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REVIEW

Removal of Textile Dyes by Ecofriendly Aquatic Plants From Wastewater: A Review on Plants Species, Mechanisms, and Perspectives

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Abstract

Water, an essential resource for sustaining life on our planet, is crucial for both human beings and the overall ecosystem. However, in recent decades, several factors, including population growth, rapid industrialization, urbanization, and unsustainable utilization of natural resources, have significantly impacted the quality of water. Industries such as textiles, leather tanning, cosmetics, and pigmentation extensively employ colored compounds called dyes for various purposes. Synthetic dyes have largely replaced natural dyes due to their superior durability against washing, heat, light, pH, and exposure to biological agents. Azo dyes, sulfur dyes, and pigment dyes are some examples of dyes used in industrial processes. Unfortunately, dyes pose serious environmental risks, being carcinogenic and mutagenic to humans. Moreover, their resistance to degradation due to their xenobiotic properties and chemical structures exacerbates the problem. Therefore, it becomes imperative to employ different methods for the removal of dyes. One promising approach is the use of plants in a process called phytoremediation, which offers a cost-effective, environmentally friendly, and efficient solution for dye removal. Phytoremediation utilizes plants to cleanse the environment by eliminating both inorganic and organic waste pollutants. In the context of dye waste, this review explores a diverse range of aquatic plant species capable of decolorizing dye-contaminated wastewater. It also delves into the mechanisms through which aquatic plants remove dyes, highlights previous studies on dye removal by different aquatic plant species, and concludes with recommendations for further research and action.

Keywords: Advantages and disadvantage, Mechanism, Phytoremediation, Removal techniques, Textile dyes, Wastewater

1. Introduction

The quality of the water is profoundly important to the wellbeing of all life on earth. The rapidly growing human population, industry, urbanization, and chemically enhanced agriculture are all contaminating water supplies. Today, many people struggle to get access to clean water, and poor countries suffer greatly as a result (Ramesh et al., 2023). Textile effluents are one of the pollutants that cause environmental problems. They are severely polluted with complex organic and inorganic chemicals, which are used during various steps of textile processing (Shaker et al., 2020). Finishing agents, inhibitors, surfactants, salts, dyes, chlorine compounds, phosphates, and dissolved and suspended solids are the main contaminants in textile effluents.

Since they are utilized in so many different industries, including leather, paint, rubber, pharmaceuticals, and textiles, dyes are quite serious pollutants in textile effluents. Dyes find extensive applications across various industries such as textile, paper, leather, dyestuff, printing, plastic, cosmetics,

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and coatings. This may be attributed to their affordability in production, vibrant color properties, and strong resistance to environmental conditions. Extensive research have shown that dyes can be detected in diverse biological samples, including coarse matter, soils, sediments, as well as water bodies like ponds, rivers, and wastewater (Saeed et al., 2022). The global consumption of dyes and pigments is estimated to be around 7×10^5 tons annually, with ~100 tons per year being discharged into wastewater (Dizge et al., 2008; Gupta et al., 2013). Consequently, a significant amount of colored effluents from these industries is released into the natural environment, posing a grave threat to both human and aquatic life in the hydrosphere. Indeed, the presence of dyes in the hydrosphere poses serious pollution problems even at very low concentrations due to their strong toxicity and high stability in the environment (Wan Ngah et al., 2011). Wastewater containing textile dyes is frequently characterized by high pH, chemical oxygen demand (COD), suspended particles, and high salinity. When concentrated dye effluents with a high pH are pumped into a body of water, it will impact the oxygen transfer system and reduce the water's ability to self-purify. Due to their intricate and difficult-to-biodegrade molecular structures, dyes are a serious contaminant in the water system. Fig. 1 depicts the harmful impacts of effluents. The worldwide standard for dye effluent is displayed in Table 1. For instance, the COD in dye effluent may be fifteen times greater than the standards' maximum. Before being released into the environment; levels of each index in dye effluent should meet the specifications that being said.

Generally, water contaminated with pollutants can seriously harm a person's health. For example, they can cause liver dysfunction and can result in serious damages to the brain, central nervous system, kidneys and the reproductive system as well

Table 1. International standard of dye effluent discharge into the environment (Katheresan et al., 2018).

Parameter	Standard allowed
Biological Oxygen Demand (BOD)	Below 30 mg/l
Chemical Oxygen Demand (COD)	Below 50 mg/l
Color	Below 1 ppm
pH	Between 6 and 9
Suspended solids	Below 20 mg/l
Temperature	Below 42 °C
Toxic Pollutants	Not allowed to be released

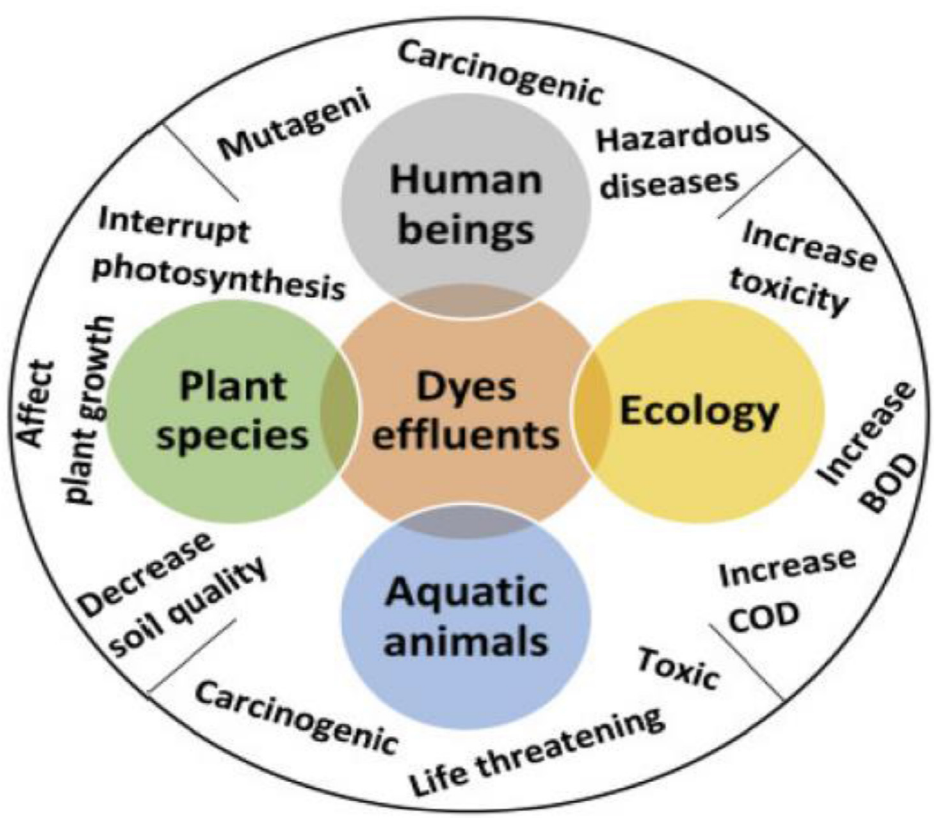

Fig. 1. Adverse impacts of dye wastewater (Qamar et al., 2020).

(Bae and Freeman, 2007). Especially wastewater containing textile dyes has compounds in dyes and degraded dyes, which are typically poisonous or even mutagenic and carcinogenic. They pose serious harm to both aquatic life and humans. For instance, in aquatic plants, it has already been shown that dyes have the ability to block sunlight and resist photochemical reactions, both of which have an adverse effect on photosynthesis process (Liu et al., 2013). In some fish tissues, harmful contaminants are likely to assemble when wastewater-containing color is discharged into the aquatic ecosystem. Finally, yet importantly, these poisons may enter human organs through the food chain, causing numerous pathological problems (Afroze and Sen, 2018). Therefore, the strategy to remove the color or to reduce the dye effect is extremely of significant importance. Finding a technology to decolorize contaminated water and lessen dye toxicity within the recommended water quality criteria is crucial.

There are many conventional techniques have been employed to eliminate dyes from wastewater, like adsorption, photocatalytic degradation, reverse osmosis, coagulation, flocculation, membrane technology, and biological treatments (Wanyonyi et al., 2014; Omran et al., 2016). Treating wastewater contaminated with dyes using physicochemical methods presents challenges due to the high solubility and stability of these dyes in water, making them resistant to light, heat, and oxidizing agents. Moreover, physicochemical treatment methods have drawbacks such as operational issues, high expenses, and the generation of chemical sludge. As a result, there has been a growing focus on biological processes as promising alternatives for treating wastewater-containing dyes. These biological methods offer advantages in terms of cost-effectiveness, efficiency, reduced sludge production, and environmental friendliness (Coronilla et al., 2014).

Phytoremediation of textile dyes is a reasonably new method of textile effluent treatment. It has gained researchers' attention and popularity as an efficient environmental-friendly and *in situ* technology, able to remove different kinds of pollutants., because of low-cost, easy-to-use, and effective method for treating wastewater (Conte et al., 2021; Wibowo et al., 2023). Moreover, in contrast to other methods, phytoremediation offers a more sustainable solution as it does not generate sludge. Phytoremediation presents a promising and scalable approach to combat the escalating issue of water pollution. This review focuses on the utilization of various species of aquatic plants for the purpose of wastewater color removal.

2. Dyes

2.1. The history of dyes

Natural dyes and their use in dyeing is probably the most ancient art of all times. People started using natural dye as their first intellectual tool to portray their surroundings and themselves by this art. Since primitive times, the natural dye was obtained mainly from plant flowers, roots, minerals, mollusks, shells, insects, and animals. The use of dyes have begun when human civilization came into existence as ancient Indian, Egyptian, Roman, and Greek civilizations were used colorants, which were of natural origin (Abel, 2012). With the development of human civilization and increasing population, the need of dyes has increased according to human desire for colors in the required amount and at low cost with high durability. The use of natural dyes was uninterrupted until mid of 19th century, after synthesis of first synthetic dye mauve or aniline purple in 1856 by William Henry Perkin. Many synthetic dyes have been synthesized and their production industries developed due to their high durability, large color range, and easy application, and low cost of dyes (Hagan and Poulin, 2021). Presently thousands of synthetic dyes are being produced mainly for textiles near about 8×10^5 tons per year in the world (Slama et al., 2021). Nowadays only 1% of natural dyes are being consumed in comparison to total synthetic dyes consumption, due to the high production cost of natural dye as plant materials contain less amount of dyes or pigments and their poor binding capacity with fabrics (Yadav et al., 2023). Synthetic dyes have advantages over natural dyes, but their use causes environmental and health issues. Many of the synthetic dyes have been banned in many countries and dye industries are now looking towards substituent natural dyes (Mittal, 2020). As human civilization has progressed and the population has grown, there has been a greater demand for dyes that meet human desires for vibrant colors, affordability, and long-lasting durability.

2.2. Dyes classification

Dyes play a crucial role in various fields, including textile, printing, food, cosmetics, and biomedical research. The structure of dye molecules consists of two essential elements: the chromophores, which generate the color, and the auxochromes, which not only complement the chromophore but also make the molecule water-soluble and increase its ability to adhere to fibers (Sharma et al., 2021). The classification of dyes is essential for understanding their properties, applications, and environmental impacts. Dyes are classified based on various factors, including their chemical structure, solubility, and application as shown in Fig. 2.

2.3. Impact of textile dyes on aquatic environment

As a result of the various textile dyes present in wastewater, the pH of water bodies is altered, leading to significant consequences for aquatic life. The presence of different types of dyes in wastewater affects parameters such as biological oxygen demand (BOD), COD, total dissolved solids (TDS), and total organic content (TOC) in the water (Tahir et al., 2016). These changes pose serious threats to the survival of aquatic species since they are unable to thrive when exposed to water contaminated with dyes (Saini, 2018). Furthermore, the chromophoric groups present in dyes have a strong ability to absorb sunlight, which inhibits the photosynthesis process of aquatic plants and green algae. This absorption of sunlight prevents adequate light penetration into the water bodies, ultimately damaging the quality of water and disrupting the aquatic ecosystem (Lellis et al., 2019). Moreover, when contaminated fishes are consumed, the harmful substances present in the dyes undergo biomagnification, meaning their concentration increases as they move up the food chain. As a result, the consumption of these contaminated fishes can lead to various diseases in human beings and other animals (Kaushal et al., 2021). The impact of synthetic dyes on different component of environment is shown in Fig. 3 and Table 2.

2.4. Impact of textile dyes on human health

Medical conditions such as nausea, hemorrhage, skin and mucous membrane ulceration, dermatitis, perforation of the nasal septum, and numerous respiratory tract irritations may result from the usage of textile dyes, as well as causing breathing problems and possibly causing nausea, vomiting, diarrhea, gastritis, and mental disorientation when inhaled (Sudarshan et al., 2023) (Fig. 4, Table 3).

3. Various technologies and methodologies for textile wastewater treatment

Obtaining safe drinking water is currently a major global concern due to human activities and limited access. It is projected that by 2030, nearly half of the world's population, approximately 47%, will face the challenge of water scarcity (Al-Tohamy et al., 2022). The industrial use of over 10,000 different dyes globally results in the production of more than 700,000 tons of these dyes and pigments each year. About 10–15% of these dyes are released into bodies of water (Rehman et al., 2023). This significant increase in dye release into aquatic ecosystems has adverse effects on water quality due to their

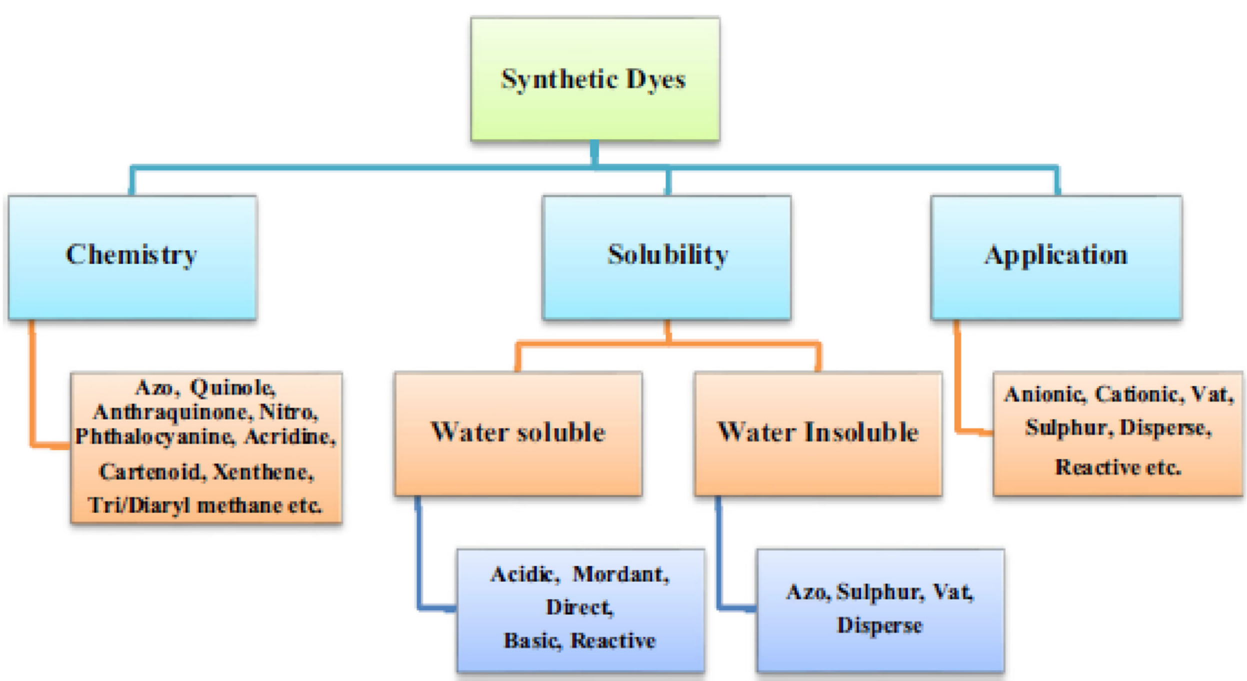

Fig. 2. Classification of synthetic dyes (Hunger, 2003).

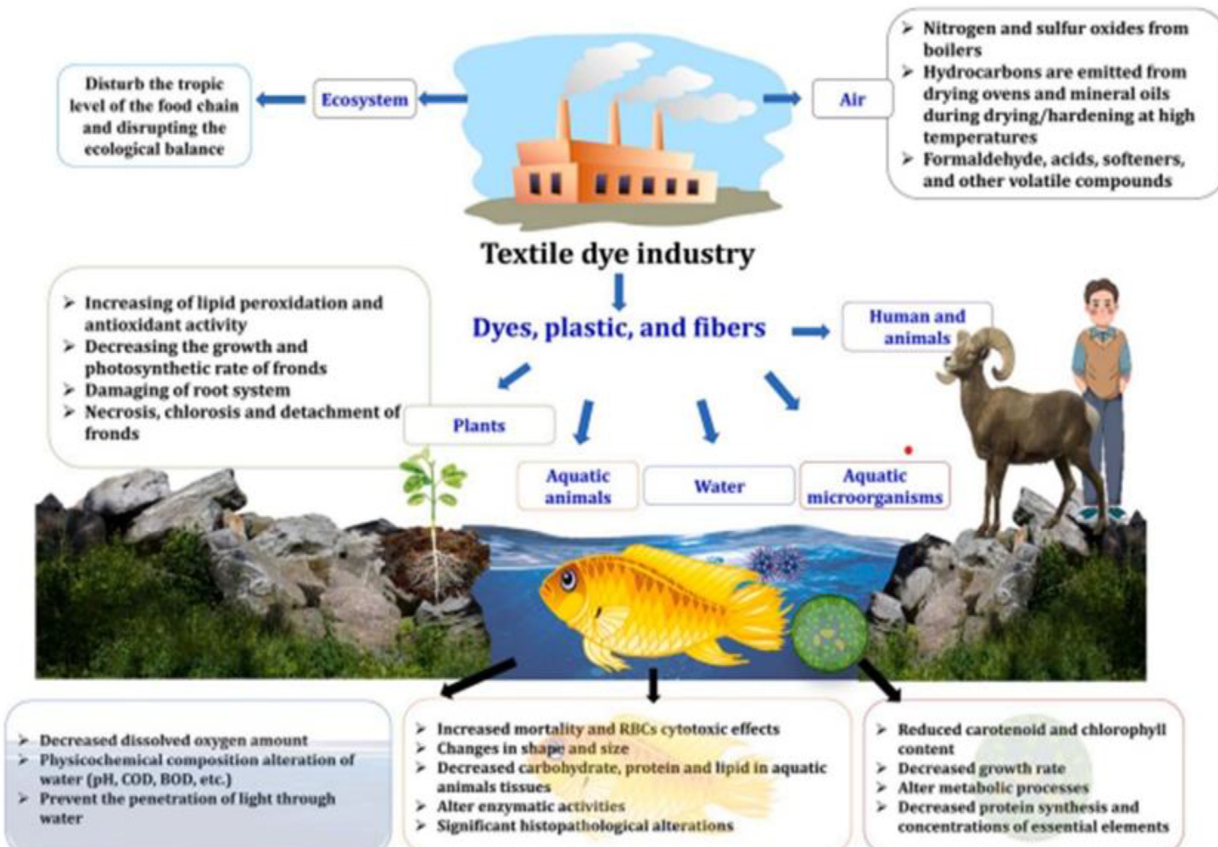

Fig. 3. Ecotoxicological impacts of dye-containing textile wastewater on the environment and living microorganisms (Al-Tohamy et al., 2022).

toxicity, resistance to degradation, and carcinogenic properties.

Therefore, it is crucial to develop a sustainable process to effectively remove dyes from wastewater. Various conventional techniques have been employed for textile dye removal, including adsorption (Wibowo et al., 2022a, 2022b), photo-degradation (Rajput et al., 2022), coagulation/

Table 2. Textile finishing dyes and their impact on aquatic environment.

#	Impact	Reference
1	Direct contamination of groundwater and surface water both	Rizwana et al. (2014)
2	Destroy the vital conditions of these different environments	Hynes et al. (2020)
3	Preventing the penetration of light to the depths of aquatic environments	Coronilla et al. (2014); Wanyonyi et al., (2014)
4	Serious ecological consequences such as changing the nature of aquatic environments	Al-Tohamy et al. (2022)
5	Reducing photosynthesis compared with aquatic flora	Viswanthan et al. (2020)
6	Aesthetic and health problems such as changes in the quality (color and odor) of water and make it toxic	Viswanthan et al. (2020)
7	The phenomenon of eutrophication, under the effect of the release of mineral elements such as nitrates, nitrites and phosphates in an uncontrolled manner	Ugya et al. (2019)
8	Effluent from the textile industry commonly contains high concentrations of organic and inorganic chemicals and are characterized by high chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solids (TDS), pH, total suspended solids (TSS) values and low dissolved oxygen (DO) value as well as strong color	Islam and Guha (2013); Berradi et al. (2019)
9	The agglomeration of organic matter (dyes, pigments, etc.) in watercourses induces the appearance of bad taste, bacterial proliferation, pestilential odors, and abnormal colorations.	Berradi et al. (2019)
10	Ions of Heavy metals (Cd and Cr), which are frequently present in the textile wastewaters can cause renal dysfunction as well as chronicle alterations in nervous system and gastrointestinal tract	Rizwana et al. (2014)
11	Accumulated in food chain and also resistant to biological degradation	Singh et al. (2017)

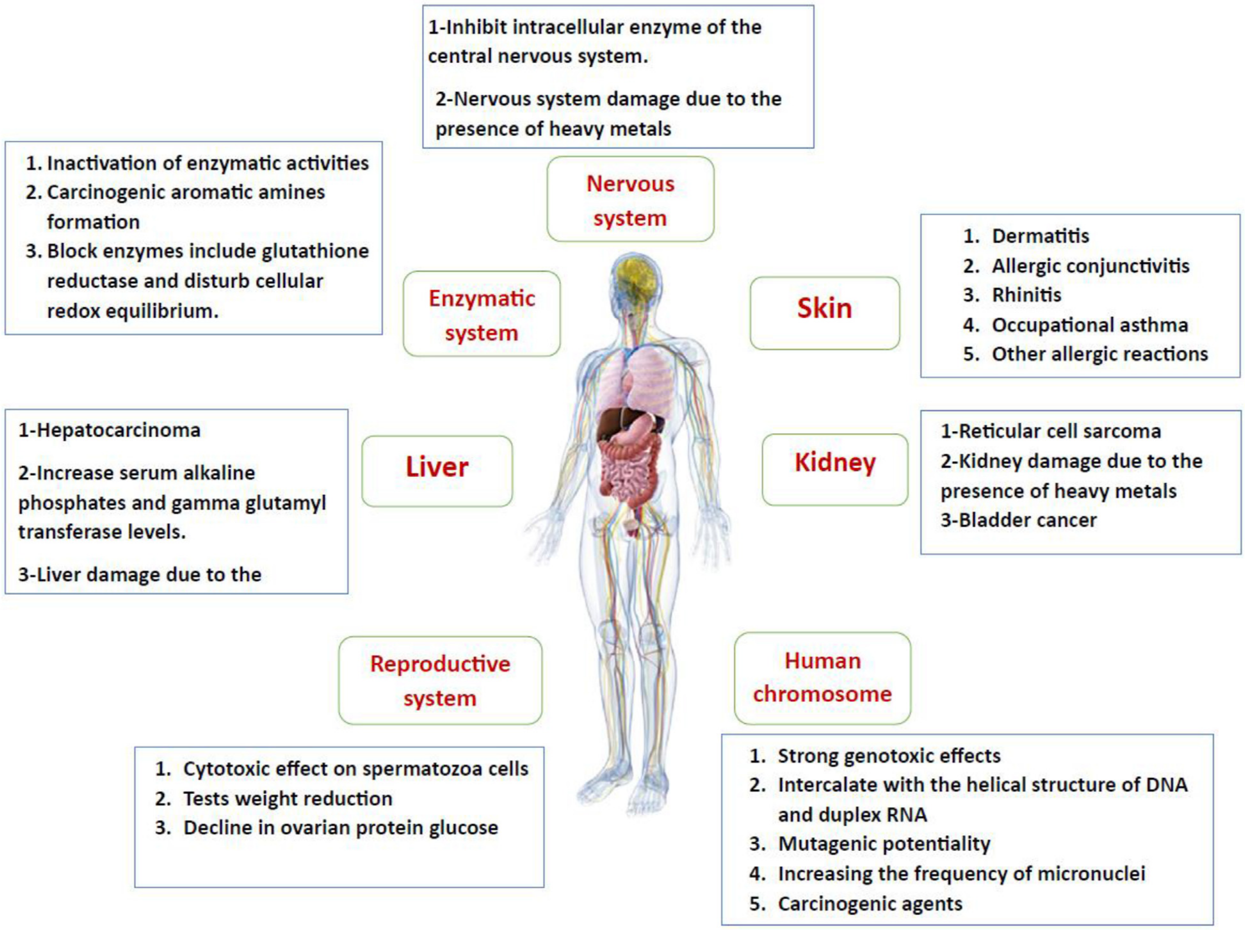

Fig. 4. Negative impacts of textile dyes on human health from dermatitis to the central nervous system (Al-Tohamy et al., 2022).

Table 3. Effects of some textile dyes on health.

	Dye	Effects
1	Azo dyes	Mutagenicity and carcinogenicity
2	Aminoazo benzene dyes	Mutagenesis and cancer
3	Erythrosine, a xanthene	Allergic, carcinogenic, DNA damaging, neurotoxic and xenoestrogenic
4	Disperse orange 1 and disperse blue 291	Genotoxic and mutagenic effect like increased micronuclei in human hepatoma
5	Malachite green	Decrease in cell viability, total protein content and colony-forming ability
6	Reactive dyes	Bladder cancer
7	Methylene blue	Decrease in specific growth rate, protein, and pigment content

flocculation (Sonal and Mishra, 2021), oxidation/ozone (Rekhate and Shrivastava, 2020), membrane separation (Feng et al., 2022), electrodialysis (Lafi et al., 2019), reverse osmosis (Ebrahim et al., 2018), trickling filters (Abu Hasan et al., 2020; Al-Sakkaf et al., 2020), bioremediation (Groudev et al., 2008), phytoremediation (Imron et al., 2023), filtration (Menzel et al., 2021), aerated lagoons (Singh et al., 2017; Peitz and Xavier, 2019), aerobic-activated sludge (Haddad et al., 2018), simple sedimentation (Dra et al., 2020; Ouakouak et al., 2021), and flocculation (Guo et al., 2018). However, these treatment techniques pose challenges as they are labor-intensive, expensive, generate hazardous chemicals, and often result in incomplete dye removal.

Phytoremediation, a relatively new method for treating textile dye effluents, has gained attention and popularity among researchers. It is an efficient, environmentally friendly, and *in situ* technology that utilizes various plant species from different regions worldwide to remove different types of pollutants, including textile dyes. Numerous studies conducted over the past decade have focused on the phytoremediation of textile dyes using different plant species.

4. Phytoremediation

The term phytoremediation refers to the use of plants that can grow in a contaminated environment and influence the biological, chemical, and physical processes taking place in it to ultimately contribute to the effective removal of xenobiotics from the biological system (Mocek-Płóciniak et al., 2023). In this alternative technology, live plants are used to clean up and adsorb organic or inorganic pollutants and to minimize the pollution impact. Several terrestrial and aquatic macrophytes have a great ability to remediate polluted environments due to an extremely diverse metabolism which allows them to remove recalcitrant pollutants (Torok et al., 2017). Phytoremediation has emerged as a green, passive, solar energy driven and cost-effective approach for environmental cleanup when compared with physico-chemical and even other biological methods. Plants naturally provide roots, stems, and leaves as habitats for a wide array of microorganisms which simultaneously can break-down contaminants enhancing the treatment process (Khandare and Govindwar, 2015).

Further, the application of aquatic plants for phytoremediation of textile dyes is preferable than the terrestrial plants, considering the huge load of wastewater generated by the textile industry, their faster growth, larger biomass production, relatively higher capability of pollutant uptake, and better purification effects due to direct contact with contaminated water (Rizwana et al., 2014; Wickramasinghe and Jayawardana, 2018). Studies have shown that a great deal of plant species like *Phragmites australis*, *Typha angustifolia*, etc. possess the ability to absorb, detoxify, and metabolize a wide range of synthetic dyes and colorants to curtail the effects of pollution on environmental compartments (Tahir et al., 2016).

5. Plant mechanisms for treatment of textile dyes and effluents

Phytoremediation, a sustainable and cost-effective approach, utilizes plants to remove, degrade, or immobilize pollutants from soil, water, and air. The removal of contaminants by phytoremediation is based on a different mechanism, which depends upon various factors such as types of contaminants, medium, and extent of the contamination (Kaushal et al., 2021, Fig. 5).

(a) Phytoextraction: The process in which plants absorb and store contaminants in their roots, stems, and leaves (Vandenhove and Van Hees, 2004).

(b) Rhizofiltration: Contaminants are taken up by plants from water and stored in their roots (Lee and Yang, 2010).

(c) Phytostimulation or Rhizodegradation: The process that breaks down the pollutants using symbiotic bacteria found in soil (Besalatpour et al., 2010).

(d) Phytodegradation: It includes uptake, and storage of pollutants with the help of secreted enzymes from plant tissue (Newman and Reynolds, 2004).

(e) Phytovolatilization: It includes the absorption of pollutants from the growth matrix of plants and the subsequent release of volatilized pollutants into the atmosphere (Limmer and Burken, 2016).

(f) Phytostabilization: The process by which pollutants are rendered immobile in the soil by precipitation or absorption by plant roots. By inhibiting soil erosion and leaching, it helps lessen the mobility of contaminants (Bolan et al., 2011).

6. Removal of textile dye effluent by different aquatic plant

Aquatic plants (macrophytes) are utilized as a natural ecological marker to quantify the phytotoxicities of textile dyes (Sharma et al., 2021) and the increased pollution in the world's rivers and lakes has led to the discovery that aquatic plants can be one of the most effective tools for extracting unwanted pollutant from water. Aquatic plants remove pollutants by directly assimilating them into their tissue, and by providing a suitable environment for microorganisms to transform pollutants and reduce their concentrations (Islam and Guha, 2013). Wetlands with aquatic plants are natural systems that can be used for the treatment of wastewater.

Eichhornia crassipes (Water hyacinth) is a free-floating aquatic plant belonging to the family *Pontederiaceae* (Coronilla et al., 2014). It has attracted significant attention as amongst the world's worst invasive aquatic plant due to its extremely rapid proliferation and congest growth, causing serious challenges in transportation, fisheries, irrigation, hydroelectric power generation and environmental health (Wanyonyi et al., 2014). In addition, the dense mats of *Eichhornia crassipes* reduce light penetration and oxygen transfer into water bodies, thereby affecting the photosynthetic and respiratory activity of aquatic organisms (Carrión et al., 2012). Efforts to develop an alternative technology of utilizing *Eichhornia crassipes* in solving environmental problems. *Eichhornia crassipes* is commonly used for wastewater treatment in tropical and subtropical climates.

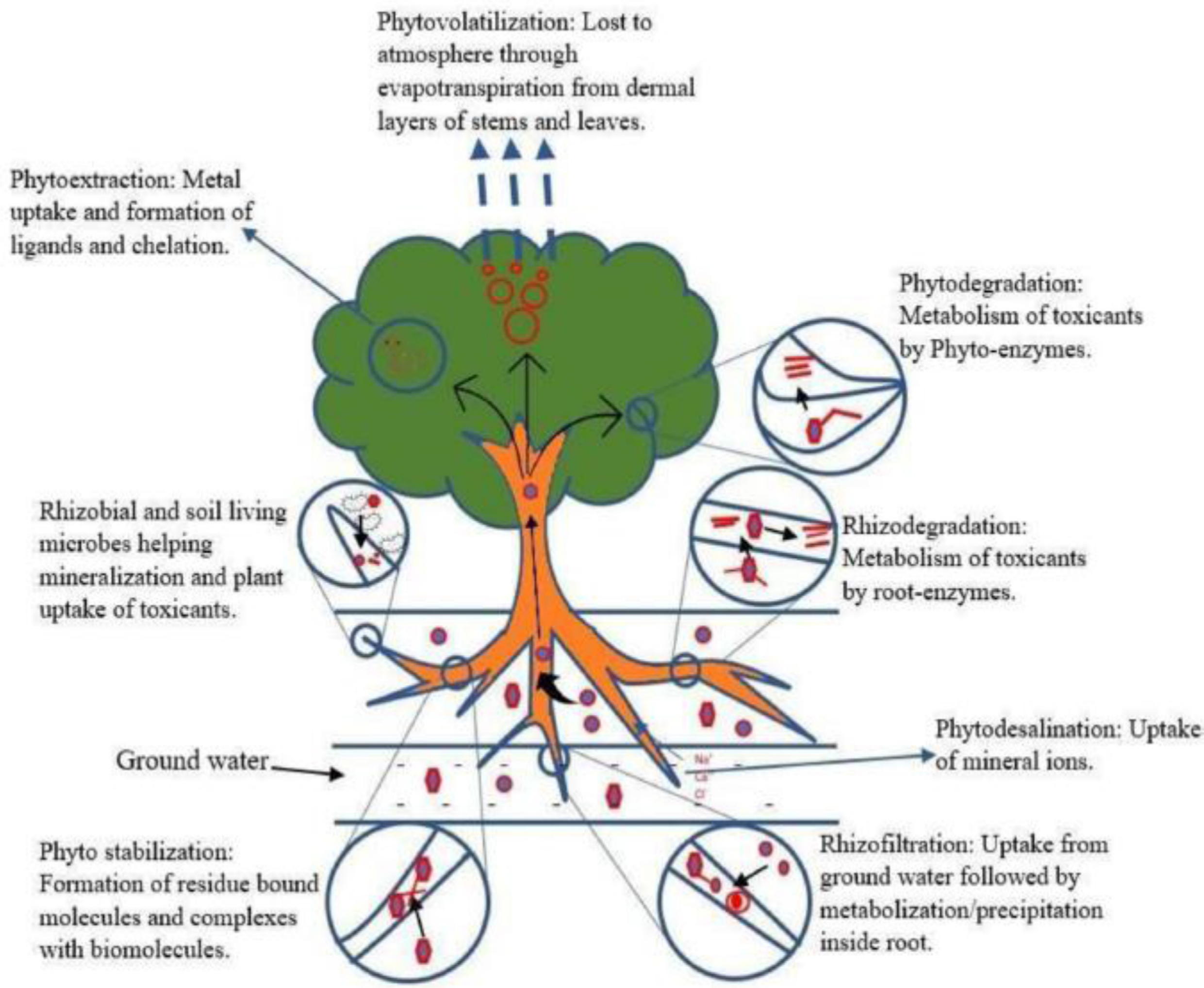

Fig. 5. Phytoremediation processes and their associated functions (Kafle et al., 2022).

Because it floats on the water's surface, it is not rooted and it is easy to harvest (Islam and Guha, 2013). Some researchers preferred to use the native form of *Eichhornia crassipes* for adsorption.

Sharma *et al*., examined the removal of organic dyes from wastewater using *Eichhornia crassipes*. The percentage efficiency of colour removal was between 79 and 90.8% for cationic dyes and in the range of 33.3–62.8% for anionic dyes. Also, *Eichhornia crassipes* modified with H_2O and NaOH are good candidates to be used for the removal of Phenol Red (PR) and Gentian Violet (GV) in aqueous solutions resulting in dye adsorption of 67.4% for PR while GV was eliminated at 71% (López-Ahumada et al., 2022). The potential of *Eichhornia crassipes* was investigated as a viable biomaterial for the biological treatment of Acid Yellow 17 dye, from the experimental data, the maximum dye removal efficiency achieved was 92.26% at pH 2 and initial dye concentration 50 mg/l (Alemu and Kerie, 2022). The possibility of using the roots and Leaves of water hyacinth (*Eichhornia crassipes*), as an alternative biosorbent to uptake BF–4B Red Reactive dye from aqueous media was analyzed (Módenes et al., 2013; Riguetoa et al., 2020).

Lemna minor (duckweed), easily grows in polluted areas. It has a simple structure and morphology, grows quickly, is easy to grow, and is resistant to some contaminants. In addition, *L. minor* contains carboxyl acid, polysaccharide, and cellulose, which play an important role in the phytosorption of dyes (Mahajan and Kaushal, 2020). It was tested for the removal of Crystal Violet and Malachite Green with a significant percentage of 80% and by 90% for Crystal Violet and Malachite Green, respectively. A study by Wibowo et al. (2023) was carried out using *Lemna minor* for the removal of Methylene Blue and Congo Red, showing impressive results in reducing both dyes up to 99% and 25% Methylene Blue and Congo Red after a 24-day period. The capacity of *Lemna minor* as viable biomaterials for removal of Methylene Blue was recorded (Imron et al., 2019; Can-Terzi et al., 2021). Yaseen and Scholz (2017) reported the ability of *Lemna minor* to remove the dye Basic Red 46 with the removal capacity.

Nymphaea nouchali was tested for the removal of Methylene Blue from industrial effluents (Narayanan and Jayasundara, 2022). The same plant was used as a cheap adsorbent for the adsorption of Malachite Green dye (Ayuba et al., 2022). The adsorption of Acid Blue 25 (AB25) ions by aquatic plants, *Potamogeton pusillus*, and *Ceratophylum demersum* from aqueous solutions was studied (Kousha et al., 2014). The ability of the aquatic plant *Ceratophyllum demersum* to remove Methylene Blue dye was examined (Kankõlõc et al., 2016; Dallel et al., 2018; Ewadh, 2020; Daengbut et al., 2021). The study by Shaalan et al. (2023) was investigated the removal of Methylene Blue dye by using of the aquatic plant *Ceratophyllum demersu*. The percentage of treatment for the fifteen days was %78.53. *Ceratophyllum demersu* was used for the removal of the Acid Blue 92 (AB92) dye (Eftekhari et al., 2023). The adsorption properties of Methylene Blue and Reactive Blue 19 on the new nanomagnetite-supported on biochar derived from the *Eichhornia crassipes* and *Phragmites australis* were successfully investigated and compared (Doan et al., 2021).

Torok et al. (2017), investigated the phytoremediation efficiency of *Elodea Canadensis* for Crystal Violet dye removal from aqueous solutions, with the optimum conditions 4 g fresh weight plant, 30 mg/l initial concentration of Crystal Violet dye, room temperature and initial pH of 7.0. The objective of the study by Al-Baldawi et al. (2018) was to investigate the ability of the aquatic plant, *Azolla pinnata* to absorb dye Methylene Blue from water. The decolourizations of dye at 5, 15, and 25 mg/l were 33, 96, and 98%, respectively. The study was performed to investigate the low-cost absorbent derived from the *Azolla pinnata* biomass for removing the Methylene Blue dye from the aqueous solution (Gyawali et al., 2022).

Eicchornia crassipes, *Lemna minor* L., and *Pistia stratiotes* proof to be more efficient in the remediation of wastewater resulting from dying and can be used in dyeing wastewater sedimentation and treatment before discharge into drainage system to prevent effects on aquatic flora and fauna (Ugya et al., 2019).

Removal of Bromocresol Green (BCG) dye from aqueous solution has been investigated using activated bio-sorbent *Phragmites karka* has been adopted (Murmu et al., 2018). The same aquatic plant *was* examined for the adsorption of Methylene Blue dye from the aqueous medium with a maximum dye adsorption capacity of 438.2 mg/g (Viswanthan et al., 2020). A study evaluated the *Ipomoea aquatic* roots as a new, environmentally friendly, and green adsorbent for the removal of Auramine O dye (Lu et al., 2020). *Ipomoea aquatica* was also used to remove toxic Methyl Violet dye in aqueous solutions (Kua et al., 2020). The potential of *Salvinia molesta* for biodecolorization of Methyl Orange dye from water was examined (Al-Baldawi et al., 2020).

The effectiveness of four aquatic floating plants: *Eichhornia crassipes*, *Pistia stratiotes*, *Lemna minor*, *Salvinia sp., and a submerged plant Hydrilla sp.* on removal of five structurally different textile dyes: was studied. The *E. crassipes* and *P. stratiotes* showed complete decolorization of all the dyes tested, while *Salvinia sp.* (79–86%), *L. minor* (16–24%), and *Hydrilla sp.* (6–13%) (Ekanayake et al., 2021).

7. Disadvantages of phytoremediation

Despite its effectiveness as an alternative method for environmental cleanup, phytoremediation has several limitations and disadvantages. Firstly, most of the research conducted on phytoremediation is done within controlled environments and over short periods. This approach may not provide accurate and representative results compared with long-term field studies. Therefore, it is necessary to conduct extensive field research over extended periods to determine the true potential of phytoremediation. Another limitation is that the success of phytoremediation relies on the successful and rapid growth of the plant species used. Since soil and climate conditions vary across different sites, a phytoremediation technique that works for one plant species in a particular location may not be effective in another site. Phytoremediation is site-specific and can be influenced by factors such as soil, climate, and the presence of living organisms like insects, pests, and pathogens. The combination of these factors, along with the presence of pollutants, can make plants more susceptible to diseases and hinder the phytoremediation process. Additionally, plants can only thrive within a certain range of contaminant concentrations. Higher levels of contaminants can slow down plant growth, thus affecting the capacity of phytoremediation. Furthermore, the toxicity of contaminants can reduce microbial diversity and biomass in the rhizosphere, further diminishing the efficiency of phytoremediation. To mitigate these issues, using mixed and local plant species or genetically engineered species, as well as incorporating amendments, can address the site-specificity concern and minimize the risks posed by diseases and pests. Another factor to consider is that the contaminants must be within the reach of the plant's roots in the rhizosphere for effective translocation. Therefore, screening for plants with long and deep roots, as well as higher root biomass, can enhance the efficiency of phytoremediation systems. The design of phytoremediation systems, such as employing a staggered pattern, is also crucial to ensure adequate coverage. Furthermore, phytoremediation is generally a slower process compared with conventional methods, often requiring three to five years to yield complete results. Additionally, there is a concern regarding the handling and proper disposal of plants that have absorbed toxic contaminants. Consumption of such plants with high concentrations of trans located contaminants can be toxic to animals and other organisms. Consequently, appropriate handling, treatment, disposal, or monitoring of these plants is necessary to minimize the adverse effects of phytoremediation. However, these actions can increase the overall cost. As a solution, the potential recovery of useful chemicals from plants or utilizing these plants in applications with a low risk of exposure and movement can offset the additional handling costs.

8. Conclusion and future respective

Polluted Water pollution is a serious global concern due to its detrimental effects on human health, plants, animals, and the environment. Phytoremediation is a green and effective method to address this problem. This review compiles a comprehensive view on the removal of dyes using aquatic plants. Phytoremediation is an environmentally friendly and cost-effective technology that utilizes plants to remediate pollution in soil, water, and even air. It employs various mechanisms such as phytoextraction, phytostabilization, rhizofiltration, phytovolatilization, phytodegradation, and phytodesalination to address a wide range of pollutants. However, the effectiveness of phytoremediation varies among plant species and contaminants, making careful plant selection based on site conditions and target pollutants crucial. While phytoremediation has limitations such as long development time and dependence on climate and plant growth, many of these challenges can be overcome through proper design and species selection. Another concern is the relatively lower efficiency of phytoremediation, the use of amendments can enhance remediation mechanisms, increase water and nutrient uptake, and promote plant growth.

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Author contributions

Idea and protocol design: Manal M. El-Sadaawy and Nancy S. Agib. All authors shared draft writing. All authors approved the submission.

Ethical information

The present manuscript is not submitted to more than one journal for simultaneous consideration. The submitted work is original and has not been published elsewhere in any form or language (partially or in full). Authors adhere to discipline-specific rules for acquiring, selecting, and processing data. All authors agreed with the content that all gave explicit consent to submit and that they obtained consent from the responsible authorities at the institute/organization where the work was carried out before the work was submitted. The authors are responsible for the correctness of the statements provided in the manuscript. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Declaration of Competing Interest

There are no conflicts of interest.

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