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Potentials of Aquatic Plants in the Treatment of Paint Industry Effluent: A review

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ABSTRACT

Nigeria's population has increased dramatically in recent years, leading to massive urbanization and industrialization with a concomitant increase in environmental pollution. Chemical industries such as the paint industry use large quantities of water in their processes, resulting in the generation and release of a lot of effluent into the environment. These effluents contain suspended solids, pigments, colorants, heavy metals, oil, and grease, which, if not properly managed, could have a negative impact on the environment and human health. Therefore, the purpose of this paper is to review the effectiveness of the various conventional methods of treating paint effluent as compared to phytoremediation.

Keywords: Paint industry; effluent; phytoremediation; aquatic plants; heavy metals

1.0 INTRODUCTION

With an increase in population, society's industrialization has led to an abundance of industrial goods and services for the well-being of its citizens. This euphoria, however, comes with a price: environmental pollution (Vinayak et al., 2014). Most industries, including the paint industry, use a lot of water for their industrial processes, which results in the release of large quantities of wastewater into the environment without proper treatment, thereby degrading the environment (Pierre et al., 2020; Yang et al., 2007; Theeta et al., 2017; Nasir et al., 2015).

It had been noted that the paint industry generates about 80% of its wastewater from activities such as cleaning the manufacturing area, mixers, packaging equipment, and reactors. These effluents are invariably discharged into the environment (Korbabiti et al., 2007; Elamur et al., 2021).

The discharged effluent water contains high amounts of suspended solids, pigments, colors, heavy metals, oil, and grease. The constituents and characteristics of paint effluent water depend on the type of paint produced. These may range from dark color, high pH, a significant amount of organic matter, and heavy metals with poor biodegradability such as Cr, Cu, Pb, Al, and Zn (Akoyl, 2012; Elamur et al., 2021). In addition to causing visual pollution, the discharge of such colored and toxic wastewaters also blocks light from entering the receiving environments, degrades the environment, and poses toxic risks to soil, sedimentary organisms, and aquatic life, invariably imparting on the food chain. Such pollution may also cause health risks like inflammation of the eyes, skin, and lungs. Paint industry effluents have also been found to cause several human health issues, including cancer, Alzheimer's disease, respiratory issues, muscular weakness, and liver and kidney damage (Vishali et al., 2018). These effluents also contain a high load of heavy metals. According to Babayemi et al. (2017), heavy metals are a common source of metal pollution in soil, presenting a serious threat to crops and people in general and causing serious concern to agrarian communities in most developing countries, including Nigeria. Heavy metal-laden wastewater is also generated by industries like dye, textile, paper, and plastic (Jaishree, 2015; Ryzhenko et al., 2017). According to the Environmental Protection Agency (EPA), the seven most prevalent heavy metals in the atmosphere are lead, cadmium, copper, chromium, arsenic, mercury, and nickel (Wang et al., 2005; Aruliah et al., 2019). They are regarded as toxic even at low concentrations because of their great density (Lenntech Water Treatment, Air Purification, 2004). It is also known that metal toxicity affects plants and other aquatic reproductive systems, which reduces the number of marine organisms (Fatima et al. 2014). Other consequences of pollutants in the aquatic environment include genetic abnormalities, oxidative stress, and deficiencies in endocrine hormones (Javed et al., 2016). Heavy metals are dangerous to the ecosystem and human health because they are non-biodegradable and build up in the food chain (Singh et al., 2011; Ali et al., 2013). The sources of some heavy metals and their toxic effects on humans and animals are highlighted in Table 1.

Table1: Sources of contamination and toxic effects of heavy metals (Gaurav et al., 2017)

Heavy metal	Sources of contamination	Environmental hazards	Toxic effects Humans/animals
Arsenic (As)	Pesticides and wood preservatives	Water and soil pollution	ATP synthesis and oxidative phosphorylation are also impacted by this analog of phosphate, which causes "pins and needles" in the hands and feet.
Cadmium (Cd)	Paints, pigments, plastic stabilizers, electroplating, burning cadmium-containing polymers, and phosphate fertilizers	Water and soil pollution	Hypercalciuria, itai-itai illness, endocrine disruptors, carcinogens, mutagens, teratogens, and teratogenic
Lead (Pb)	Leaded gasoline combustion, battery production, herbicide and insecticide use, and other sources of aerial emissions	Water and soil pollution	The risk of cardiovascular disease, foot or wrist drop (palsy), nephropathy, impaired development, decreased IQ, short-term memory loss, sleeplessness, anorexia, encephalopathy, learning and coordination problems, and anorexia

Heavy metal	Sources of contamination	Environmental hazards	Toxic effects Humans/animals
Chromium (Cr)	Steel mills, fly ash, pigments, dyes, and tanneries	Water and soil pollution	Hair loss, pulmonary fibrosis (lung scarring), lung cancer, and harm to the kidney, circulatory, and nervous systems are all side effects of this highly hazardous, confirmed carcinogen, according to the IARC, WHO, ATSDR, and USEPA.
Mercury (Hg)	Release from surgical equipment, medical waste, and coal combustion	Water and soil pollution	Possible human carcinogens (methyl-Hg) as determined by the USEPA include anxiety, Minamata, autoimmune conditions, depression, difficulty balancing, drowsiness, fatigue, hair loss, insomnia, irritability, memory loss, recurrent infections, restlessness, vision problems, tremors, temper outbursts, ulcers, damage to the brain, kidney, and lungs, neurasthenia (neurotic disorder), and parageusia (metallic taste)
Copper (Cu)	Pesticides fertilizers	Water and soil pollution	Wilson's disease, kidney and brain damage, liver cysts, chronic anemia, gastrointestinal discomfort, and even death might occur.
Nickel (Ni)	industrial waste, home equipment, medical equipment, steel alloys, and automobile batteries	Water and soil pollution	Hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic, pulmonary toxic, nephrotoxic, and hepatotoxic; allergic dermatitis (itching); cancer of the lungs, nose, sinuses, throat, and stomach; hair loss and birth problems in babies; cardiovascular and musculoskeletal system.

As a result of the negative impacts of these pollutants on the environment, food security, and safety, appropriate pollution containment through efficient waste management is required (Conley et al., 2009; Pierre et al., 2020). To eliminate insoluble particles and soluble contaminants from effluent, current wastewater treatment techniques combine physical, chemical, and biological processes. Annad et al. (2019) observed that different physical and chemical techniques, such as chemical precipitation, reverse osmosis, ion exchange, and electrochemical deposition, have been used in the past for the containment of pollutants in industrial effluents. The physio-chemical processes used in the treatment of paint effluent, such as sedimentation, flocculation, coagulation, and filtration, are all geared towards separating colloidal and suspended particles.

The limitations of these conventional techniques for the removal of heavy metals from contaminated water include their high cost and the production of secondary pollutants. However, phytoremediation has been found to be an excellent and economical remediation technique with great potential for treating paint wastewater. In addition to its eco-friendly remediation potential, it is capable of restoring contaminated aquatic environments.

2.0 PAINT INDUSTRY EFFLUENT

The raw materials used in the paint industry, which are a combination of pigment, binder, solvent extenders, and additives, make it distinct**.** The characteristics of a specific paint are determined by the kind and quantity of the ingredients in the mixture. They also affect the features and constituents of the wastewater generated during its production and application (Korbahtietal, 2009). Typical pollutants associated with wastewater from the paint industry are biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, color, elevated pH, significant amounts of organic matter, and heavy metals such as Cr, Cu, Pb, Al, and Zn with poor biodegradability abilities (Aboulhassan *et al.,* 2006; Akoyl, 2012; Elamur et al., 2021). In the next section, we give a brief review of some general convectional wastewater treatment methods that also apply to the treatment of paint industry wastewater.

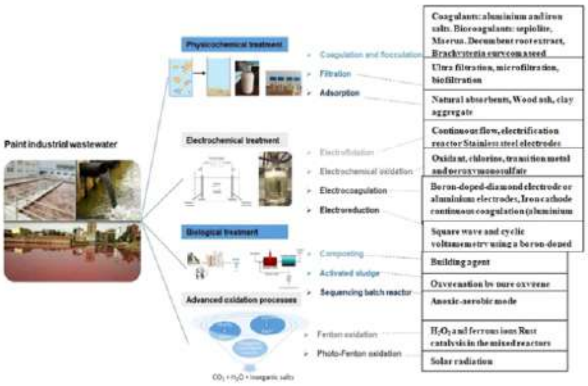

Figure 1: Conventional treatment methods of paint waste water (Nicolette et al 2022)

3.0 PHYSICOCHEMICAL TREATMENT PROCESSES

3.1 Sedimentation

Gravity is used in the physical process of sedimentation to clear suspended solids from water, which is a step in the treatment of wastewater. It is one of the fundamental first stages in the treatment of water. This treatment method involves the removal of entrained solids by the use of settling basins and clarifiers (AOS treatment solutions, 2018).

3.2 Flocculation and Coagulation

When chemical substances known as coagulants are added to waste effluents, particles form flocs and drop down by gravity through sedimentation by means of the physicochemical processes of coagulation and flocculation. Filtration is then used to separate the liquid waste from the entrained solid particle segregation; however, this method produces a lot of sludge.

3.3 Chemical Precipitation

The removal of the pollutants and the separation of the created products are accomplished through a chemical procedure. It reduces the chemical oxygen demand significantly and is effective at removing metals. However, this method has the disadvantage of not being able to remove the metals completely if the entrained metals are complex and in low concentration, except for an oxidation step. This method also produces high sludge (Gregoria et al., 2019).

3.4 Chemical Oxidation

It is a physicochemical method of treating effluent that separates waste materials using oxidants like trioxides, chlorides, peroxides, and permanganates. It is an excellent way to get rid of color and smell (ozone), sulfur, and cyanide. The oxidation method gives rise to increased product biodegradability, rapid throughput, the absence of sludge formation, and the potential for water recycling. However, the high expense associated with chemicals, the handling of oxidants, the creation of intermediates, and the release of volatile compounds and aromatic amines are some of the drawbacks of this method (Gregoria et al., 2019).In order to mitigate some of the disadvantages of the various convectional physiochemical treatment methods, an eco-friendly method of waste treatment that can effectively eliminate lethal chemicals and metals from generated waste needs to be developed. Research has shown that phytoremediation is a ready solution. Phytoremediation has been found to have great potential for the remediation of contaminated sites, especially aquatic environments.

A comparison of phytoremediation with other methods of treatment of paint wastewater is shown in Figure 1.

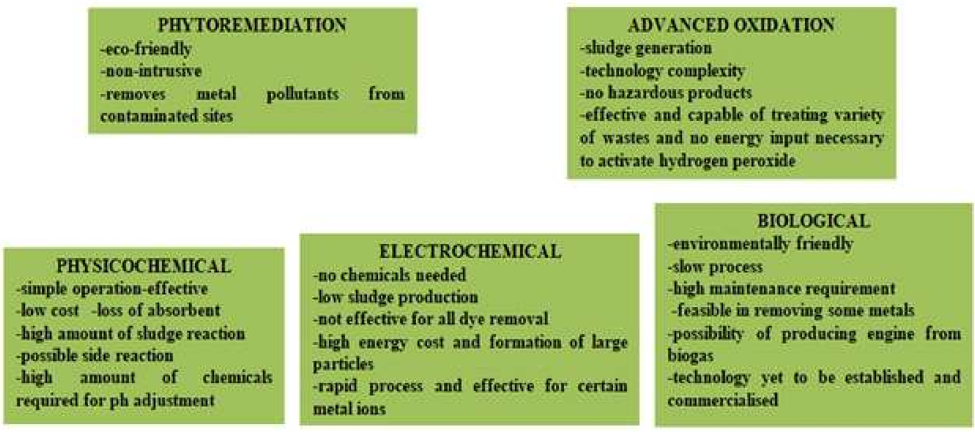

Figure 2: Comparison of phytoremediation with other treatment methods

4.0 PHYTOREMEDIATION

The use of metabolic processes by green plants to remove pollutants from the environment or make them harmless is known as phytoremediation (Poltorak, 2014; Naaem et al., 2021). Phytoremediation is a promising and efficient technique that removes pollutants from contaminated environments. Singh and Bauddh (2015); Kumar et al. (2013a). This technology has demonstrated success in the removal of pollutants from wastewater and soil, including heavy metals, radio-nuclides, nutrients (nitrate, phosphate, etc.), solvents, explosives, crude oil, and organic pollutants like pesticides, persistent organic pollutants (POPs), and polycyclic aromatic hydrocarbons (PAHs) (Kumar et al., 2013b; Arora, 2018b). From studies conducted, it is shown that many aquatic plants such as duckweed (Lemna minor), water hyacinth

(Eichhornia crassipes), hydrilla (hydrilla verticillata), water spinach (Ipomoea aquatica), water ferns (azolla caroliniana, azolla filiculoidea, and azolla pinnata), and water cabbage (Pistia stratiotes) can accumulate heavy metals. The roots of these plants naturally absorb heavy metals from water (Oporto et al., 2006; Neag et al., 2018; Ergen and Tunca, 2018; Marta et al., 2020). The use of different aquatic plants in the treatment of domestic and industrial wastewater has been investigated by several academics and researchers (Hauwa et al., 2020).

The ability of Spirodela polyrhiza, Salvinia molesta, and lemna sp. to remediate synthetic effluent was compared by Yin et al. in 2017. They evaluated the macrophytes in the water sample to see how well they could remove nutrients like nitrate, phosphate, ammonium nitrate, molecular oxygen demand, and pH. In their findings, it was recorded that the removal efficiency of ammonium nitrate by S. polyrhiza and lemna sp. was 60% and 41%, respectively, within 2 days. Their results also showed that S. polyrhiza was successful in reducing the nitrogen content of wastewater by 30%. The highest phosphate reduction of 86% was attained by lemna sp. within 12 days of the experiment. Despite producing less material than the other two macrophytes, S. polyrhiza was the most effective at removing nutrients.

Research on the phytoremediation of wastewater from emulsion paint using azolla pinnata, eichhornia crassipes, and lemna minor was conducted by Echiegu et al. in 2021. After six weeks of treatment, a physicochemical analysis of the wastewater revealed an 80% decrease in total dissolved solids but an increase in total suspended solids due to debris from withered test plants. Chemical oxygen demand was reduced by 51.7%, and dissolved oxygen was lowered to 50.0%. Heavy metals were reduced by 92.5% and the biochemical oxygen demand by 54.7. Of all the macrophytes, A. pinnata was the most productive.

Alocasia puber phytoremediation of nickel in a built wetlands (CW) microcosm was studied by Naaja et al. 2020. In the research, response surface methodology (RSM) with a central composite design (CCD) was used to determine the ideal conditions for nickel (Ni) removal from wastewater. Exposure time and initial Ni concentration were operational factors that were evaluated. In their research, a 10-day exposure period and an initial Ni concentration of 99.76 mg/L were found to be the ideal conditions for the maximum removal of Ni from water. According to their findings, 95.6% of the removal was accomplished under optimal circumstances, and there was a strong correlation (R^2 = 0.97) between the statistical model and the experimental data.

Pierre et al. 2020 studied the phytoremediation and post-treatment conditions of wastewater using Eichhornia crassipes and Pistia stratiotes. They used a kinetic model with a complete factorial design to identify the ideal circumstances for the removal of phosphates, nitrates, ammonium, and chemical oxygen demand in the target wastewater. These parameters' responses to operational variables like residence time, plant density, and initial PO_4^{3-} concentration were tracked. Global desirability of 0.96 and 0.97 for E. crassipes and P. stratiotes, respectively, were obtained from the statistical analyses used to validate the regression models for a residence time of 30 days, a plant density of 60 feet/m^2 and an initial PO_4^{3-} concentration of 10 mg/L. The removal efficiency was 94.2%, 93.3%, 95.0%, and 63.6% for phosphate, nitrate, ammonium, and chemical oxygen demand, respectively, for E. crassipes. The removal efficiency obtained for P. stratiotes was 93.9%, 83.4%, 99.5%, and 84.4% for phosphate, nitrate, ammonium, and chemical oxygen demand, respectively.

A study on the phytoremediation of effluent from the real coffee industry using a continuous, two-stage constructed wetland system was done by Nor et al., (2019). According to their research, phragmites karka and eichhornia crassipes were used in a continuous two-stage constructed wetland system to eliminate pollutants from an effluent from the coffee industry at a volumetric flowrate of 4.1 L/day for 3 days and 4 days, respectively. Their results indicate that 94%, 79%, and 95% removal efficiency of suspended solids, color, and COD, respectively, were attained.

Tamara et al., (2019) carried out optimization research on lemna valdiviana's phytoremediation of arsenic-contaminated water. In the research, the effect of pH, phosphate, and nitrate concentrations on lemna valdiviana's ability to absorb arsenic from contaminated water was assessed. A central composite rotational design (CCRD) model with three variables, six axial points, and six rotations in the central point comprising twenty trials was used. The data were analyzed using the response surface technique. Their results show that 1190 mg/kg arsenic accumulation was obtained with a pH range of 6.3–7.0. Concentrations of phosphate and nitrate of 0.0488 mm/mol and 7.9 mm/mol, respectively, were also reported.

Theeta et al. (2017) studied the possibility of two aquatic plants, typha angustifolia and eichhornia crassipes, being applied as biomass fuel in the synergistic phytoremediation of wastewater. In their research, these plants were used for 21 days to remediate wastewater from a Thailand fresh market (Nong Ping market). To determine the degree of remediation, the physicochemical characteristics of the effluent were assessed both before and after treatment. In their findings, they reported a significant decrease in turbidity after 7 days and a 91% reduction in metabolic oxygen demand after 21 days. Zinc, cadmium, and lead buildup were detected in the plant's roots and branches.

In another study, Ng et al. (2017) investigated *S. molesta's* effectiveness in the treatment of Raceway Pond's wastewater. After the plant was grown for 16 days, the wastewater underwent physiochemical analysis, which revealed an improvement in the water quality, with 95% of the phosphorus being removed, bringing the level down to as low as 0.17 mg/l, while nitrate and ammonia were reduced to 0.50 mg/l and 2.62 mg/l, respectively. Turbidity was reduced to 0.94 NTU, and a 39% efficiency for chemical oxygen consumption was reported.

Ahila et al. (2021) studied the ability of freshwater macrophytes to remediate wastewater containing dye through phytoremediation. They evaluated the capacity of aquatic plants (*Pistia stratiotes L., Salvinia adnata Desv., and Hydrilla verticillata (L. f.) Royle*) to remove pollutants such as color, total dissolved solids, chemical oxygen demand, and chloride from dyestuff industrial effluent. Stratiotes L was found to be very effective as it eliminated 86%, 66%, 77%, and 61.33% of these pollutants.

Sharma et al. (2021) studied the integration of phytoremediation into the treatment of pulp and paper industry wastewater. Field observations of native plants for the detoxification of metals and their promise as part of a multidisciplinary approach were published. In their investigation, they used native herbs for the removal of heavy metals from wastewater from the pulp and paper sector. The results of the study show the possibility of reducing the concentration of heavy metals and metalloids by 60% using local herbs to treat pulp and paper industry wastewater. A significant bio-concentration factor was also seen for all heavy metals other than cadmium. The findings indicated that most of the native plants considered in the research had a tendency towards hyperaccumulation.

In another study, Singh et al. (2021) examined the efficacy of water lettuce (*Pistia stratiotes L.*) in removing pollutants from paper mill wastewater (PME). In the study, they used different percentages of bore well water (0%, 25%, 50%, 75%, and 100%) to cure PME in the laboratory. According to the findings, total dissolved solids (TDS) were effectively reduced by 71.20%, biological oxygen demand (BOD) was reduced by 85.03%, and chemical oxygen demand (COD) was reduced by 71.20%, total Kjeldahl's nitrogen (TKN) by 93.03%, and phosphorus by 85.56%.

Abbas et al. (2021) conducted research on the phytoremediation potential of Typha latifolia and water hyacinth for the removal of heavy metals from industrial wastewater. After a 16-day experimental period, they recorded a reduction efficiency of 90.03% for turbidity, 82.31% for conductivity, 95.98% for iron, 87.78% for copper, and 75.81% for zinc, respectively. They, therefore, concluded that Typha latifolia was very effective in the removal of certain heavy metals in the following order: Fe > Cu > Zn from most industrial wastewater. According to them, water hyacinth was the more effective of the two plants, as it removed 64.15% turbidity and 62.19% conductivity from the target wastewater.

Pollutant removal efficieny by plants during phytoremediation is influenced by the exposure time, concentration of the pollutants, environmental conditions (pH, temperature), and characteristics of the plants (species, root system, etc.) (Anand S. et al., 2017). Through their roots, stems, and foliage, plants can take in heavy metals, storing them in their organs. The effectiveness of heavy metal remediation can be increased by understanding the various elements that influence the uptake mechanisms of heavy metals, such as plant species, the addition of chelating agents, and physical and climatic circumstances.

4.1 Factors affecting Phytoremediation

The factors influencing the uptake mechanisms of pollutants by plants, thereby enhancing their removal efficiency, are divided into two categories: biotic and abiotic.

4.1.1 Biotic factors

Biotic factors as defined by Saxena et al. (2017) are a living organism that shapes its environment. For plants used for phytoremediation, plant species and plant organs are two important biotic factors that determine the effectiveness of the process.

4.1.1.1 Plant species

Phytoremediation techniques depend upon the species that can accumulate heavy metals and produce more biomass using established crop production and management practices (Anand et al., 2019; Rodriguez et al., 2005). Due to their roots' capacity to adsorb and transport these substances within plant cells, some plants can absorb heavy metals from soil or water. An example of plant species that are effective in reducing heavy metals in industrial wastewater is the water hyacinth (*Eichhormia crappisses*). This plant lowers the concentration of pollutants by storing metals like Cd, Cr, Ni, and Fe, as well as Cu and Zn, in its root system.

4.1.1.2 Plant organs

Plant organs like the roots can absorb pollutants into the cell wall, preventing them from moving to other parts of the plant (Anand et al., 2019; Merkl et al.,). Heavy metals such as zinc and cadmium are stored in the roots and stems of the plants, while copper is found more in the leaves (Rezania et al.).

4.1.2 Abiotic factors

Abiotic factors are those factors that are physical in nature that may contribute to or impede the effectiveness of plants used in phytoremediation. Some of these factors are:

4.1.2.1 Temperature

An important factor affecting the plant's transpiration, growth metabolism, and capacity to access heavy metals is temperature (Burken et al., 1996; Bhargava et al., 2012; Chen et al., 2015). From the research conducted by Sanyahumbi et al. (1998) and Anand et al. (2019), it was observed that the removal efficiency of lead averages about 90% at a temperature range of between 10 °C and 50 °C. Thus, efficiency of removal increases with an increase in temperature. However, the structure, plant length, and root, as well as the greenhouse conditions, are different (Yu et al., 2011; Merkletal, 2005).

4.1.2.2 pH

The initial concentration of lead changes from 30% to 95% depending on the pH value, which ranges from 1.5 to 4.5. According to research on the effect of salinity on the uptake of heavy metals, metal removal efficiency rose with both a decrease in salinity and a rise in temperature (Fritioff et al., 2005; Anand et al., 2019).

4.1.2.3 Chelating agents

Chelating agents are frequently used to improve the bioavailability of heavy metals, enhancing their uptake by plants (Tangahu et al., 2011; Anand et al., 2019). A powerful chelating agent with a high potential for complex formation, ethylene diamine tetra-acetic acid (EDTA), has been extensively utilized (Yen et al., 2012; Anand et al., 2019). This chelating agent has proved to be very effective in many applications, such as the paper, pulp, and textile industries, as well as removing heavy metals from chlorine-free bleaching solutions that could inactivate the peroxides and phosphonates. Phosphonic acids had also been found to be an effective chelating agent (Gledhill et al., 1992; Anand et al., 2019).

4.2 Mechanism of Phytoremediation

Plants exhibit avoidance and tolerance mechanisms in the reduction of heavy metal toxins (Jutsz et al., 2015; Yan et al., 2020; Monika et al., 2021). As an avoidance mechanism, plants limit heavy metal uptake and entry into the root tissues as a first line of defense (Dalvi et al., 2013; Monika et al., 2021). This is done by:

(i) Modifying the cell wall through the deposition of callose, suberin, or lignin (Miransari, 2011; Monika et al., 2021).

(ii) metal accumulation within cell walls (Oves et al., 2016; Monika et al., 2021).

(iii) The secretion of an ion-binding root extracellular matrix, which stabilizes heavy metals in the rhizosphere and restricts their uptake (Meier et al., 2012; Monika et al., 2021).

(iv) Leaf glands' removal of extra metals (Miransari, 2011, Monika et al., 2021).

4.2.1 Phytostabilization

Phytostabilization is a process whereby plants immobilize metals in the substrate or in the rhizosphere, thereby preventing their leaching into groundwater. Microorganisms from the rhizosphere are also involved, which cooperate with plants, thus improving phytostabilization (Jutsz et al., 2015; Yan et al., 2020; Monika et al., 2021).

4.2.2 Phytoextraction

Phytoextraction is a process whereby plants extract metals into the roots or underground organs, then translocate and accumulate them in above-ground tissues.

4.2.3 Phyto-Volatilization

Phyto volatilization is a process whereby assimilated contaminants are evaporated through the leaves of the plant (Jutsz et al., 2015; Yan et al., 2020; Monika et al., 2021).

4.2.4 Phytofiltration

Phytofiltration is a process whereby plant organs such as plant roots (rhizofiltration), shoots (caulofiltration), and seeding (blastofiltration) are used for the remediation of contaminated waters.

Table 2 Summary of mechanism of phytoremediation (Alietal.2013; Chandraetal.2015; Chirakkaraetal.2016; Sarwaretal.22017; Guarav et al., 2017)

Phytoremediation processes	Mechanism	Pollutants	Applicability	Benefits	Comments/issues
Phyto extraction / phyto sequestration	Hyper accumulation	Pb, Cd, Zn, Ni, Cu,	Contaminated soil/sites, water, waste waters.	Abundant biomass in short time, reduced soil erosion and cost- effective, wide application.	Slow process; contaminant concentration is important, and it depends on the depth of contamination, the risk of metal leaching, and thus ground- water pollution; require post-harvest treatment for contaminated biomass volume reduction, metal recovery (i.e., phytomining), and bioenergy production.
Phytofiltration or rhizofiltration	Rhizosphere accumulation	Pb, Cd, Zn, Ni, Cu, radionuclides (Cs, Sr, U)	Contaminated water and waste waters.	Cleanup of polluted surface water, industrial waste-waters, and agri-cultural run off.	Plant roots act as filters for clean up of polluted water/ waste waters; less generation of sec-ondary waste and minimize the need of further disposal, if terrestrial plants are used due to high biomass as compared to aquatic plants (highly species specific); long- term maintenance depends on the type of contaminant and contamination depth.
Phyto stabilization or Phyto immobilization or Phyto transformation	Precipitation, com-plexation, and metal valence reduction.	Pb, Cd, Zn, As, Cu, Cr, Se, U, polycy-clic aromatic hydro-carbons (PAHs), polychlorinated biphenyl (PCBs), dioxins, furans, pentachlorophenol, DDT, dieldrin		Ecologically effi-cient, stabilization of contaminated medium without disposal of contaminated biomass, reduces soil erosion, applicable in the field and mine polluted areas.	Not a permanent solution because plants only limit mobility/bioavail-ability of metal pollutants at the place, and hence the site cannot be used for plant growth
Phytovolatilization or phytoevaporation	Volatilization or evaporation by leaves	Chlorinated solvents like carbon tetrachloride, trichloroethylene, methylene chloride, tetrachloroethylene, carbontetrachloride,	Contaminated waste waters, soil, sediments, and sludges.	Environmental cleanup without harvesting plants and biomass disposal.	Suitable for Hg2+ removal; limited in case of Se, elemental Hg, and As due to their gaseous forms; most controversial because there may be a chance

		1,1,1-trichloroethane, Hg(mercuric ion), Se			of staying toxic metals in air and thus no control over migration (air pollution); redeposition of pollutant back into the ecosystem by precipitation (elemental Hg)
Phytodegradation	Degradation in plant tissues	DDT, PAHs, bisphenol A, organophosphorus compounds	Contaminated soil, sediments, sludges, ground-water, surface water, and waste waters.	Biodegradation of various recalcitrant pollutants in the rhizosphere.	Key enzymes for degradation are nitroreductase, dehalogenase, oxygenase, peroxidase, nitrilase, nitroreductase, and laccase; depends on factors such as concentration and composition, plant species, and soil conditions
Rhizodegradation or rhizoremediation or phytostimulation	Degradation in rhizosphere	Atrazine, ammunition wastes, petroleum hydrocarbon, PCBs, PAHs, TCE, diesel fuel	Contaminated soil, sediments, sludges, ground-water, and waste waters	Release of organic acid; rhizosphere enhances biodegradation; metabolic products are further utilized by micro organisms' in rhizosphere	Depends on the action of root exudates and enzymes; increased activity of rhizosphere microbes

4.3 Aquatic Plants

Aquatic plants are a variety of photosynthetic organisms found in water areas that, according to reports, originated in South America and spread to other continents through ballast water in ships. (Cordoetal, 1981; Ogaga et al., 2022). These plants are divided into different groups, such as floating, emergent, submerged, marginal, filamentous, and planktonic algae.

4.3.1 Floating aquatic plants

These are aquatic plants that are not rooted to the waterbed's floor but instead have floating vegetative parts. Examples include duck weed (*Lemna spp.*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotoies*) (Ogaga et al., 2022).

4.3.2 Emergent aquatic plants

These are aquatic plants that have deep roots in the water and have leaves and other vegetative sections that protrude above the surface. Examples include eleocharis, eleocharis planta species, scirpus mucronatus, typha latifolia, phragmite saustralis, sagittaria trifolia, water lily (Nymphaea spp.), and alternan theraphiloxeroides (Anand et al., 2019; Ogaga et al., 2021).

4.3.3 Submerged aquatic plants

These aquatic plants grow below the water's surface with their leaves and roots fully submerged. Examples include hydrilla verticillata, ceratophyllum demersum, and C. submersum; myriophyllum aquaticum; elodea canadensis; vallisneria americana; utricularia vulgaris; and najasgraminea (Anand et al., 2019; Ogaga et al., 2021).

4.4 Efficiency of selected plants in phytoremediation

4.4.1 Eichhornia crassipes

Water hyacinth, also known as Eichhornia crassipes, is an aquatic plant that grows quickly and can double its size within a short interval**.** It is among the class of invasive aquatic plants found in waterways (Dhote et al., 2009; Anand et al., 2019). Numerous studies have demonstrated the effectiveness of water hyacinth in the elimination of a wide range of heavy metals from aqueous solutions, including Fe, Zn, Cu, Cr, Mn, Hg, Cd, and As (Jadia et al., 2009; Mohammed et al., 2010; Priya et al., 2014; Rezania et al., 2015; Anand et al., 2019). Metals are initially stored in the bladders of water hyacinths before moving to the stalks, leaves, and roots of the plant (Rizwana et al., 2014; Anand et al., 2019). In addition to determining the amount of Cd and Zn absorbed in various areas of the water hyacinth, Mokhtar et al. (2011) and Anand et al. (2019) used E. crassipes through the leaves, roots, stems, and flowers to remove Cd and Zn from water.

4.4.2 Lemna

Lemna, also known as duckweed, is an aquatic plant that floats freely on the surface of water. It is globally dispersed in lakes, ponds, wetlands, and some effluent lagoons; it is fast-growing and adaptable to a variety of aquatic environments; and it has been employed to reclaim heavy metals for over 3 decades (Anand et al., 2019). The species of Lemna include *L. genus, L. minor, and L. gibba*, which have been used in a wide range of studies (Guimaraes et al., 2012; Anand et al., 2019). Duckweed (Lemna sp.) has the ability to eliminate toxic heavy metals from water. Up to 90% of soluble lead can be removed from water by *L. minor* (Singh et al., 2011a, b). According to Sasmaz et al. (2009) and Anand et al. (2019), the aquatic plant L. gibba is an alternative treatment plant for the removal of secondary effluents. They used this plant to accumulate As, B, and U. Their findings show that during the first three days of the experimental research, As was rapidly assimilated by L. gibba.

4.4.3 Salvinia

Salvinia is a member of the Salviniaceae family, which is a free-floating aquatic plant. It is broadly dispersed, fast-growing, and closely related to Lemna and Azolla. Other species in the Salvinia genus include *S. herzogii*, *S. minima*, *and S. natans*, which demonstrate the ability to eliminate different pollutants, including metals, from efffluents (Nicholsetal. 2000; Olguinetal. 2005; Suneetal. 2007; Sanchez-Galvanetal. 2008; Xuetal. 2009; Anand et al., 2019). The ability of *S.*minima to eliminate Ni, Cu, and As from wastewater has been well established (Mukherjee and Kumar, 2005; Rahman et al., 2009; Anand et al., 2019). Further studies conducted by Fuentesetal (2014) and Anand et al. (2019) demonstrated that S. minima can hyperaccumulate nickel, despite the possibility that the plant's physiological function may be impacted by higher concentrations.

4.4.4 *Pistia stratiotes*

Pistia, also known as water lettuce, is a species of aquatic macrophyte belonging to the Araceae family. It floats on the water's surface with its roots dangling below the foliage. These plants are naturally occurring hyperaccumulators of numerous harmful heavy metals (Anand et al., 2019). According to reports by Odjegba et al. (2004), pistia may be a good option for the elimination of Zn, Cr, Cu, Cd, Pb, and Hg. Its accumulation potential for Zn and Cd is very high, while that for Hg is only moderate and not effective for Ni (Guimaraes et al. 2012). Miretzky et al. (2004) reported that the removal rate by Pistia stratiotes was extremely high (>85% for Pb, Cr, Mn, and Zn). They added that within the first 24 hours of exposure, the metals can be almost eliminated. Phytoremediation of industrial wastewater can be achieved by using appropriate plants (aquatic, terrestrial, and marsh) in special installations called constructed wetlands (CW).

5.0 CONSTRUCTED WETLAND (CW)

Constructed wetland is a green treatment technology that is used in phytoremediation to mimic natural wetland processes (Haiming et al., 2014). CWs are mainly used for treating municipal, industrial, storm, and agricultural waters, landfill leachate, and mine drainage wastewater, thus facilitating the recovery of both organic and inorganic compounds (Kadlec et al., 2000; Stefanakis et al., 2014; Fitch et al., 2014; Monika et al., 2021). Constructed wetlands are frequently used for the pollutant recovery of wastewater from various sources, and the effectiveness of their recovery of heavy metals relies critically on the variations in heavy metals and other pollutant uptake and translocation among plants used for phytoremediation. Since the environment produced in the CWs significantly influences pollutant removal efficiencies, it is challenging to quantify plant performance. The wetland bed depth has a direct and substantial impact on heavy metal removal efficiencies in vertical flow CWs, as demonstrated by Yadav et al. in their study. When the gravel bed depth of CWs was raised from 0.3 to 1.5 m, the removal of Cr, Ni, Cu, Zn, and Co increased by 16.6%, 22.9%, 20.4%, 21.5%, and 21.8%, respectively. Additionally, the early concentration of heavy metals and the presence of different microorganisms both have an impact on plant performance (Calheiros et al., 2019). The CWs' structure has a significant impact on how effectively plants absorb pollutants. According to Sandoval et al.'s (2019) synthesis, which could be applied to the creation of novel CWs, "there is no obvious pattern in the use of a specific plant species for a certain type of wastewater," making it challenging to link plants to a given pollutant uptake. Thus, phytoremediation is more effective than chemical and physical methods in combating Zn, Cu, and other metal contamination sources. Additionally, it provides new methods for recovering metal, producing valuable organic molecules, and producing novel, high-value raw materials. Phytoremediation is a reliable tool for contaminant (i.e., excess nutrients, heavy metals, radionuclides, etc.) removal from wastewater to prevent eutrophication of receiving water bodies and for preventing adverse health effects on aquatic biota and higher consumers in the food chain (Landesman et al. 2011).

6.0 CONCLUSION

This paper highlights the polluting and toxic effects of heavy metal contaminants in paint wastewater. Also the setback of the conventional methods employed in the treatment of wastewater before discharge into the environment. Coagulation, amongst other convectional treatment methods for paint wastewater, is a simple and useful method for the elimination of suspended particles. However, the heavy metals present in paint industry effluents can precipitate in their toxic form; therefore, high amounts of sludge can be produced, which cannot be eliminated by filtration. A review of the mechanisms and techniques of a more efficient and eco-friendly technology for the containment of pollutants has been presented in this paper. Phytoremediation is an emerging technology employed to remove various pollutants from polluted water. The application of aquatic plants in phytoremediation of wastewater improves the quality of wastewater before discharge into natural bodies. Four aquatic plants, Eichhornia crassipies, Salvinia molesta, Lemna, and Pistia stratiotes, have been highlighted as massively used for the treatment of agricultural, domestic, and industrial wastewater. The massive application of these plants is due to their availability, resilience in a toxic environment, bioaccumulation potentials, invasive mechanisms, and biomass potentials. Despite the promising potential exhibited by these plants, their full potential has yet to be explored. There is a need for further study of the plant in the remediation of radioactive, nanoparticle, and pharmaceutical wastewater.

REFERENCES

Aboulhassan, M.A., Souabi, S., Yaacoubi, A.&Baudu, M. (2006). Improvement of Paint Effluents Coagulation Using Natural land Synthetic Coagulant Aids. *Journal of Hazardous Material*, 138(1), 40–45.
Akyol,A. (2012). Treatment of Paint Manufacturing Wastewater by Electrocoagulation.*Desalination*.285,91–99.
Ali, H., Khan, E. & Sajad, M.A. (2013). Phytoremediation of heavy metals concept.
Allenby, Braden, R., & Richards, D. (2001). The Greening of Industrial Ecosystems. *Washington Journal of eds*.
Anand, S., Bharti, S.Dviwedi, N. & Barman, S.K.N. (2019). Macrophytes for the reclamation of degraded waterbodies with potential for bioenergy production.*Springer Singapore*, 333–351.
Anand, S., Bharti, S.K., Kumar, S. Barman, S.C. & Kumar, N. (2019) Phytoremediation of Heavy Metals and Pesticides Present in Water Using Aquatic Macrophytes Springer Nature Singapore Pte Ltd. 89 N. K. Arora, N. Kumar (eds.), Phyto and Rhizo Remediation, Microorganisms for Sustainability 9.
AOS Treatment solutions, (2018). What is sedimentation, 936, 228-653.
APHA, AWWA & WEF (American Public Health Association, American Water Works Association and Water Environment Federation) (2005). Standard methods for examination of water and wastewater. American Public Health Association, Washington, DC
Aruliah, R., Selvi, A., Theertagiri, J., Ananthaselvam, A., Kumar, K.S., Madhavan, J. & Rahman, P. (2019). Integrated remediation processes towards heavy metal removal/recovery from various environments-a review. *Journal of Frontiers Environmental Science*, 7, 66.
Bal,K., Unlu,K.C. Acar,I. Guclu,G. (2017). Epoxy-based Paints from Glycolysis Products of Postconsumer PET Bottles: Synthesis,Wet Paint Properties and Film Properties. *Journal of Coating Technology.* 14(3),
Calheiros,C.S.C., Pereira,S.I.A., Franco,A.R.&Castro,P.M.L. (2019).Diverse Arbuscular Mycorrhizal Fungi (AMF) Communities Colonize

Plants Inhabiting a Constructed Wetland for Wastewater Treatment.Water, *11*,1535.
C h a n d r a R , S a x e n a G . & K u m a r V (2 0 1 5) P h y t o r e m e d i a t i o n o f e n v i r o n m e n t a l p o l l u t a n t s : a n e c o - sustainablegreentechnologytoenvironmentalmanagement.*In:ChandraR(ed)Advancesin biodegradation and bioremediation of industrial waste. CRC Press, Boca Raton,* 1–30.
C h i r a k k a r a , R . A . , C a m e s e l l e , C . & R e d d y , K . R . (2 0 1 6) A s s e s s i n g t h e a p p l i c a b i l i t y o f p h y t o r e m e d i a t i o n O f soilswithmixedorganicandheavymetalcontaminants.*ReviewEnvironmentalScienceBiotechnology,*15, 299–326.
Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F. Seitzinger, S.P., Havens, K.E., Lancelot, C.& Likens G.E (2009), Controlling Eutrophication: *Nitrogen and Phosphorus, Science*, 323, 1014-1015.
Dalvi, A.A.& Bhalerao, S.A. (2013). Response of plants towards heavy metal toxicity: An overview of avoidance,tolerance, and uptake mechanism. *Annual Plant Sci*. 2, 362–368.
Dhote, S. & Dixit, S. (2009).Water quality improvement through macrophytes – a review. *Environmental Monitoring Assessment,* 152, 149–153.
E.P-S.,(2005). Phytoremediation.*Annual Review of Plant Biology*, 56, 15-39.
Elamur, A., Fatih, I.& Ahmet, A., (2021). Different methods applied to remove pollutants from real epoxy paint wastewater: modelling using the response surface method, *Journal of Separation science and technology*.
Ergen, S.F.& Tunca, E.Ü. (2018). Nanotoxicity modelling and removal efficiencies of ZnONP 741 with consortium. *International Journal of Phytoremediation*, 20, 16-26.
Fatima, M., Usmani, N., Hossain, M.M., Siddiqui, M.F., Zafeer, M.F., Fidaus, F.& Ahmad, S. (2014). Assessment of genotoxic induction and deterioration of fish quality in commercial species due to heavy metal exposure in an urban reservoir. *Archive Environmental Contamination. Toxicology*, 67(2), 203 – 213.
Fitch, M.W. (2014).Constructed Wetlands Comprising Water Quality Purification,*3*,268–295.
Fuentes, I.I., Espadas- Gil, F., Talavera-May,C., Fuentes, G. & Santamaría, J.M. (2014). Capacity of the aquatic fern (*Salviniaminima*Baker) to accumulate high concentrations of nickel in its tissues, and its effect on plant physiological processes. *Aquatic Toxicology* 155, 142–150.
Gaurav, S., Diane, P., Sikandar, I., Mulla, G., Dattatraya, S.& Ram, N.B. (2017). Phytoremediation of Heavy Metal-Contaminated Sites: Eco-environmental Concerns, Field Studies, Sustainability Issues, and Future Prospects, *Journal of Impact Factor*
Gregoria, C.& Eric, L. (2019). Advantages and disadvantages of techniques used for wastewater treatment.*J. Environmental chemistry*, 17, 145–155.
Guimaraes,F.P., Aguiar, R., Oliveira,J.A.,Silva,J.A.A.&Karam, D. (2012). Potential of macrophyte forremoving arsenic from aqueous solution. *Planta Daninha*, 30, 683–696.
Hauwa, M.M.& Gasim, H.(2020). Recent studies on application of aquatic weed plants in phytoremediation of wastewater; A review article.*Journal of Ain shams engineering,* 2090 – 4479.
Jadia, C.D.&Fulekar, M.H. (2009).Review on phytoremediation of heavy metals recent techniques. African. *Journal of Biotechnology*, 8(6), 921–927.
Jaishree, K.T.I. (2015). Assessment of heavy metals' risk on human health via dietary intake of cereals and vegetables from effluent irrigated land Jaipur District, Rajasthan. *International Journal 0f Innovative Resource Science Engineering Technology,* 4(7), 5142–5148.
Javed, M., Ahmad, L., Usmani, N.& Ahmad. M., (2016). Bio – accumulation, oxidative stress, and genotoxicity in fish (Channapunctatus) exposed to a thermal power plant effluent. *Journal of Ecotoxicological Environronmental. Safety,* 127, 163 – 169.
Joshua, O., Babayemi, M.B.&Ogundiran,L.O. (2017). Overview of Environmental Hazards and Health Effects of Pollution in Developing Countries: A Case Study of Nigeria, *Journal of Environmental Quality Management* Wiley Periodicals, Inc. Published online in Wiley Online Library (wileyonlinelibrary.com)
Jutsz, A.M.&Gnida,A. (2015). Mechanisms of stress avoidance and tolerance by plants used in phytoremediation of heavy metals.*Archive of Environmental Protection*.41, 104–114.
Kadlec, R.H., Knight, R.L., Vymazal, J., Brix, H.,Cooper, P. &Haber, l.R. (2000).*Constructed Wetlands for Pollution Control: Processes, Performance,* Design and Operation; Scientific and Technical Report; IWA Publishing: London, UK, (8), 1–15.
Kakoi, B., Kaluli, J.W., Ndiba, P. &Thiong, G. (2017). Optimization of Maerua Decumbent Bio – Coagulantin in Paint Industry Wastewater Treatment with Response Surface Methodology.
Korbahti, B.K., Aktas,N.&Tanyolac,A. (2007).Optimization of Electrochemical Treatment of Industrial Paint Wastewater with Response Surface Methodology.*Journal of Hazardous Material*. 148(1–2), 83–90.
Lenntech Water treatment and air purification (2004) Water Treatment. Lenntech, Rotterdamseweg.
Marta, J., Anna, G. & Franck, V. (2020). Modelling assisted phytoremediation of soils contaminated with heavy metals – 2 main opportunities, limitations, decision making and prospects, Elseveir publication.
Meier,S., Alvear,M., Borie,F. Aguilera,P., Ginocchio,R.&Cornejo,P. (2012). Influence of copper on root exudate patterns in some metallophytes and agricultural plants. *Ecotoxicology Environmental Safety*, 75,8–15.
Miransari, M. (2011). Hyperaccumulators arbuscular mycorrhizal fungi and stress of heavy metals.*Biotechnology Advancement*,29, 645–653.
Miretzky, P.,Saralegui, A. & Cirelli, A.F. (2004). Aquatic macrophytes potential or the simultaneousremoval of heavy metals (Buenos Aires, Argentina).*Chemosphere*57, 997–1005.
Mishra, J., Singh, R. & Arora, N.K. (2017). Alleviation of heavy metal stress in plants and remediation of soil by rhizosphere microorganisms. *Front Microbiol*. https://doi.org/10.3389/ fmicb.2017.01706.
Mohamad, H.H. & Latif, P.A. (2010).Uptake of cadmium and zinc from synthetic effluent by water hyacinth (Eichhorniacrassipes). *Environ Asia*, 36–42
Mojiri, A., Aziz, H.A., Zahed, M., Aziz, S.Q.& Selamat, M.R.B. (2013). Phytoremediation of Heavy Metals from Urban Waste Leachate by Southern Cattail (Typhadomingensis). *Int. J. Sci. Res. Environ. Sci*. 1, 63–70.
Mokhtar, H., Morad, N.& Ahmad, F.F. (2011).Phytoaccumulation of copper from aqueous solutions using *Eichhornia crassipes* and *Centellaasiatica. Int J EnvironSciDev,* 2(3), 46–52.
Monika, H., Elisabetta, O., Alessandra, M., Maurizio, B., Cinzia, C., Nadia, S. &Luciana,R. (2021). Heavy-Metal Phytoremediation from Livestock Wastewater and Exploitation ofExhausted Biomass, *International. Journalof Environmental research and public health*.
Mukherjee, S. &Kumar, S. (2005).Adsorptive uptake of arsenic (V) from water by aquatic fern Salvinianatans. *Journal of Water Supply Resource Technology,* 54, 47–52
Mustapha, H.I., Van Bruggen, J.J.A.& Lens, P.N.L. (2018). Fate of heavy metals in vertical subsurface flow constructed wetlands treating secondary treated petroleum refinery wastewater in Kaduna, Nigeria. Treatment. Petroleum. Refining. *Wastewater Constructed. Wetland*. 20,

147–172.
Naeem, A.Muhammad, T.B., Muhammad, M.A., Farah, D.&Naqi, H. (2021). Phytoremediation potential of Typha latifolia and water hyacinth for removal of heavy metals from industrial wastewater International. *Journal of. Chemistry*,7(2), 103-111.
Najaa, S.M.T., Rozidaini, M.G.Ikarastika, R., AbdulWahab, M.F., Mohd Amin, Z.H.&NikRaihan, N.Y. (2020). Optimization of Phytoremediation of Nickel by Alocasiapuber Using Response Surface Methodology.
Namasivayam, C. & Ranganathan, K. (1995). Removal of Pb (II), Cd (II) and Ni(II) and mixture of metal ions by adsorption onto waste Fe(III)/Cr(III) hydroxide and fixed bed studies. *Journal of Environmental Technology* 16, 851–860.
Nasir, N.M., Abu Bakar, N.S., Lananan, F., Abdul Hamid, S.H., Lam, S.S. & Jusoh, A. (2015). Treatment of African catfish, Clariasgariepinus wastewater utilizing phytoremediation of microalgae, Chlorella sp. with Aspergillusniger bio-harvesting. *BioresourTechnol,* 190, 492–498.
Neag, E., Malschi, D.&Maicaneanu, A. (2018). Isotherm and kinetic modelling of Toluidine Blue (TB) removal from aqueous solution using Lemna minor. International. *Journal of. Phytoremediation,* 20, 1049 - 1054.
Nichols, P.B., Couch, J.D. & Al-Hamdani, S.H. (2000). Selected physiological responses of *Salvinia min-ima*todifferent chromium concentrations. *Aquatic Bot,* 68, 313–319.
Nicolette, V., Agneša, S.&Svetlana, H. (2022). Recent Developments and Emerging Trends in Paint Industry Waste Water Treatment Methods.*Journal of. Analytical Chemistry*.
Ntakiyiruta, P., Briton, B.G.H., Nsavyimana, G., Adouby, K., Nahimana, D., Ntakimazi, G. &Reinert, L. (2020), Optimization of the phytoremediation conditions of wastewater in post-treatment by *Eichhornia crassipes* and *Pistia stratiotes*: kinetic model for pollutants removal, *Journal of Environmental Technology*.
Odjegba,V.J.&Fasidi,I.O. (2004). Accumulation of trace elements by Pistiastratiotes: implications forphytoremediation.*Ecotoxicology*, 13, 637–646.
Ogaga, A.&Aghoghovwia, B.O. (2022).Occlusion of the Niger Delta Rivers and creeks by aquatic weeds: Impact on humans and fisheries.*International Journal of Fauna and biological studies,* 9, 25-29.
Olguin, E.J.,Sanchez-Galvan, G., Perez-Perez, T. &Perez-Orozco, A. (2005).Surface adsorption, intra-cellular accumulation and compartmentalization of Pb (II) in batch-operated lagoons with Salvinia minima as affected by environmental conditions, EDTA and nutrients. *Journal of Industrial Microbiology Biotechnology,* 32, 577–586.
Oporto, C., Arce, O., Van den Broeck, E., Van der Bruggen, B.& Vandecasteele, C. (2006). Experimental study and modelling of Cr (VI) removal from wastewater using Lemna minor. *Journal of Water Resources*, 40, 1458-1464.
Oves, M.,SaghirKhan, M.,HudaQari, A.,NadeenFelemban,M.,Almeelbi,T. (2016). Heavy metals: Biological importance and detoxification strategies.*Journal of Bioremediation and .Biodegradiation,* 7,334
Poltorak, M.R., (2015). Field and green house studies of phytoremediation with California native plants for soil contaminated with petroleum hydrocarbons, PAHs, PCBs, chlorinated dioxins /furans, and heavy metals. Thesis, the Faculty of California Polytechnic State University, San Luis Obispo.
Priya, E.S. &Selvan,P.S. (2014).Water hyacinth (*Eichhornia crassipes*)–an efficient and economic adsorbent for textile effluent treatment–a review. *Arab Journal of Chemistry*.
Rahman, A., Bhatti, N.H. &Habib-ur-Rahman,A.(2009), Textile effluents affected seed germination and early growth of some winter vegetable crops: a case study.*Water Air Soil Pollution:* 155–163.
Rezania, S., Ponraj, M.,Talaiekhozani, A., Mohamad, S.E., Din, M.F.M. &Taib,S.M. (2015).Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganicpollutants in wastewater.*Journal Environmental Management* 163, 125–133.
Rizwana,M.,Darshan, M. & Nilesh, D. (2014).Phytoremediation of textile wastewater using potential wetland plant: Eco sustainable approach. *International Journal of Interdisciplinary /Multidisciplinary Studies,* 4, 130–138.
Ryzhenko, N.O.,Kavetsky, S.V. &Kavetsky, V.M. (2017). Cd, Zn, Cu, Pb, Co, Ni phytotoxicity assessment. *Pollution Journal of Soil Science,* 50 (2).
Sanchez-Galvan, G.,Monroy, O., Gómez, G. & Olguín, E.J. (2008). Assessment of the hyper accumulating lead capacity of *Salvinia minima* using bio adsorption and intracellular accumulation factors.*Water, Air and Soil Pollution*, 77–90.
Sandoval,L., Zamora-Castro, S.A., Vidal-Álvarez,M., Marín-Muñiz, J.L. (2019). Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review.*Appl.Sci.*,9,685.
Sarwar,N.,Imran,M.,Shaheen,M.R.,Ishaq,W.,Kamran,A.,Matloob,A.,Rehim,A.,Hussain,S.(2017). Phytoremediationstrategiesforsoilscontaminatedwithheavymetals:modificationsandfutureperspectives.Chemosphere171:710–721
Sasmaz, A. &Obek, E. (2009) The accumulation of arsenic, uranium, and boron in *Lemna gibba*L. exposed to secondary effluents. *Ecological Engineering,* 35, 1564–1567.
Singh, R., Gautam, N., Mishra, A. & Gupta, R. (2011) Heavy metals and living systems: an overview. *Indian Journal of Pharmacology,* 43(3), 246–253.
Sricoth,T., Meeinkuirt, W.&Pichtel, J.,Taeprayoon, P. &SaengwilaiP. (2017). Synergistic phytoremediation of wastewater, fuel, *Journal of Environmental Science and Pollution Research.*
Stefanakis,A., Akratos,C.&Tsihrintzis,V. (2014).Constructed Wetlands Classification. In Vertical Flow Constructed Wetlands; Elsevier:Amsterdam, The Netherlands;17–25.
Sune, N., Sanchez, G, Caffaratti,S. & Maine, M.A. (2007). Cadmium and chromium removal kinetics from solution by two aquatic macrophytes.*Journal of Environmental and Pollution Research,* 145, 467–473.
Tripathi, S., Sharma, P., Purchase, D. &Chandra, R. (2021}, Distillery wastewater detoxification and management through phytoremediation employing Ricinus communis L. *Journal of Bio resource technology*.
U.S. Environmental Protection Agency (1983, 1984 and 1985) Chemical information fact sheet.
Vishali, S.&Karthikenyan, R. (2018). Application of green coagulants on paint industry effluent, a coagulation – flocculation – study. *Journal of Institute of Science and Technology*, 122, 112 – 113.
Xu, Q.S., Ji, W.D., Yang,H.Y., Wang,H.X., Xu,Y., Zhao, J. & Shi, G.X. (2009). Cadmium accumulation andphytotoxicity in an aquatic fern, *Salvinianatans*(Linn.).*Acta Ecol Sin* 29, 3019–3027.
Yadav,A.K., Abbassi,R., Kumar,N., Satya,S., Sreekrishnan,T. &Mishra,B. (2012).The removal of heavy metals in wetland microcosms: Effects of bed depth, plant species, and metal mobility.*Chemical Engineering Journal*.211,501–507.
Yan,A.,Wang, Y.,Tan,S.N.,Yusof,M.L.M., Ghosh, S.& Chen, Z. (2020). Phytoremediation: A Promising Approach for Revegetation