through rhizofiltration and rapid biomass production, making them well-suited for small-scale and community-managed treatment ponds [25]. *Moringa oleifera*, a tree widely cultivated across the Sahel and humid zones, provides an additional advantage: its seeds contain natural coagulant proteins capable of promoting flocculation and reducing turbidity, offering a low-cost and non-toxic alternative to chemical coagulants for household and village-level water treatment [26]. Aromatic and medicinal species such as *Ocimum gratissimum* (African basil) and *Azadirachta indica* (neem), which are deeply integrated into West African agro-ecological and cultural systems, contribute antimicrobial and antiparasitic properties through their diverse phytochemicals, thereby helping to reduce microbial loads in wastewater and surface waters [9].

These characteristics highlight the suitability of phytoremediation for addressing region-specific environmental challenges, particularly given the local availability, rapid growth, and strong cultural acceptance of many of these species. Despite its promise, however, the adoption of phytoremediation in West Africa remains limited due to technical constraints, low institutional awareness, and gaps in mechanistic understanding under local environmental conditions. Strengthening field-based research, community training programs, and policy frameworks is therefore essential to support large-scale implementation and unlock the full potential of phytoremediation systems across the region [7] [24].

3.2.2. Phytoremediation: Mechanisms and Types

Phytoremediation stands at the intersection of plant biology, environmental science, and sustainable engineering. Presented by **Figure 1**, it encompasses a series of natural, plant-based mechanisms that effectively remove, transform, or stabilize contaminants in water and soil ecosystems [7] [22].

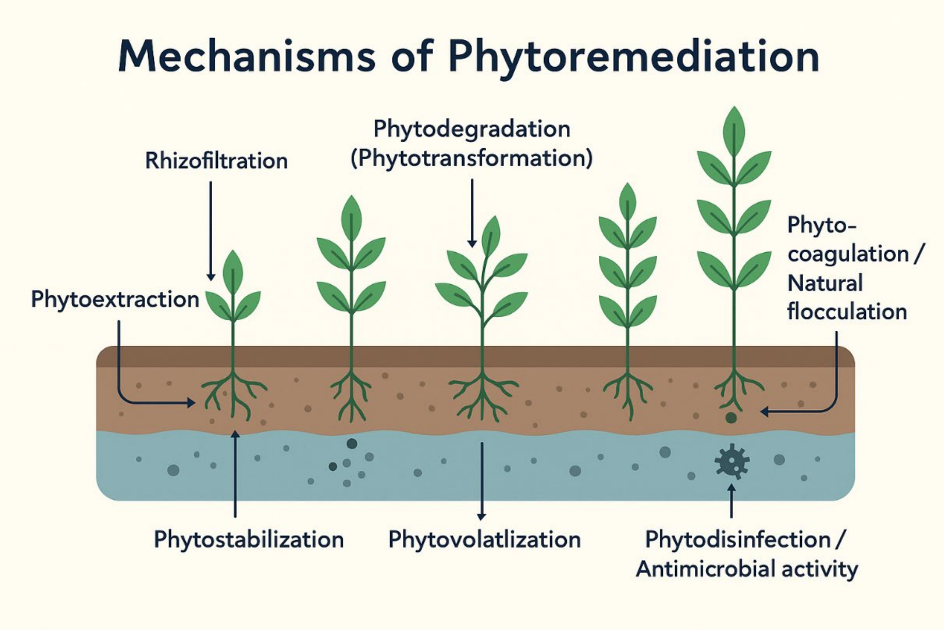

Figure 1. The mechanisms the versatility and potential of phytoremediation.

These processes leverage the unique physiological, biochemical, and microbial interactions of plants [often enhanced by root-associated microorganisms] making phytoremediation an eco-friendly and cost-effective alternative to conventional remediation methods [23] [27]. In **Table 2** below, the following key mechanisms illustrate the versatility and potential of phytoremediation.

Table 2. Description of the mechanisms and potential of phytoremediation.

Mechanism	Description	Plants	References
Rhizofiltration	Plant roots absorb, adsorb, or precipitate pollutants (e.g., heavy metals, nutrients) directly from contaminated water. Ideal for aquatic systems.	*Eichhornia crassipes*, *Lemna minor*	[25]
Phytoextraction	Plants uptake toxic metals from the substrate and translocate them to above-ground tissues, enabling pollutant concentration in biomass for safe disposal.	Mechanisms mediated by HMA, transporters	[28]
Phytodegradation [Phytotransformation]	Organic contaminants likes pesticides or pharmaceuticals are broken down by plant enzymes (e.g., peroxidases, laccases) into less toxic metabolites.	Engineered or naturally metabolically active plants	[29]
Phytostabilization	Plants reduce contaminant mobility by binding them in root tissues or altering rhizosphere pH and redox potential, thus preventing leaching.	Sediment-root interface systems	[29]
Phytovolatilization	Volatile contaminants are absorbed and chemically converted into gaseous forms, then released into the atmosphere.	Mercury, selenium detoxification pathways	[25]
Phytocoagulation/ Natural flocculation	Certain plant extracts (cationic proteins, polyphenols) induce coagulation and flocculation of suspended particles or microbes in water.	*Moringa oleifera* seeds (natural coagulants), *Vigna unguiculata*	[26] [28]
Phytodisinfection/ Antimicrobial activity	Plants produce secondary metabolites (essential oils, tannins, alkaloids) with antimicrobial, antifungal, or antiviral activity, enhancing water and soil hygiene.	*Ocimum gratissimum*, *Azadirachta indica*, *Moringa oleifera*	[2] [9] [28]

These mechanisms are not mutually exclusive. In natural and constructed environments, plants frequently combine several phytoremediation pathways while interacting closely with microbial consortia in the rhizosphere, an essential component of pollutant degradation that is often overlooked [23] [27]. Rhizospheric microorganisms enhance remediation efficiency by producing extracellular enzymes, transforming contaminants into more bioavailable forms, and stimulating plant detoxification pathways. In constructed wetlands planted with *Typha latifolia*, root exudates have been shown to promote the proliferation of hydrocarbon-degrading bacteria such as *Pseudomonas* and *Acinetobacter*, thereby significantly accelerating the breakdown of petroleum-derived pollutants compared with plant-only systems [24]. This illustrates the synergistic nature of phytoremediation as a plant-microbe process, where both partners contribute complementary functions.

Furthermore, phytoremediation technologies remain particularly relevant for low-income and rural contexts, where conventional wastewater treatment options may be economically or technically unfeasible. The use of locally abundant species such as *Moringa oleifera* or *Ocimum gratissimum* offers a low-cost, community-driven approach to water purification, while also leveraging the beneficial microbial communities naturally associated with their root systems [6] [28].

4. Stages of Water Treatment and Corresponding Phytotechnologies

Water remediation using plants, commonly known as phytoremediation, is increasingly recognized as a sustainable and cost-effective approach tailored to local African contexts, particularly in rural and peri-urban areas where conventional treatment infrastructures are limited [7] [22]. This green technology presented by **Table 3** integrates various plant species and their associated microbial communities to support or replace conventional water treatment stages, offering eco-friendly solutions for complex pollutant removal [23] [24]. **Figure 2** illustrates the integration of phytotechnologies at each stage of the water treatment process, highlighting their specific roles in pollutant removal and ecological remediation.

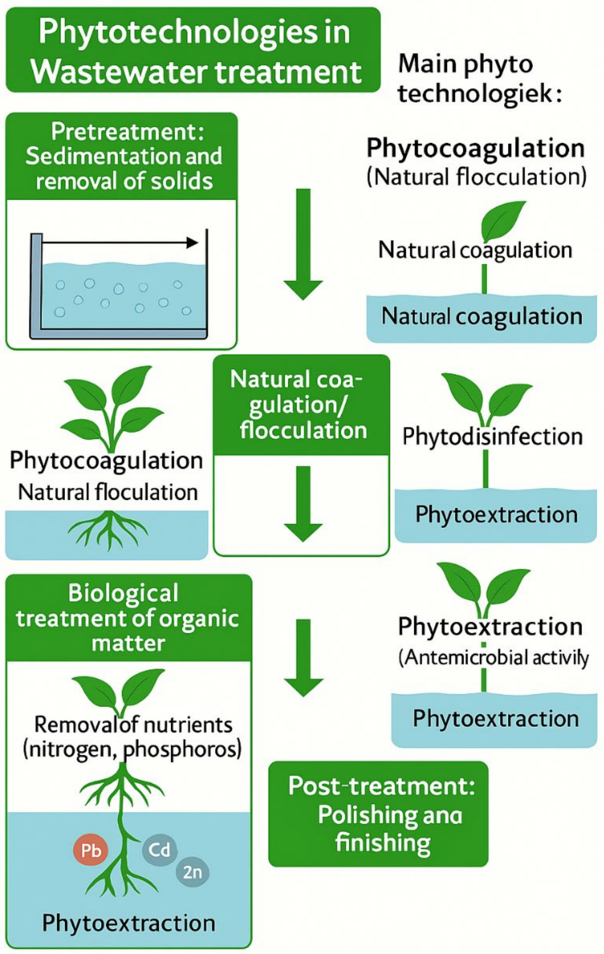

Figure 2. Application of phytotechnologies in stages of water treatment.

4.1. Pretreatment: Decantation and Removal of Solids

The initial stage focuses on eliminating coarse solids such as plant debris, sediments, and sludge to reduce pollutant load downstream. Floating aquatic plants like *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) excel in promoting sedimentation by slowing water flow with their dense root mats, enhancing natural particle settling and water clarification [25] [30] [31]. These species prepare water for subsequent biological or chemical treatments while contributing to habitat complexity.

4.2. Coagulation Natural Flocculation

Phytocoagulation leverages cationic proteins found in plants such as *Moringa oleifera* (miracle tree) and *Vigna unguiculata* (cowpea) to neutralize the negative charge of colloidal particles, inducing natural floc formation and facilitating their removal by sedimentation [26] [32] [33]. This method provides an environmentally friendly, affordable alternative to chemical coagulants, especially valuable in low-resource settings.

4.3. Biological Treatment of Organic Matter

The degradation of dissolved organic pollutants in phytoremediation systems is not only driven by rhizofiltration and enzymatic phytodegradation but also by a complex set of plant microbe interactions operating within the rhizosphere. Macrophytes such as *Phragmites australis*, *Typha latifolia*, and *Canna indica* actively absorb organic contaminants while releasing oxidative enzymes (including peroxidases, laccases, and dehydrogenases) that catalyze the breakdown of aromatic and aliphatic compounds into less toxic intermediates [25] [33] [34]. Beyond direct enzymatic action, these plants create oxygenated microzones around their roots, stimulating the growth of specialized microbial consortia capable of degrading pesticides, pharmaceuticals, and other organic pollutants through co-metabolic pathways. In wetlands dominated by *Phragmites australis*, the oxygen released by roots fosters an active microbial community capable of degrading a wide spectrum of organic pollutants. This microbial contribution greatly improves BOD reduction and leads to significantly higher treatment performance than vegetation-only systems [27]. This dual action plant-derived enzymatic transformation combined with microbially mediated mineralization, forms a synergistic pollutant degradation process that is central to the functioning of effective phytoremediation systems.

4.4. Removal of Nutrients [Nitrogen, Phosphorus]

Excess nitrogen and phosphorus from agricultural runoff induce eutrophication, a major environmental concern. Species such as *Lemna minor* (duckweed), *Eichhornia crassipes*, and *Typha* spp. actively uptake nitrates, ammonium, and phosphates, mitigating algal blooms while their root-associated microbes facilitate nitrification and denitrification cycles, promoting nutrient balance in aquatic ecosystems [17] [25] [30].

4.5. Heavy Metal Removal

African water bodies are increasingly contaminated by heavy metals like lead, cadmium, and arsenic due to mining and industrial discharges [12] [13]. Hyperaccumulator plants such as *Brassica juncea* [brown mustard], *Helianthus annuus* [sunflower], and *Vetiveria zizanioides* (vetiver) perform phytoextraction and phytostabilization by absorbing metals into aerial parts or immobilizing them within roots or sediments, thereby reducing their bioavailability and ecological risks [23] [29] [35].

4.6. Disinfection: Reduction of Microbial Load

Phytoremediation also offers natural disinfection solutions through plants rich in bioactive compounds. *Ocimum gratissimum* (African basil), *Azadirachta indica* (neem), and *Cymbopogon citratus* (lemongrass) produce essential oils, tannins, and flavonoids with antibacterial, antiviral, and antifungal properties that inhibit pathogens in contaminated waters [6] [9] [28]. When incorporated into slow-flow planted filters, these species enhance ecological sanitation and public health.

4.7. Post-Processing: Polishing and Finishing

The final polishing stage improves water clarity, removes residual contaminants, and reoxygenates treated effluents. Constructed wetlands and lagoon systems often combine species such as *Cyperus* spp., *Scirpus* spp., *Typha* spp., and *Iris* spp., which synergistically filter pollutants, stabilize ecosystems, and provide aesthetic and biodiversity benefits [24] [27]. This step ensures the treated water is suitable for agricultural use, ecosystem restoration, or non-potable domestic purposes.

Table 3. Role of plants in the different stages of water decontamination.

Plant Species	Pollutants	Mechanisms	References
Eichhornia crassipes	Heavy metals (Cd, Pb, Zn, Mn, Cu)	BCF > 1 [root accumulation], TF < 1, removal efficiency up to 97%	[8]
	Cr, Mn, Fe, Cu, Zn, pH, conductivity	Reduction of pH, EC, and heavy metals in wastewater (field conditions, Nigeria)	[3]
Moringa oleifera	Turbidity, fecal coliforms	Up to 99.8% turbidity reduction, *E. coli* reduced by 1 - 3 log units, natural flocculation via cationic proteins	[8]
	TDS, COD, phosphates, heavy metal	Combined with Aloe vera: 92% TDS, 93.9% PO_4^{3-}, 52.6% COD reduction	
Azadirachta indica	Pb, Cu, Cr, Zn, Cd, Co	Pb(II) adsorption up to 93.5%, biosorption capacity ~39.7 mg/g with bark-based activated carbon	[36]
	Multi-metal contamination (mining context)	Multi-metal adsorption under optimized pH 6 - 7, effective for Pb, Cd, Zn	[37]
Ocimum gratissimum	Cd, hydrocarbons	Accumulates 14.05 mg/kg Cd, reduces ~46.6% TPH in 60 days in association with bacterial bioaugmentation	[38]
Phragmites australis, *Typha latifolia*, *Canna indica*	Organic matter (BOD)	Rhizofiltration and enzymatic degradation (laccases, peroxidases); effective BOD removal	[25]
Lemna minor, *Typha* spp.	Nutrients (nitrate, phosphate)	Nutrient uptake and stimulation of nitrification/denitrification microbial pathways	[17]

Continued

Brassica juncea, *Helianthus annuus*, *Vetiveria zizanioides*	Heavy metals	Phytoextraction/Phytostabilization for Pb, Cd, Zn; accumulation in roots or immobilization in soil	[12] [13]
Cymbopogon citratus, *Ocimum gratissimum*, *Azadirachta indica*	Microbial pathogens	Natural antimicrobial metabolites (phenolics, essential oils) reduce pathogens (bacteria, viruses, parasites)	[12] [18]
Cyperus spp., *Scirpus* spp., *Iris* spp.	Residual nutrients, aesthetics	Final polishing: absorption, reoxygenation, improved ecosystem health	[39]

5. Specific Properties of Depolluting Plants

5.1. Phytochemical Richness and Functional Potential of Selecting Plants in Phytoremediation

A growing body of research underscores the essential role of phytochemicals in determining a plant's capacity for environmental remediation. Plants endowed with diverse arrays of secondary metabolites are not only more resilient to environmental stressors but also act as bioactive agents in the detoxification, transformation, or immobilization of pollutants. Species such as *Ocimum gratissimum*, *Moringa oleifera*, *Eichhornia crassipes*, and *Azadirachta indica* have already shown substantial promise. They have also recognized for their complementary roles in sustainable remediation systems. These species exhibit high concentrations of bioactive compounds such as flavonoids, alkaloids, tannins, saponins, and phenolic acids, which serve as biochemical foundations for their antioxidant, antimicrobial, and metal-chelating activities [9]. Flavonoids and phenolic acids abundant in *Eichhornia crassipes* and *Ocimum gratissimum* enhance plant antioxidant systems, increasing their resilience and capacity for pollutant detoxification [6]. Tannins and saponins further enable these plants to bind toxic metals and disrupt microbial integrity, making them effective for both phytoextraction and pathogen control. Among the most striking plante example, *Eichhornia crassipes* [water hyacinth] boasts a high content of mucilage and proteins, which support its exceptional rhizofiltration capacity absorbing metals such as lead, cadmium, and chromium [30] [31]. Its rapid growth and extensive root system offer vast surface areas for pollutant uptake and microbial colonization. *Moringa oleifera* stands out for its dual capacity to flocculate suspended particles and biosorb heavy metals, thanks to coagulant proteins like glucomoringin and bioactive seed cakes [6]. Its natural flocculating ability and absence of chemical residues make it especially attractive in low-resource settings. *Azadirachta indica* [neem], rich in limonoids such as azadirachtin and nimbolide, not only accumulates metals like copper and lead in its bark and leaves [34], but also combats microbial pollutants due to its strong antimicrobial phytochemicals. *Ocimum gratissimum* [African basil], known for its essential oils and polyphenolic compounds, supports microbial pathogen suppression in wastewater systems. Overall, these properties make these species promising candidates for sustainable and eco-friendly strategies in soil and water decontamination.

5.2. Plant Toxicity and Safety Considerations for Water Purification

The use of medicinal and multipurpose plants in wastewater phytoremediation requires a careful balance between their remediation efficiency and their potential toxicological risks. While several species (see **Table 4**) have demonstrated promising abilities to absorb, degrade, or neutralize pollutants, their integration into water purification systems must be supported by robust safety assessments, particularly when treated water or residual biomass may eventually interact with humans, livestock, or agricultural systems. Ensuring environmental and health safety therefore remains a critical aspect of phytotechnology applications.

5.2.1. Low-Toxicity Plant Models and Their Safety Profile

A number of plants commonly used in water purification exhibit low intrinsic toxicity while providing significant pollutant-removal capacity. *Eichhornia crassipes*, for example, is widely recognized for its efficiency in removing heavy metals such as Pb, Zn, Cd, and Mn from contaminated water sources [25] [40]. Although intrinsic toxicity data in mammals remain limited, *E. crassipes* is generally considered non-toxic. However, its capacity to bioaccumulate high metal loads introduces major secondary pollution risks if the biomass is reused as compost, animal feed, or fuel. Additionally, its rapid growth and invasive potential require strict management to avoid ecological disruption [25] [30] [40].

Similarly, *Moringa oleifera* is extensively used in natural water purification due to its coagulating and antimicrobial properties. Seeds and leaves contain bioactive proteins and compounds capable of reducing turbidity and suppressing bacterial contamination, making the species particularly valuable for community-level water treatment [6] [26]. Despite these benefits, recent toxicological studies highlight possible risks associated with chronic or high-dose exposure. In Wistar rats, methanolic leaf extract (0 - 400 mg/kg over eight weeks) induced dose-dependent increases in ALT, AST, and creatinine—markers of hepatic and renal stress [41]. Seed extract administration (50 - 100 mg/kg over 90 days) similarly produced elevated liver enzymes and histological damage, although partially reversible [41] [42]. These findings underscore that while *M. oleifera* is safe for water clarification, residual biomass should not be reused as food, feed, or medicine without detoxification.

Another low-toxicity species with high remediation potential is *Ocimum gratissimum*. Its leaves contain antimicrobial and antioxidative compounds that contribute effectively to water disinfection without causing toxic effects in aquatic organisms [9]. Toxicological studies indicate a high margin of safety: acute and subacute oral exposure up to 2000 mg/kg of aqueous extract revealed no adverse effects in rodents, and its methanolic LD_{50} exceeds 5000 mg/kg [43] [44]. These results support its safe integration into phytoremediation systems, provided biomass is properly handled post-treatment to prevent pollutant release.

5.2.2. Toxicological Variability in Multipurpose Species

The toxicological profile of *Azadirachta indica* (neem), a species increasingly explored for its antimicrobial and pesticidal potential in environmental systems, varies widely depending on plant part and extraction method [45]. Neem oil given orally at 1600 mg/kg/day for 28 days induced hepatic, renal, and testicular lesions in rodents despite stable serum biochemistry. Ethanolic bark extracts (100 - 300 mg/kg) also produced organ disturbances, while aqueous leaf extracts at 1000 mg/kg/day caused no detectable toxicity [45]. This variability indicates that while neem leaves may be relatively safe, the use of neem oil or bark extracts in environmental systems presents higher risks if residues enter agricultural or domestic water pathways. Appropriate monitoring and post-treatment handling are therefore essential.

5.2.3. Implications for Safe Phytotechnology Deployment

Taken together, these species illustrate both the potential and the challenges of using plant-based systems for water purification. Many high-performing plants have low intrinsic toxicity, making them suitable for rural and community-level applications. However, the safety of phytotechnologies depends not only on the plant itself but also on:

- the nature and concentration of pollutants accumulated,
- the fate of post-treatment biomass,
- potential invasiveness (e.g., *Eichhornia crassipes*),
- and the risk of indirect human exposure through reuse pathways.

A comprehensive toxicological assessment (including plant metabolites, pollutant accumulation, and biomass management) is therefore essential to ensure the safe and sustainable deployment of phytoremediation strategies.

Table 4. Toxicity plants used in water purification.

Plant	Key function	Non-toxic profile	References
Eichhornia crassipes	Heavy metal removal (Pb, Zn, Cd, Mn)	Effective but must be carefully managed to prevent invasiveness	[25] [40]
Moringa oleifera	Coagulant & antimicrobial agent for water	Safe and culturally accepted; ideal for community-scale use	[6] [26]
Azadirachta indica	antimicrobial agent	Ideal for community-scale use	[45]
Ocimum gratissimum	Antimicrobial phytochemical for water disinfection	Shows no harmful side effects in aquatic ecosystems	[9]
Phragmites australis	Phytoextraction of metals	Native, non-invasive, and well adapted	[29]
Typha latifolia	Nutrient & metal filtration via roots	Eco-safe, commonly used in wetland remediation	[29]
Lemna minor	Absorbs nutrients and metals	Effective but requires biomass control	[30]

6. Phytotechnologies for Environmental Remediation: A Sustainable Plant-Based Approach

In response to the growing challenges of environmental pollution, phytotechnologies are emerging as an ecological, cost-effective, and sustainable solution for the remediation of contaminated sites. Unlike conventional remediation methods which are often expensive and energy-intensive phytoremediation relies on the natural abilities of certain plants to absorb, accumulate, degrade, or immobilize pollutants such as heavy metals, excess nutrients, or organic toxins. However, the effectiveness of this approach depends on several factors, including the environmental context, the type of contaminant, and, most importantly, the selection of suitable plant species [7] [22].

6.1. Key Advantages of Phytotechnologies

Phytotechnologies represent a sustainable and environmentally friendly approach to pollution remediation, offering a range of ecological and socio-economic benefits. These plant-based systems generate no toxic by-products and actively contribute to the restoration of degraded ecosystems [7] [23]. Their low installation and maintenance costs make them particularly appealing for application in rural and low-income communities [7]. Moreover, their simplicity facilitates local implementation and fosters community involvement, especially when indigenous or culturally significant plants are used, reinforcing social acceptance and participation [28].

Beyond their accessibility, phytoremediation techniques are highly versatile, employing various mechanisms such as phytoextraction, rhizofiltration, phytodegradation, and antimicrobial activity. A notable example is *Moringa oleifera*, widely recognized for its natural coagulant and antimicrobial properties, making it effective for water purification [6] [26]. Additionally, the strategic use of native species like *Phragmites australis*, *Typha latifolia*, *Canna indica*, *Ocimum gratissimum*, and *Azadirachta indica* not only supports local biodiversity but also enables the valorization of plant biomass. These plants can be transformed into valuable resources such as compost, biogas, or materials for eco-friendly construction, thus integrating environmental cleanup with circular economic benefits [29].

6.2. Challenges and Limitations

Despite the numerous advantages of phytotechnologies, these nature-based solutions are not without their limitations. One of the main challenges lies in the slow remediation process, as achieving effective decontamination may require several weeks or months depending on pollutant type, concentration, and site-specific environmental conditions [22]. Additionally, phytotechnologies have limited effectiveness against certain persistent or non-biodegradable contaminants, which may require coupling with complementary treatment methods to ensure complete remediation [28].

Another important constraint concerns land availability. Because these systems typically require extensive surface areas, their implementation can be challenging in densely populated urban settings where space is scarce [7]. Furthermore, the management of contaminated biomass remains a critical issue. Species such as *Eichhornia crassipes* and *Lemna minor*, which accumulate heavy metals or organic pollutants, must be carefully harvested and handled to avoid secondary contamination risks [25] [29]. Several strategies have been proposed to address this challenge. For metal-rich biomass, phytomining offers a promising approach by recovering valuable elements such as nickel or zinc through controlled thermal treatment. For organic pollutant-laden biomass, controlled incineration or pyrolysis can neutralize contaminants while generating heat or bioenergy, thereby contributing to a more sustainable end-of-life management pathway. Composting or anaerobic digestion may also be considered when contaminant levels are low, allowing partial valorization while maintaining environmental safety. Finally, some highly efficient species present risks of invasiveness. *Eichhornia crassipes*, while effective in pollutant uptake, may proliferate rapidly if not strictly managed, potentially displacing native species and altering aquatic ecosystem structure [30].

7. Conclusions

Phytoremediation is a promising strategy for addressing water contamination by emerging pollutants in Africa. Several plant species exhibit significant remediation capacities, especially in tropical climates. Plants like *Eichhornia crassipes*, *Moringa oleifera*, and *Ocimum gratissimum* have proven effective in removing pollutants without causing toxic effects, making them valuable tools for safe water purification. Despite some limitations such as slower treatment times, land requirements, and biomass management challenges, these methods complement conventional techniques, especially in rural or resource-limited settings. Their integration into environmental management strategies, alongside proper species selection and local involvement, can promote ecological restoration and support a "One Health" vision that links human, animal, and environmental well-being.

Future field trials in West Africa should focus on several key areas to enable the effective and sustainable deployment of plant-based remediation systems such as developing effective strategies for managing contaminated biomass, exploring options such as phytomining, energy recovery, or safe composting adapted to local contexts, assessing long-term performance of phytoremediation under regional climatic variability, including seasonal floods, high evapotranspiration rates, and prolonged dry periods and evaluating the economic feasibility and cost-benefit ratio of different phytoremediation configurations, particularly for rural communities with limited financial resources.

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Conflicts of Interest

The authors declare no conflict of interest.

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