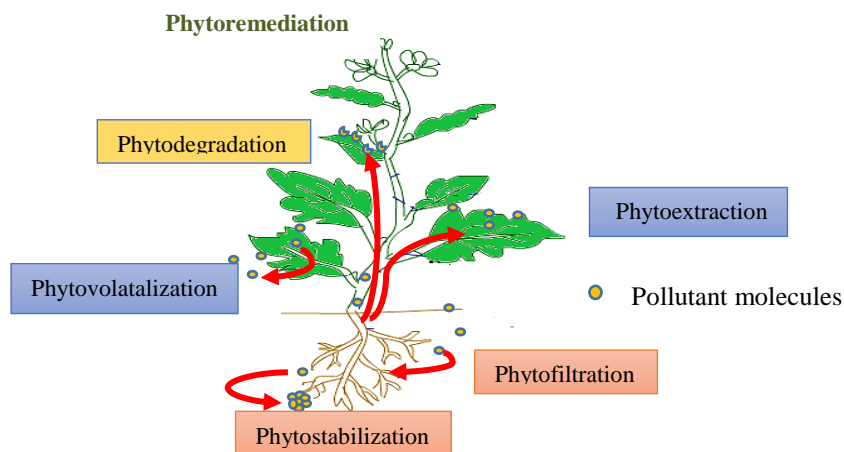# Phytoremediation of wastewater using aquatic plants, A review

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GRAPHICAL ABSTRACT

ARTICLE INFO

ABSTRACT

Disposal of waste products and residuals into the natural water bodies can have fatal consequences for aquatic ecosystems, posing severe threats to natural habitats and human health. Natural treatment systems are the most suitable treatment technologies for various types of wastewaters, which has attracted much attention in recent years. Phytoremediation is a plant-based technique used to eliminate or recover surplus nutrients in contaminated environments. The use of aquatic plants in wastewater phytoremediation is very efficient due to they have a very significant ability for assimilating and degrading contaminants (e.g., nitrates, phosphates, and heavy metals). Phytoremediation is a relatively new technology that is considered as an operational, efficient, new, and environmentally friendly technology that is still in the early stages of development and optimization. Its application on a large scale is still limited. It should also be noted that a clear vision of this innovation should be taken into account and, accurate data should be made available to the public as it will enhance its efficiency as a manageable solution in the worldwide. Additionally, phytoremediation has been evaluated as a separate low-tech and environmentally friendly green option compared to the existing technologies. The present study attempts to review the recently published literature to explain phytoremediation technology and its advantages in purifying water and wastewater.

1. Introduction

Contaminant-free water, along with food and shelter, are unavoidable necessities in human life. The primary sources of water are surface and groundwater sources. However, with rapid population growth and increasing industrial development in countries around the world, a large number of water resources have been polluted, which can lead to continuous discharge of organic and inorganic wastes from human activities to the natural water bodies (Ganghi et al. 2013; Safaukleen et al. 2019). In recent years, groundwater quality is declining daily due to rapid urbanization and rapid industrial growth. Discharge of untreated industrial effluent and domestic sewage water into the water bodies destroys water quality and causes water pollution (Misra et al. 1994). Disposal of waste products and residuals into the natural water pools can have fatal consequences for aquatic ecosystems, posing severe threats to natural habitats and human health (Petrovic et al. 2013). Therefore, wastewater should be treated and refined appropriately before discharge to the environment. At present, conventional wastewater treatment methods are not always efficient in eliminating water pollutants. Hence, small amounts of the pollutants can still be present in the treated water (Mohiyaden et al. 2016). because of the toxic nature of the pollutants, these materials may endanger the habitat and affecting many cellular functions in plants (Cichy et al. 2019).

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2. Various contaminants of aqueous environments

The most dangerous forms of pollutants are found in industrial wastewater. Different industrial sections produce various pollutant types. The wastewater flows from an industrial part are not limited to suspended solids, types of organic and inorganic materials, special oils, and dyes frequently used in the textile industry (Tichonovas et al. 2013; Ebrahim et al. 2017). It is estimated that about 1 million tons of textile dyes are consumed annually (Tichonovas et al. 2013). Water is also contaminated with various pharmaceutical products, but most water contaminants are various metals, weighty metal Besides, there is a new phenomenon as "emerging pollutants," which refers to the presence of chemical pollutants in the water bodies. The influence of these materials on both the environment and human health has not yet been determined (Deblonde et al. 2011). Organic pollutants are divided into several subgroups:

2.1. Wastes which demand oxygen

As implied by the name, these materials refer to all wastes that have a high concentration of biodegradable organic compounds. These wastes belong to the canning, leather, paper, and beer industries, and so on. These oxygenated organic wastes can be dissolved or suspended in colloidal forms. Because this type of waste contains high amounts of organic matter, its destruction requires oxygen, which usually takes place through the bacterial community's aerobic activity. The utilization of oxygen leads to the depletion of dissolved oxygen and, therefore, affects water quality and makes the water very unsuitable for aquatic organisms; when the dissolved oxygen value falls below 4 mg/ml, which could be referred to as a prominent indicator for water contamination (Comstock. 2019).

2.2. Synthesized organic compounds

These are synthetic organic compounds that generally include plasticizers, pharmaceuticals, detergents, paints fumes, insecticidals, volatile organic compounds, etc. The main problem of these pollutants is their lack of biodegradability, and their small amounts lead to unhealthy water for consumption. synthetic chemicals such as polychlorinated biphenyls (PCBs) have been produced and used in industry since the 1930s. These complex phenyl chlorides dissolve very quickly and could move into body's cells and, even tissues, making the water very unsuitable. Such compounds are stable in the environment because they are highly resistant to degradation (Potter and Pawliszyn. 1994).

2.3. Oil and petroleum

Oil and oil products are naturally occurring substances produced through plant fossils over several million years under very high-pressure conditions. It practically consists of hydrocarbons mixing that is degraded by the bacterial community. Biodegradation content varies from one oil type to another. pollution of water bodies with oil occurs through accidents of oil carriers or effluents with naphtha that enter the treatment tanks, leaks through pipes, etc. Because oil is lighter than water, it forms a thin layer above the water surface that no air reaches the bottom layer, leading to a decrease in dissolved oxygen. It can also affect the conduction of light by complete obstruction the entry of light into the water and, therefore affecting aquatic plants' photosynthesis.

2.4. Nutrients

Runoff from industries of chemical fertilizers producer and other sources such as sewage sludge and agricultural waste are rich in nitrogen and phosphorus. Surplus of these compounds leads to the growth of cyanobacteria, algae, and other aquatic weeds, leading to a decrease in dissolved oxygen and thus to the eutrophication of the water mass. Atrophy of the mass turns fresh water into dead water that smells bad and is not suitable for consumption.

2.5. Heavy metals

High-density, highly toxic metals are known as heavy metals even at deficient concentrations (Duruibe et al. 2007). According to the standards, metal and metalloid has a density greater than 4 g/cm^3. They inhibit normal developmental and physiological functions of living organisms in tiny amounts (Fu and Wang. 2011; Inoue. 2013); Metals generally act as co-enzymes for catalytic enzymes in metabolic cell reactions, but increasing their concentration might result in various carcinogenic effects (Inoue. 2013). Exposure of humans to even low amounts of heavy metals can lead to neurological, behavioral, and developmental disorders (Jaishankar et al. 2014). It can also lead to insomnia, lack of concentration, fatigue, movement, and nervous disorders.

3. Water and wastewater treatment

Considering the damaging impacts of contaminants on human life and the aquatic environments, alternating wastewater treatment methods are required (Kumar et al. 2013; Anand et al. 2017). Some conventional methods such as reverse osmosis, adsorption, ion – exchange, deionization, chemical precipitation, etc., are using to remove organic and inorganic contaminants (Mohiyaden et al. 2016). However, surplus sludge production, high energy demand carbon emissions, and high maintenance costs pose severe challenges to applying these treatment methods.

Natural treatment systems are one of the most suitable treatment technologies for various types of wastewaters, which has attracted much attention in recent years. These systems rely on renewable energies such as solar, wind and stored energy in biomass and soil. Natural systems include natural soil systems, aquatic systems, and wetlands. After stabilizing the pond system, one of the natural treatment systems that have been considered in many countries in the last few decades, especially developed countries, is the wastewater treatment system with plants' help (phytoremediation) or wetland systems. Nowadays, understanding plants' ability to help decompose and purify pathogenic microorganisms and the excretion of many contaminants, has led to increased application of plant systems and a more comprehensive range of research in this area (Keddy. 2010). Wetland systems are expanding day by day due to the ability and mechanism of multiple purifications (physical, biological, and chemical), being the natural system, cheap and straightforward operation and maintenance, and the high efficiency of purification. The primary role of plants in this system is to supply the oxygen required by heterotrophic microorganisms in the root zone, absorb nutrients, increase and stabilize the hydraulic conductivity of the substrate. As a high-efficiency secondary treatment unit, wetlands can remove a variety of contaminants such as organic matter, inorganic matter, and a variety of pathogenic microorganisms to an acceptable level (Vymazal. 2010). Phytoremediation is an innovative method used to eliminate or regain nutrients surplus from contaminated environments. The use of aquatic plants in wastewater phytoremediation is very efficient since they can assimilate and degrad pollutants (e.g. phosphates, nitrates, and metals ions, etc.) from polluted water. Therefore, they improve the wastewater quality before discharging it into the natural environment. Phytoremediation methods can also be used to recover nutrients such as phosphates and nitrates from wastewater, which can be applied to produce chemical fertilizers and food additives for livestock. Between the various aquatic plants, *Pistia stratiotes* and *Salvinia molesta* are widely used for wastewater treatment. Extensive use of these plants has been because of their accessibility, sustainability in an environment containing pollutants, the potential for bioaccumulation, invasive mechanisms, and potential for biomass production. Also, *P. stratiotes* and S. *molesta* have high amounts of biomass, making them good bioenergy production choices. Contrary to the potentials shown by these two plant species, their full potential and ability are not yet known. Therefore, there is a need for more research on plants in refining radioactive compounds, nanoparticles and pharmaceuticals and chemicals in wastewater.

4. Phytoremediation

Phytoremediation using green plant engineering, including herbaceous and woody species, is used to remove contaminants from water and soil or reduce the risks of hazardous environmental pollutants such as heavy metals, trace elements organic, and radioactive materials. Sludge generated from refinery effluents is one of the most critical environmental pollutants which their burial and incineration have dangerous effects on the environment and human health. Therefore, methods that reduce the toxic effects of sludge containing hydrocarbons should be used. Therefore, phytoremediation of organic sludge compounds effectively reduces or eliminates soil petroleum hydrocarbons (Chehregani et al. 2009). Among chemical pollutants, heavy metals are of importance in terms of ecological, biological, and health effects. The use of plants to extract heavy metals from the soil is a new and promising method for soil improvement and is called plant-improvement. This method can be conducted immediately, and due to its innate nature, it is compatible with the environment and has no

specific side effects (Chehregani et al. 2009). Phytoremediation is defined as applying compatible plants to decompose or reduce pollutants in soil, sediment, and groundwater. Phytoremediation is one of the methods that have advantages such as the low volume of waste, the capture of sunlight, excellent stability, ease of use, the possibility of using it on a large scale, improving soil quality, reduction of greenhouse gases, elimination of air and groundwater pollution, lower cost, promotion of other plants and public acceptance, have been given special attention to eliminate pollution (Cunningham et al. 1991). Phytoremediation is a technology based on a combination of plant activity and its associated microbial community for the decomposition, transfer, inactivation, and immobilization of contaminants from groundwater. When contaminants are degradable, phytoremediation technology demonstrates the stimulatory effect that roots have on microbial processes and causes a series of physical and chemical modifications in the soil. In such cases, phytoremediation may be carried out by rhizosphere decomposition (microbial decomposition in the root environment), plant decomposition (decomposition of compounds adsorbed by the plant), and hydraulic control (limiting the spread of contaminants in the soil and vapor). Plant transpiration should be performed. In cases where contaminants are non-degradable, such as heavy elements, terms used in the phytoremediation system may include root filtration (elements in water), plant uptake (elements in soil), plant volatilization (elements such as mercury and selenium), and plant stabilization (prevention of spread by leaching and infiltration). Also, the availability of nutrients and microbial degradation may be in phytoremediation (Flathman et al. 1998). While several studies have shown that plants increase the biodegradation of a wide range of contaminated waters, the processes involved are poorly understood (Flatman et al. 1998; Schnoor.1998).

4.1. Phytoremediation processes

The plant's capability to absorb and transfer large volumes of groundwater in phytoremediation is known as the process of hydraulic monitoring of contaminated sites. This hydraulic control can be managed to prevent horizontal movement and contaminants vertical leaching. During the evaporation and transpiration of water absorbed by the plant, dissolved organic and inorganic compounds enter the plant that may enter other phytoremediation processes. Organic compounds introduced into the plant can be degraded by plant enzymes, which is called plant degradation. Also, the uptake and accumulation of minerals in plant tissues is known as plant accumulation. The subsequent uptake and evaporation of volatile compounds through the leave are known as plant volatilization (Fig. 1).

4.1.1. Plant fixation

The first interaction between the contaminant and the remediating plant takes place in the root zone, and the initial process of plant fixation occurs there. This process involves immobilizing (assimilation) contaminants in soil, sediments, and groundwater by absorbing and accumulating them in the root zone. These contaminants then tend to be converted to the steady-state.

4.1.2. Rhizo-degradation

Rhizosphere decomposition, commonly referred to as plant-based biodegradation, involves the decomposition of contaminants in the medium through activities in the plant root zone. The processes of increasing decomposition in the root zone are not fully understood, and the explanation for these processes may be related to the complexity of the environment in which these processes occur.

4.1.4. Plant decomposition

Plant decomposition, often called plant decomposition, refers to the adsorption of organic compounds from polluted water by their subsequent decomposition by plants.

4.1.5. Plant volatilization

The last process (in the atmosphere-plant-soil continuum) is one of the phytoremediation processes that can modify various organic and inorganic pollutants, plant volatilization. In the root zone, the contaminants' chemical properties may change before or after the plant's uptake. When the primary contaminants or their modified form are transferred into the leaves inside the plant, they are released into the atmosphere through evapotranspiration processes.
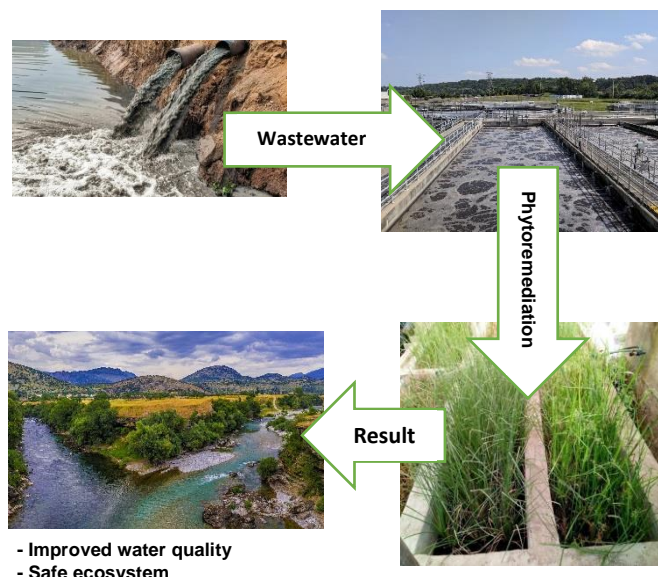

- Improved water quality
- Safe ecosystem

Fig. 1. Phythoremediation by plants for refining and absorbing metals in wastewater.

4.1.6. Plant evapotranspiration

Besides the ability of plants to stabilize and absorb mineral compounds and enhance biodegradation, organic compounds can affect the region's hydrology. In particular, some plants absorb and transpire a significant volume of groundwater (if the water is in the root zone) (Parrish et al. 2005).

5. The role of aquatic plants in phytoremediation of water and wastewaters

Phytoremediation, the use of plants and related microorganisms, is one of the new technologies that provide an efficient, cost-effective, and sustainable means for developing countries to achieve this goal because it is cheaper to do and requires less skill to their implementation is required. This method is a cost-effective plant-based approach to removing heavy metals from water (Terry and Banuelos. 2000; Mohanty et al. 2005; Mohanty and Petra. 2011; Mohanty. 2015).

Aquatic plants are significant for biological treatment of wastewater because they can be used for phytoremediation through methods of root filtration, plant extraction, plant sublimation, plant degradation, and decomposition and conversion for phytoremediation (Anand et al. 2017). Removal of contaminants depends on the exposure duration, the contaminants concentration, environmental agents (temperature, pH), and plant features (root system, type of species, etc.) (Anand et al. 2017). However, it is worth noting that different aquatic plants have been used with considerable success in the wastewater phytoremediation process (Akinbile et al. 2016). Several aquatic macrophytic species such as blue HHyacinth (*Eichhornia* sp.), Duckweeds (*Lemna* sp., *Spriodella* sp.), Small water fern (*Azolla* sp.) and blue cabbage (*Pistia* sp.) have been used to remove heavy metals from wastewater (Okunowo and Ogunkanmi. 2010; Suhag et al. 2011; Saha et al. 2015). Yasar et al. (2017) evaluated the potential of weeds and *Pistia. stratiotes* species in the vertically and horizontally designed wetland systems in wastewater treatment. In the vertical system with *P. stratiotes*, the elimination efficiency for BOD was 82 %, 95.4 % for phosphate, and 51 % for chloride. At the same time, TSS reduction and water turbidity were both 98.8 %. This result shows the capability of *P. stratiotes* to absorb nutrients and release toxins to disinfect pathogens. A similar result for chloride was reported by Aswathy et al. (2017). Kumar et al. (2017) used *P.* Stratiotes species as hyper-accumulator plants in the sugar phytoremediation factory effluent streams. Schwantz et al. (2019) demonstrated *P. stratiotes* as phytoremediation agents for domestic wastewater in Brazil. The results firmly demonstrate that P. *stratiotes* are an excellent complement to domestic wastewater post-treatment. Tabinda et al. (2019) considered the recovery potential of *Eichhornia. crassipes*, *P. stratiotes*, and an alga (Oedogonium sp.) in textile wastewater enriched with BOD, COD, heavy metals, and dyes (cadmium, copper, iron, and lead) for seven days. High storage of lead and iron was observed in *P. stratiotes* relative to *E. crassipes*. Reza Nia et al. (2015) showed that water hyacinth is a suitable option for industrial wastewater treatment and refinement. They also showed that

between aquatic plants, aquatic Hyacinth had a high potential for improved water quality and nutrient uptake. Rezania et al. (2016) also found that between the free-floating species (*Eicchornia* spp., *Pistia stratiotes*, *Salvinia* spp. and *Lemna* spp.), *Pistia stratiotes* had the highest potential for plant accumulation and therefore phytoremediation.

6. Application of hydrophytes for phytoremediation

The plants that grow in water are considered hydrophytes; these aquatic species are the first option when evaluating water's phytoremediation (Förstner and Wittmann. 2012). These plants have been considered for this aim since the 1970s; Aquatic plants are preferred to terrestrial plants due to their high ability to accumulate approximately 1450 times more heavy metals in water (Rezania et al. 2016). The fast growth rate and high biomass accumulation, high capacity to absorb pollutants, and their more prominent filtration due to their close contact with water are among the advantage of using aquatic plants (Wani et al. 2017). Hydrophytes include plants in water habitats seen with the naked eye (Pflugmacher et al. 2015). These hydrophytes include spermatophytes (flowering plants), Petri endophytes (mosses), and bryophytes (mosses, hornworts, and liverworts) (Kolada et al. 2016). Mohd Nizam et al. (2020) examined the efficiency of five selected aquatic plant species in aquaculture wastewater phytoremediation. They observed a significant reduction in pollutant concentrations after 14 days, where C. *asiatica* removed 90 % of NH_3-N, 90 %. TSS and 64 % phosphate, while I. *aquatica* had a high potential to remove 73 % of total soluble salts, and ammonia nitrogen, and 50 % of phosphate and, *E. crassipes* dramatically removed 98 % of phosphate, 96 % of soluble salts and 74 % of NH_3-N. In comparison, *P. stratiotes* removed 98 % of TSS, 78 % of NH_3-N and 89 % of phosphate. S. *molesta* removed 89.3 % of TSS, and 88.6 % phosphate but removed only 63.9 % of NH_3-N.

7. Mechanisms of aquatic plants for phytoremediation
7.1. Removing heavy metals using aquatic plants

The continuous release of contaminated wastewater containing heavy metals into the environment threatens human health. Lasat (2002) showed that plants are thriving in removing heavy metals. Using plants as bio-sorbents to remove heavy metals is considered a cheap, efficient, and environmentally friendly technology. Phytoremediation can be evaluated as an advantage if the plant can extract and accumulate a particular type of metal element in the contaminated wastewater (Tripathy and Upadhyay. 2003). Plant roots help absorb pollutants in wastewater, weighty metals and improve water quality (Sooknah and Wilkie. 2004). Four aquatic plants named Hyacinth, Water lettuce, Zebra surge, and taro were evaluated for their efficiency in removing mercury from wastewater. The results showed that roots seem to play an essential role in the uptake of mercury from wastewater (Skinner et al. 2007). According to Park et al. (2010), bio-sorbents used to heavy metals from wastewater can be ordered into seven categories: 1) fungi, 2) bacteria, 3) industrial waste 4) algae, 5) natural residues 6) Agricultural waste, and 7) other biological materials. Suzuki et al. (2005) reported using seaweed as the cheapest and most available material, which has attracted much attention as a bio-sorbent. Klumpp et al. (2002) showed that aquatic macrophytes with higher growth rates, such as the aquatic Hyacinth, could potentially be used to eliminate metal ions from wastewater. This plant has lately earned much attention as a potential sorbent for treating wastewater contaminated with metal ions (Mahamadi and Nharingo. 2007). Macrophytes have a higher capacity for accumulating heavy metals in plant water bodies (Priya and Selvan. 2004), which has been shown to have a high potential for removing a wide range of contaminants from wastewater. Jadia and Fulekar (2009) reported that heavy metals absorbed by the plant roots were transported to shoots and other plant tissues. They were concentrated, and plant harvesting could permanently eliminate these pollutants. Also, precious heavy metals can be regained from plant ash by burning and extracting metal ions from plant ash. Atashgahi et al. (2012) investigated the efficiency of removing heavy metals Cd, Pb, and vanadium from the wastewater of Bidboland gas refinery by natural (wetland) method. For this purpose, samples of refinery effluent and straw samples were collected from nature. Sewage samples entering the treatment tank and wastewater samples were collected after 2, 6, and 10 days. After concentration and acidic digestion of samples, the concentrations of heavy metals Cd, Pb, and V in the wastewater were measured. According to the results, vanadium had the highest reduction with 66 % and the reduction of lead and cadmium was 61 % and 59 %, respectively.

Plants use different strategies to decontaminate metals, but the primary step is to absorb the plant's metal. Plant roots absorb metals, but excess metal can have toxic effects that cause tissue and cell death in plants. To avoid this, plants use several strategies (Venegas et al. 2015). One of these strategies is to limit the transfer of toxic metals to plant roots by mycorrhizal fungi (Marques et al. 2009). Plants are also classified as excluders. Inhabitants are a type of plant that can survive even if heavy metals accumulate inside them; Excluders, on the other hand, restrict the entry of metals after reaching an absolute threshold value (Tangahu et al. 2011). Metal chelation or adsorption occurs through the presence of metal-binding proteins and peptides (Merlot et al. 2018). Mechanisms for transporting and translocation of the ions, metals, and nutrients from the environment are performed through proton pumps, synchronous transmitters, and carriers or channels, for example, proteins that facilitate the transfer of ions to the cell (Thakur et al. 2016). Plants that are hyperaccumulators with heavy metals usually accumulate these metals in concentrations of 100-1000 times more than non-hyper-accumulator ones (Tangahu et al. 2011). Sometimes rhizosphere and mycorrhizal interactions in plants also facilitate this increase in metal uptake (Ullah et al. 2015).

7.2. Removal of organic and inorganic compounds

Aquatic Hyacinth has been extensively studied on a laboratory scale and on a large scale to remove organic matter from wastewater compared to other aquatic plants (Costa et al. 2000). Although water hyacinth is recognized as a stable plant worldwide, it is widely used as a significant source for waste management and agricultural processes (Malik. 2007). Both laboratory and field studies have shown that this aquatic plant can remove large amounts of contaminants in the effluent of the wine industry (Valero et al. 2007). Aquatic Duckweed and Hyacinth have been used to treat animal manure and animal manure leachate (Sooknah and Wilkie. 2004). The treated effluent in the presence of aqueous Hyacinth for 25 days reduced 37, 47, 54, and 33 % in total solids, calcium, magnesium and total hardness, respectively. The effluent from the poultry farm was treated with aqueous Hyacinth, which resulted in the removal of 64 %, 23 %, and 21 % of total COD, phosphorus, and nitrogen, respectively (Jinbo et al. 2008). Combining the use of aquatic Hyacinth and Duckweed for animal wastewater treatment, this treatment removed 79 % of total nitrogen and 69 % of total phosphorus (Tripathy and Updhayay. 2003). Chen et al. (2010) showed that 36 % of nitrogen and phosphorus could be removed from the wine industry's effluent from water using Hyacinth. Hassan et al. (2016) compared three aquatic plants in phytoremediation of lead from wastewater. They showed that the three aquatic plants (*E. crassipes*, H. *verticellata*, C. *demersum*) had a difference in their ability to accumulate lead in tissues. According to the results, the *E. crassipes* plant has the ability to accumulation of lead more than *H. verticillate*, C. *demersum* plants which accumulated lead in leaf water hyacinth by 0.453, 0.749, 0.885 ppm at 100, 50, and 25 % concentrations of the wastewater in the age of thirty-day experiment, respectively (Fig. 2). Ismaeil et al. (2015) demonstrated the efficacy of aqueous Hyacinth and aqueous Lettuce in absorbing nitrate, orthophosphate, nitrite and ammonia nitrogen. They showed that aqueous Hyacinth performed better at reducing nitrate than orthophosphate. Valipoor et al. (2015) showed in their research that the water hyacinth roots are mainly involved in the transmission where the shoots are involved in the accumulation of significant amounts of nutrients (nitrogen and phosphorus) compared to the root zone.
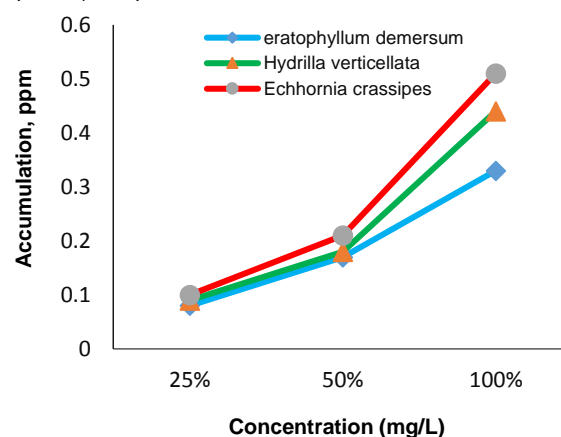

Fig. 2. Comparing the lead accumulation rate in three aquatic plants after one day of the experiment (Hassan et al. 2016).

The dewatered sludge of the Isfahan refinery water recycling unit first dried in the air. Then, proportions of 0, 10, 20, 30, and 40 % by weight were added to the water. For phytoremediation, 100 seeds of *Festuca arundinacea* and *Agropyron Smithii* were planted. The results showed that by increasing the percentage of sludge to the level of 40 %, the amount of petroleum hydrocarbons in the rhizosphere of *Festuca arundinacea* plant decreased by 65 %. While in the rhizosphere of *Agropyron Smithii* plant increasing the percentage of sludge and at the level of 30 % the number of petroleum compounds decreased by 55 %. Overall, the   40 % sludge level had a lower root and shoot yield than other sludge levels in *Agropyron Smithii* and *Festuca arundinacea*. Decomposition of petroleum hydrocarbons was higher in the *Festuca arundinacea* rhizosphere at 40 % sludge mixed. However, the yield obtained at this level is meager and it isn't easy to get a suitable vegetation cover. However, in general, the yield of this plant at the level of 20 % of sludge mixed did not decrease much compared to the control. The decomposition of petroleum hydrocarbons was relatively acceptable at this level. Therefore, phytoremediation is recommended by this plant at 20 % sludge level and in poultry yard at 30 % sludge level.

Hutchinson et al. (2001) introduced phytoremediation as a useful method for the degradation of petroleum hydrocarbons produced in the oil industry, provided that time is required for plant establishment and growth in water biodegradation. In a three-month greenhouse experiment, the plants could decompose an average of 3 percent of total petroleum hydrocarbons in contaminated waters. They observed that the highest decomposition rate of organic compounds in the rhizosphere of *dactylon Cynodon* and the presence of *Festuca arundinacea.* Emamjomeh et al. (2016) combined the combined anaerobic and phytoremediation systems and evaluated their potential and efficiency for sanitary wastewater treatment. The results showed that applying the hybrid process of anaerobic and phytoremediation systems resulted in the hybrid process of anaerobic and phytoremediation systems resulting in the removal rate of COD TSS up to 80 % each and the turbidity and BOD5 removal rates up to 90 %. The system caused the removal efficiencies of total coliform and intestinal nematode by 99, 999 % and 100 %. The quality of the treated wastewater was acceptable, according to the Iranian effluent standards for irrigation.

8. Plants in the phytoremediation of water and wastewater

The types of plants used to treat industrial, sanitary and municipal effluents are very diverse and each of them can remove some of the pollutants in the water. These plants' choice depends on various factors, including the type of pollutants and the amount of contamination. Among the plants used for this purpose are Reed, Narrow-leaved *cattail*, Yellow flag, Reed grass, Rushes bulrushes, Broad-leaved cattail, Sweet flag, *Carex*, *Fabaceae*, *Brassicaceae*,

Asteraceae, *Amaranthaceae.* As mentioned, each type of plant used to treat wastewater with plants can remove some metals and organic and inorganic materials (Hinchman et al. 2002). For example, *pistia stratiotes*, which belong to the Araceae family, can easily to the Araceae family, easily decompose and remove cadmium, nickel, lead and zinc, copper, and mercury, chromium and silver. *lemna gibba* is also able to decompose and remove arsenic in sanitary and industrial effluents. Phytoremediation of aquatic environments with aquatic plants (species such as *Eichhornia crassipes* and varieties such as minor Lemna and *Spirodela polyrrhiza*) is an effective, efficient and inexpensive way to remove residues of nitrogen and other contaminants from water and pollutants (Fox et al. 2008; Polomski et al. 2009). Lettuce has a high potential for purification of nitrogen and phosphorus, reducing stable suspensions of water and mud from floods, and increasing water and wastewater quality (Schröder et al. 2009; Lu et al. 2010). The deciduous herbaceous plant, also known as the water fork (*Ceratophyllum L. demersum*), is one of the most critical and dominant aquatic plants in Iran's rivers and canals that can remove pollutants from aquatic mediums (Aravind and Prasad. 2005). Hinchman et al. (2002), in three-month greenhouse experiments, the researchers were able to decompose an average of 3 percent of total petroleum hydrocarbons in contaminated soils. They reported the highest decomposition of organic compounds in the Cynodon dactylon plant's rhizosphere by 8 % and *Festuca arundinacea* by 62 % and overall degradation of total petroleum hydrocarbons were obtained by 1.7 times higher than control in the presence of plant. *Pistia stratiotesor* is an invasive species that is considered as one of the most important and prolific free-floating macrophytes in the world (Neuenschwander et al. 2009). The ability of P. *Stratiotes* in the phytoremediation of synthetic wastewater composed of silver nanoparticle (AgNP) and silver ion indifferent concentrations has been studied by Hanks et al. (2015). The results suggested that P. *stratiotes* can survive under 0.02 mg/L AgNP and ions by retaining the contaminants within the plant. In the end, the researchers concluded that P. *stratiotes* could act as a promising species for phytoremediation of heavy metal nanoparticles. *Salvinia molesta* D.S Mitchell also introduced as *Giant Salvinia* is a free-floating and heterosporous fern in the Salviniaceae family (Nelson et al. 2009). Pavithra and Kousar. (2016) assessed S. molesta plants' potentialS. molesta plants' potentials in the treatment of textile wastewater and affirmed the effectiveness of the plants in the treatment of textile wastewater. Ugya et al. (2019) evaluated the efficiency of macrophytes in phytoremediation of wastewater containing dye. The Authors' reported that S. *molesta* has the highest removal efficiency for phenol and ammoniacal nitrogen compared to *Lemna minor*, *Eichhornia crassipes*, *Pistia stratiotes* and *Azolla pinnata* macrophytes. Table 1 summarizes some aquatic plants' potential in the phytoremediation of aquatic environments (Mustafa and Hayder. 2020). Fig. 3 shows some of the aquatic plants utilized for phytoremediation of water and wastewater.

Table 1. Phytoremediation potential of some aquatic plants.

Plants	Wastewater type	Pollutant	References
Eichhornia crassipes (Water hyacinth)	Industrial wastewater	BOD, COD, Fe, Oil, grease, Zn, Ni, etc.	Patel and Kanungo. 2012; Priyanka saha et al. 2017
Pistia stratiotes (Water lettuce)	Industrial wastewater	Cd, Zn, Ni, Pb, Cu, Nitrite	Suggu Sri Gowri Reddy et al. 2015; Lu et al. 2018
Typha angustifolia L.	Textile wastewater	BOD, COD, color, TDS	Chandanshive et al. 2017; Al-Baldawi. 2017
Lemna minor	Industrial wastewater	BOT, Chloride, sulphate, BOD, COD, TDS, Cu, Ti, Pb	Sood et al. 2012; Priyanka saha et al. 2015
Ipomeo aquatica (Water spinach)	Palm oil mill effluent	COD, TDS, Nitrate, NH_3-N, Phosphorous, Ni, Pb, Cd	Kumar et al. 2013; Sa'at and Zaman. 2017
Myriophyllum aquaticum	River water	(BOT) waste water (Chloride,	Coetzee et ali. 2011; Mustafa and Hayder. 2020
Ceratophyllum demersum	Fish pond	N, P	Abdallah. 2012; Matache et al. 2013
Salvinia natans	Raw wastewater	BOD, COD, NH_4-N	Dhir et al. 2008; Laabassi and Boudehane.2019
Vertiveria zizaniodes	Fish pond wastewater	NH_3, NO_2, NH_4, PO_4	Yeboah et al. 2015; Effendi et al. 2020
Myriophyllum spicatum	Polluted rural river water	Cod, TN, TP, NH_4-N	Milojković et al. 2016; Saleh et al. 2019
Typha orientalis	Municipal wastewater	BOD, Na, TOC, turbidity, nitrate	Oladejo et al. 2015; Di et al. 2020
Hydrilla verticillata	Secondary domestic wastewater	BOD, COD, TSS, TP	Patel and Kanungo. 2012; Abu Bakar et al. 2013

9. Future perspectives of phytoremediation of water and wastewater

Water pollution with effluents from industries and heavy metals increases, which has led to increased safety warnings. Lack of contaminant-free water due to industrialization and urbanization are growing concerns associated with estimates of the depletion of clean water reserves in the upcoming years. This has led scientists to study and find available ways to purify water. Detoxifying water using conventional approaches is costly and time-consuming, so scientists have moved to more economical methods such as phytoremediation using special plants that live in it and hydrophytes to purify water. Many plants, such as *Eichhornia crassipes* have been reported as purifiers of organic matter pollution (Rai and Panda. 2014). In this way, the use of

plants in reducing pollutants may contribute to their operational applications (Rai. 2015). Also, the use of aqueous Hyacinth in wastewater treatment has been widely reported and treatment regimens have been created as a result of recent developments and advances in phytoremediation approaches (Priya and Selvan. 2014). The percentage of arsenic in drinking water has caused great concern in many communities around the world, which has already affected many people. Although different aquatic plants have been shown to absorb arsenic and have been recommended for arsenic phytoremediation, the management, transfer, and burial of these aquatic macrophytes is another important consideration in the effective use of the phytoremediation initiative because of the essential need to create cheaper systems for the removal of arsenic and heavy metals from drinking water, given the materials available (Raju et al. 2015).

a

b

c

e

Fig. 3. some of the aquatic plants utilized for phytoremediation of water and wastewater. a) *Eichhornia crassipes* (Water hyacinth), b) *Pistia stratiotes* (Water lettuce), c) *Ipomeo Aquatica* (Water spinach), and d) Common reed.

10. Conclusions

The current state of environmental pollution by contaminants will affect all components of the ecosystem. The results obtained to date indicate that some plants can be useful in removing toxic metals and toxic contaminants from water. To restore the balance of the environment, the phytoremediation technique has several benefits such as low cost compared to physical and chemical methods, lack of impact on biodiversity, etc. Therefore, one of the most appropriate methods to address. Due to the accumulation of heavy metals in the environment. However, the efficiency and effectiveness of this method to design and select a scientific, accurate, and comprehensive strategy, taking into account the type of metal ions in the water, geographical location and climatic conditions of the region and the potential of the plant to remove contaminants from the environment are dependent. Phytoremediation is still in the research and development stage and has many technical issues that need to be considered and evaluated. On the other hand, to increase its acceptance as a sustainable global technology, it is essential to introduce this technology with clear and accurate information that can be understood and used by all members of society. To transform the phytoremediation process into a commercially viable method, it is necessary to optimize both management and plant genetic capabilities. It should also be noted that a clear vision of this innovation should be taken into account and accurate data should be made available to the public as it will enhance its adequacy as a manageable solution worldwide. Phytoremediation has been considered a separate low-tech and environmentally friendly green option for refining methods.

More research, innovation and initiatives are needed for this technology to upgrade it and encourage developing countries to use it due to its low cost and operational nature.

The future perspective includes exploiting genetically engineered plants by increasing the adsorption capacity of heavy metals to ensure the metals' decontamination; These genetically engineered plants must have rapid growth cycles to have much less time to complete the growth cycle and have a high phytoremediation potential. These plants can be used to remove other contaminants from water such as hydrocarbons and other toxic and carcinogenic compounds. The application of growth- promoting bacteria that stimulate the growth of rhizosphere plants and the overgrown plants could be another modification that can have the maximum treating effect.

Aknowldgments

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