A Review of Wastewater Treatment Using Biodegradable Polymers for Dyes Removal

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1 Introduction

Because of the rapidly rising population and their regular standard of living, freshwater shortages and resources are in grave danger. The removal of manufacturing waste materials and environmental effects like global industrialization are the main reasons for the rise in toxicity and population on a global scale [1–3]. As a result of manufacturing growth in textiles, tannery, plastics, and food, the clean water issue has become one of the greatest challenges threatening life in the entire world. Many industrial processes, such as those used to make leather, paper, and textiles, release extremely dangerous and cancer-causing chemicals into wastewater. Scientists estimate that 65% of the number of people worldwide will require tremendous quantities of water in their daily live, and millions of people will experience drinking water shortages [4, 5]. Human health is put at risk because of mismanagement and poor water supply management. In other words, water pollution caused by significant amounts of industrial effluents that are not properly cleaned before being released into sources of water creates a substantial threat to human beings.

The textile industries are receiving a lot of attention from water specialists and scientists due to a large amount of unwanted dye waste entering water bodies. The dyes are harmful to the ecosystem and do not constitute biodegradable. The biological

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A. M. Negm et al. (eds.), *Engineering Solutions Toward Sustainable Development*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-46491-1_8

treatment eventually decreases because of the dye effluents from textiles' ability to block sunlight from entering the aquatic environment, compete with oxygen transfer, and prevent the receiving water from reoxygenating. Therefore, it is inevitable for drinking water to become contaminated with numerous dangerous metal ions and dyes, which have a serious harmful effect [6–8]. Millions of dyes are used in a variety of industries, notably textiles, and most of them are extremely poisonous or even lethal to animals and humans, posing a significant barrier to the purification of the world's aquatic environment. Thus, removing dyes from wastewater is critical in large-scale applications to preserve human health. A range of water treatment procedures is available based on the application and potential of wastewater treatment.

Many methods for removing these compounds from unclean wastewater have been proposed, including flocculation, biodegradation, adsorption, improved oxidation, precipitation, ultrafiltration, ion exchange, electrochemical degradation, and coagulation [9]. Adsorption is regarded as the most promising and financially viable option. Unfortunately, due to reduced capacity of adsorption, sluggish adsorption movement, pricey and difficulty in implementation, many of them are limited. To solve these issues, new materials containing functional groups are constantly required to simplify the water treatment process [10]. Because of their simplicity, cost-effectiveness, and practicality, adsorption techniques have emerged as viable and sustainable alternatives in recent decades. To boost adsorption capabilities, a variety of active compounds have been utilized [7, 9, 11]. Biomaterials are gaining popularity because of their low cost and ability to be prepared from a variety of sources, including agricultural waste. Bio-adsorbents made from shells, lemon peels, maize cobs, mango seeds, tea trash, coconut shells, orange peels and biopolymers like chitosan and alginate are just a few recent discoveries in environmentally friendly products.

To remediate dye-induced wastewater, biodegradable polymers are utilized. These techniques offer various advantages, including simple design, cheap cost, fewer chemical needs, flexibility, and ease of operation. They have received a lot of attention in the latest generations for dye wastewater treatment because of their benefits such as regeneration, simplicity, flexibility, appealing features, and high efficiency. A key strategy for reducing the overuse of industrial activated carbon is the use of biodegradable polymers in water treatment [12, 13]. Even though activated carbon is the most utilized adsorbent, regeneration is difficult and expensive, especially for powdered activated carbon. Agricultural operations generate a substantial amount of garbage. It must be used with caution. It must be borne in mind that the ultimate objective is to rescue the planet. It must also incorporate biomass valorization. Considering these environmental concerns, our effort focused on the development of affordable adsorbents that were persuasive, cheap in cost, non-dirty, and easily disposed of away. Continuous adsorption researches have the potential to assist with the evaluation of processes. It enables us to appreciate and assess the elements, such as the pollutant feed concentration, contact time, solution pH, temperature, stirring rate, and adsorbent mass [14, 15], that have an impact on the phenomena. In this review, we covered a variety of dyes, their impact on the well-being of individuals, parameters influencing this adsorption phenomenon, and a few biodegradable polymers to optimize the elimination of dyes by adsorption. We will offer an overview of the review and future projections for this subject. The use of biodegradable polymers in wastewater treatment aligns with several Sustainable Development Goals (SDGs) by promoting sustainable practices and addressing environmental challenges. Biodegradable polymers can play a role in improving water quality by aiding in the removal of pollutants from wastewater wgixh meets (SDG 6), (SDG 9) and (SDG 12).

2 Dyes in Wastewater

Water is a renewable resource that is required for all life on Earth. It is a "special gift of nature" used for everyday necessities, the timber industry, livestock production, farming, manufacturing processes and other purposes [16, 17]. All of these activities require water, but some dangerous compounds are found in water bodies that contaminate them and make them unusable for bathing, cooking, or other uses. "The water you pollute will always come back to bite you," is a proverb that perfectly captures the fact that humans are the ones who cause pollution, and as a result, they are suffering from several serious illnesses [18, 19]. Because businesses, industries, and mills release large amounts of dye, water is already polluted. Most of the industries producing dye wastewater are the textile, printing, paper, food processing, and tannery industries as shown in Fig. 1.

In addition to acids, glues, salts, and other contaminants, dye effluent also contains auxiliaries that are toxic, teratogenic, carcinogenic, and xenobiotic. The human body experiences these effects as eye burns, skin irritations, allergic conjunctivitis, and occupational asthma. Even though the dye industry produces a variety of pollutants in different amounts [20, 21]. As a result, dye effluent poses a risk to both aquatic and terrestrial environments as well as human health. Because of the tremendous increase in the number and variety of colors used in textile and other industries, dyes are also a significant source of water pollution. These dyes can be categorized as azo, Sulphur, indigo, phthalocyanine, anthraquinonoid, nitro, nitroso, and others, which we will discuss in more detail later in this book. These dyes also have a variety of functional groups. Several pharmaceutical companies poured waste into rivers, possibly triggering a variety of illnesses in those who drank and utilized the water.

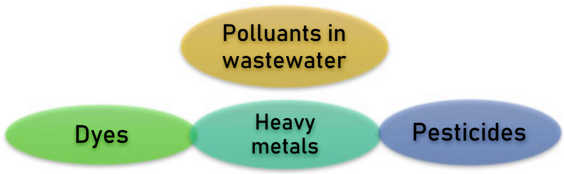

Fig. 1 Pollutant types in wastewater

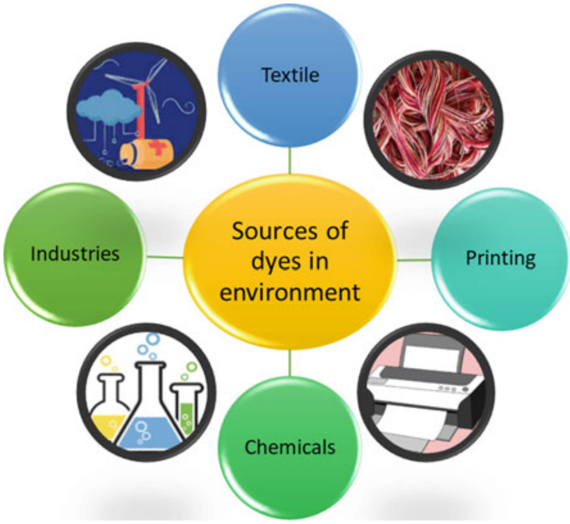

Fig. 2 Sources of dyes in environment

Water contamination is mostly caused by dyes, heavy metals, medications, bacteria, and others, are mentioned in Fig. 2.

3 Environmental and Health Effects of Dyes

Dyes are often used to improve a product's look and quality. As a result, dye production, processing, and use raise several health and environmental problems. Dye is widely used in the pharmaceutical, textile, food, lather, paint industries, household and wastewater treatment plant. When straight black, methyl red, acid red, acids blue, blue dye, methyl blue, hair products, mordant red dyes, and indigo are used and released into the environment, they damage the ecosystem [22, 23]. Dye effluent contains ammonia, leveling chemicals, hydrochloric acid, acetic acid, soap, formaldehyde, sulfur dioxide, organic polymer, softener, and other compounds [24, 25].

Long-term workers in these dye industries face health concerns when handling, processing, and transporting the colors. Breathing problems, pneumonia, burning, allergens, immune response loss, coughing, cardiovascular disease, skin rashes and itching, and other physical problems are frequently caused by inhalation and ingestion of pollutants. Additionally, dyes can negatively impact human health in several ways, including dermatitis, the central nervous system, the liver, the kidney, the skin, the enzymatic system, the reproductive system, human chromosomes, the neurological system, and the epidermis [26, 27].

Because animals and humans use water for everyday activities including bathing, cooking, drinking, and cleaning, the presence of synthetic dyes in freshwater resources is undesirable. While some textile manufacturers filter their wastewater to dissolve and remove dyes and other industrial wastes, others released dyes and other manufacturing waste straight into sources of water, creating major ecotoxicological problems, inflicting environmental harm, and risking human health.

Because of the dye, sunlight becomes obstructed and is unable to penetrate the bottom of bodies of water, resulting in an oxygen deficit. If dye is present on the surface of water bodies, it is unsightly and produces a foul stench. Ultimately, dye degrades soil quality, productivity, and fertility while polluting the air quality [28, 29]. Wastewater, particularly untreated industrial effluent, was used by farmers in less developed countries to irrigate their crops, which harmed the integrity of the soil, crop growth, and the emergence of seed rates, ultimately harming people or animals. Furthermore, the deterioration of water quality could be caused by wastewater containing color.

Dyeing can obstruct access to the aquatic environment's photic domain, as well as the absorption and visible reflection of sunlight. As a result, potential ecological concerns include changed aquatic environments and diminished process of photosynthesis. On the other hand, if people consume colored fish and other aquatic foods, it could result in fever, cramps, hypertension, and other medical issues. Dyes can be detected in the environment because of their extensive use, and they physiologically increase in the aquatic ecosystem, including in fish and algal species.

The environment and human health could be harmed by dye wastewater. Therefore, it is important to manage dye-containing wastewater in a way that is both economical and responsible for the environment. A safe, acceptable, and sustainable dye wastewater treatment is critical for preserving human health, reducing environmental harm, and improving environmental protection [30]. The effects of dyes direct and indirect which impact various substrates are shown in Fig. 3.

4 Dye Classifications and Applications

One of the things we use the most in our daily lives is dyes, which can be either natural or artificial substances that can be found in many settings. Dyes are now widely used in a variety of sector-specific industries, such as textiles and clothing, personal care items, polymers, and printing [31].

Chromophores and auxochromes are the two main parts of dye molecules. Chromophores provide color, but auxochromes can help by boosting the chromophore's affinity for fibers and making it more water-soluble. Dyes are chemical substances that can bond to the outer layer of clothing to add color. Synthetic dyes are available in many different kinds of sizes and forms and are categorized according to their chemical composition, color, and purpose of use. Based on their solubility, colors may occasionally be categorized in different ways. Insoluble dyes include azo, dispersion, sulfur, solvent, and vat, while soluble dyes include acid, basic, direct, mordant, and reactive as it is shown in Fig. 4.

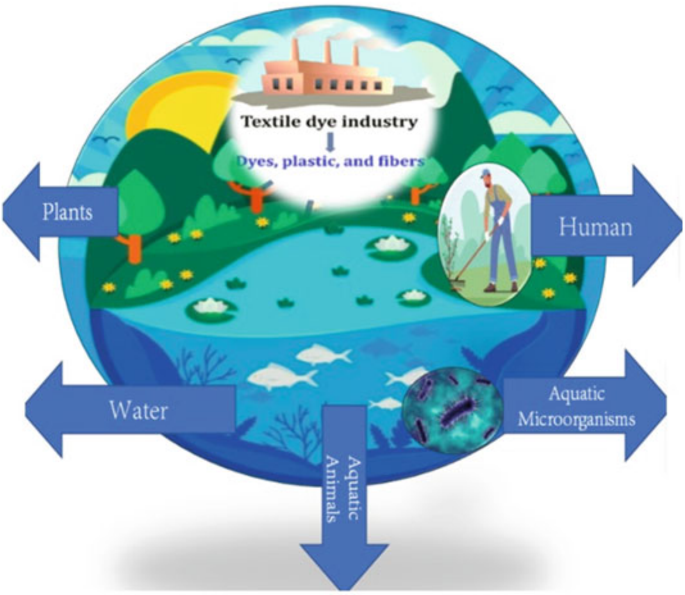

Fig. 3 Effects of dye on several substrates

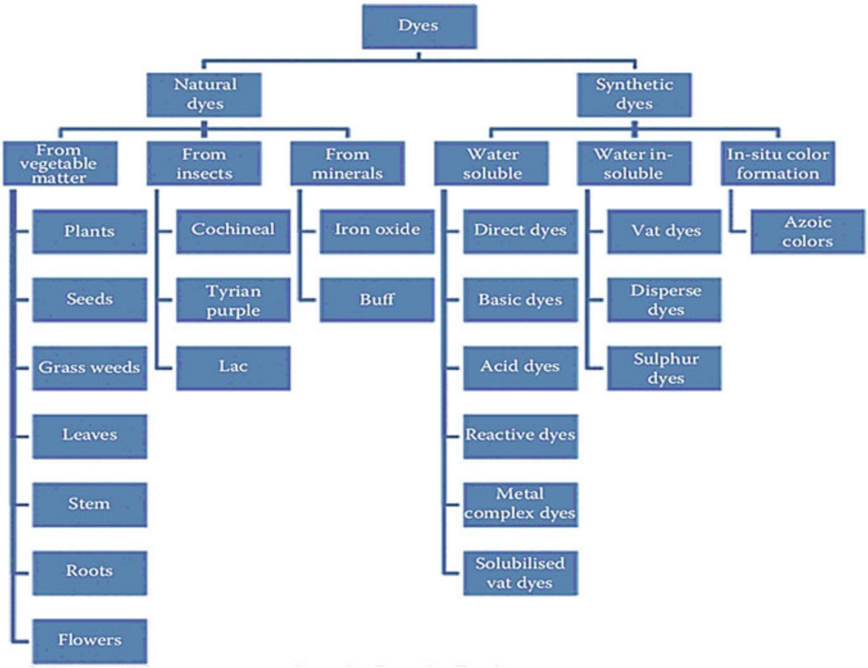

Fig. 4 Dyes classification based on the source of the material

Table 2 provides several examples of synthetic dyes and their possible applications, as well as the ingredients necessary and the chemical structure of different dyes as shown in Fig. 5. Dyes combined wastewater is a significant contamination as well as one of the world's current challenges and burning dilemmas. Dye wastewater is rising because of industrial expansion and human demands. According to the US EPA, 1 kg of fabric requires at least 40 L of clean water, which might vary depending on the textile material and coloring procedure [32, 33].

Untreated wastewater from many dye manufacturers has the potential to harm the environment and human health. Dyes have an impact on water quality by interfering with photosynthesis, slowing plant development, infiltrating the nourishment chains, causing accumulation in the body, and perhaps increasing poisoning. Dye effluent contains organic pollutants, hazardous colors, and heavy metals such as mercury, chromium, cadmium, lead, and arsenic. Azo dyes are the most widely used in the manufacturing of textiles, calculating more than 60% of all textile dyes [32, 33].

Azo dyes, such as diazo, monoazo, and triazo, are typically synthetic aromatic colors consisting of two or more N=N groups linked to benzene and naphthalene

Table 2 Applications and examples of dyes

Types	Applications	Constituent chemicals	References
Acid	Skincare products, nutrition, leather and suede, polyester, printing pigments for paper, natural fibers such as wool, silk, and paints	Azo, azine, nitro, xanthene	[30, 34]
Basic	Medical science, pigments, synthetic polyester, paper goods, polyester, fibers such as wool, silk and wood for its operations	Oxazine, azine, thiazine, triarylmethane, cyanine	[34]
Disperse	Acetate, acrylic fibers, cellulose, nylon, polyamide, polyester, cotton, plastic	Anthraquinonoid, benzo difuran, and styryl	[33, 35]
Direct	Leather, cotton, cellulose	Stilbenes, azo and poly azo	[30, 33]
Azo	Cellulosic materials, detergents	Ana phthalimides	[30, 36]
Mordant	Cotton, fibers, wool, leather, and hair	Azo and anthraquinone	[34, 37]
Sulphur	Paper, cotton, leather, rayon, wool, silk, and polyamide fibers	Thiazoles, thiazone, thianthrene, and phenothiazonethioanthrone subunits	[35, 36]
Solvent	The fats, varnishes, petrol, paints, fluids, lacquers, oily substances, spots polymers and waxes	Anthraquinone and phthalocyanine	[30, 33]
Vat	Rayon, cellulosic fibers, cotton, polyester-cotton, and wool	Anthraquinone, carbazole, indigoids	[34, 35]
Reactive	Cellulosic, nylon, cotton	Oxazine, anthraquinone, azo, basic, formazan, triphenylmethane, and phthalocyanine	[36, 37]

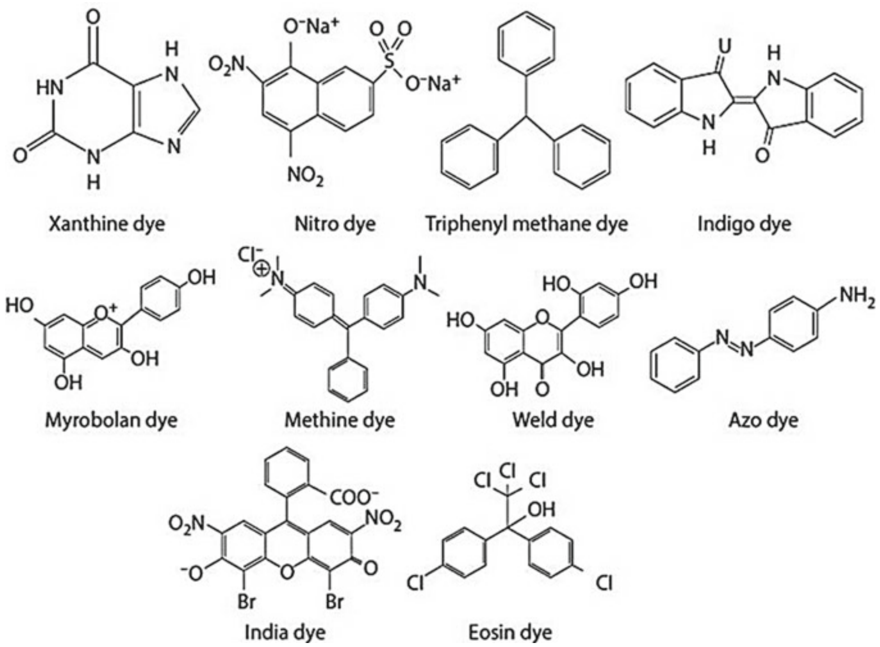

Fig. 5 Chemical structure of different dyes

rings. Azo dyes have a wide range of applications including medications, textiles dyeing, pharmaceuticals, and paper printing. Azo dyes are widely used in the textile industry because they are affordable, stable, and provide a wide range of colors. The following industries contribute to and release dye into the environment: textile businesses (54%), concurrent dyeing businesses (21%), paper and pulp companies (10%), paint and tanneries (8%), and dye producing facilities (7%) as shown in Fig. 6.

Figure 7 depicts the quantity of dye combinations ejected throughout the textile production process. Among the many different chemical combinations of the various substances used during manufacturing and processing are inorganic compounds, polymers, and natural products.

5 Biodegradable Polymers-Based Adsorbents for Dyes Removal

Researchers and scientists have employed biodegradable polymers extensively for the adsorption of many contaminants, including colors. Given that they feature a range of functional groups on their backbone, these combined polymers may be readily altered or changed to match the component's requirements. By effectively adsorbing specific metal ions, polymer selection can also increase selectivity. Due to

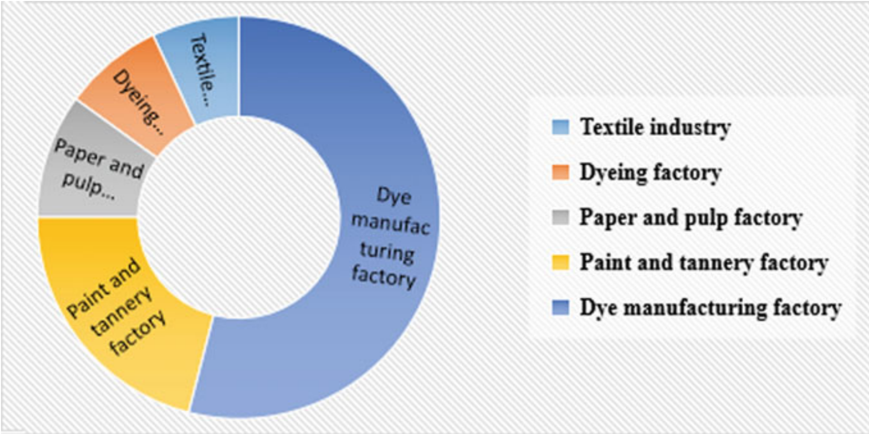

Fig. 6 Sector wise dye producing industries

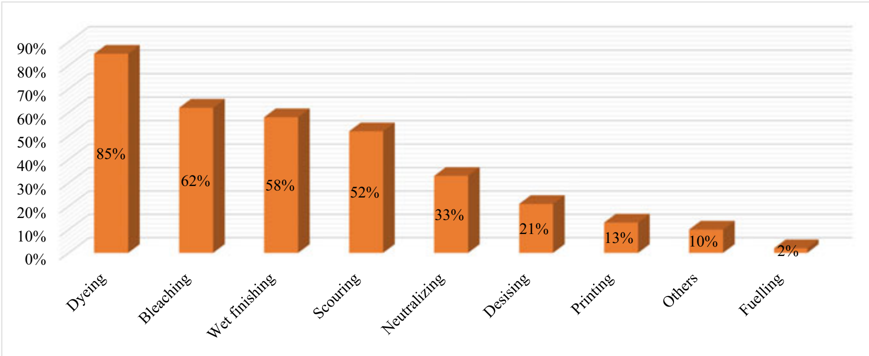

Fig. 7 Rate of dye granting in textile manufacturing processes

their simplicity in synthesis, lack of toxicity, low cost, structural strength, stability, high porosity, and low water solubility, conducting polymers have become more popular as adsorbents [25, 38].

Table 3 provides several examples of biodegradable polymers used as adsorbents in dye removal and shows their maximum capacity for adsorption and their condition for removing the specific dye with a specific polymer.

As indicated in Table 3, Bio-adsorbents derived from agricultural waste such as citrus fruits, olive kernels, shells of palm nuts, peach and apricot kernels, corn husk, coffee beans, fruit waste, nut shells, and biopolymers such as chitosan and alginate are now being studied. The use of biomass in wastewater treatment serves as a key alternative for minimizing the overuse of industrial activated carbon. Agricultural operations generate a substantial amount of garbage. It must be used with caution. It must be borne in mind that the ultimate objective is to rescue the planet. It must

Table 3 Biodegradable polymers-based adsorbents for dye removal

Adsorbent	Type of adsorbent	Adsorbate	Conditions	Removal performance	References
Cassava starch-based-polyacrylamide hydrogels	Agricultural biodegradable polymer	Methylene blue	40% of the MB was eliminated within 1 h and continued to decrease over time until a plateau was established at 10 h. 85% of MB was removed by the CS50 hydrogel before elimination leveled off	Highest adsorption capacity = 2000 mg/g	[39]
Aloe vera-acrylamide-acrylic acid-based interpenetrating polymer network	Agricultural biodegradable polymer	Malachite green	Time = 180 min pH = 4.5 Adsorbent dose = 5 g/l	97.3% dye removal efficiency	[40]
Gum ghatti-acrylamide-based hydrogel	Agricultural biodegradable polymer	Brilliant green, congo red, methyl orange and rhodamine B	At 25 °C, with concentrations ranging from 50 to 400 mg/l Using 40 mg of Gg-cl-PAAM resulted in the highest adsorption efficiency (94%) while using 50 mg of the adsorbent resulted in the adsorption efficiency for RhB (87%), CR (32%), and MO (30%)	Highest adsorption Capacity = 523.62 mg/g for BG Capacity = 421.60 mg/g for RhB Capacity = 179.09 mg/g for CR Capacity = 173.69 mg/g for MO	[41]

(continued)

Table 3 (continued)

Adsorbent	Type of adsorbent	Adsorbate	Conditions	Removal performance	References
Unmodified citrus peels	Agricultural biodegradable polymer	Methylene blue dye	C_o = 100 mg/L M = 10 mg V = 10 mL Speed = 200 rpm T = 24 ± 1 °C pH = 6.4	Q ads max = 185.83 mg/g	[42]
Rice flour (RF)	Agricultural biodegradable polymer	Methylene orange	pH = 7:5.5 In 20 ml solution Time = 220 min	Capacity = 173.24 mg/g	[43]
Pine leaves	Agricultural biodegradable polymer	Methylene blue	T° = 30 °C Speed = 120 rpm for a period of 240 min	Capacity = 126.58 mg/g	[44]
Mango seed	Agricultural biodegradable polymer	Orange 16	Biosorbent mass 50.0 mg; pH fixed at 2.0, contact time 6 h	Capacity = 52.5 mg/g	[45]
Graham flour (GF)	Agricultural biodegradable polymer	Methylene orange	pH = 7:5.5 In 20 ml solution Time = 260 min	Capacity = 151.27 mg/g	[43]
Alginate-activated lemon peels composite beads	Biodegradable polymer	Methylene blue dye	C0 = 25–2200 mg/L V = 10 mL M = 10 mg Speed = 200 rpm T° = (24 ± 1 °C)	Q ads max = 841.37 mg/g	[46]

also incorporate biomass valorization. Considering these environmental concerns, our effort focused on the development of affordable adsorbents that were persuasive, cheap in cost, non-dirty, and easily disposed of away. Unending adsorption study results give valuable data for process analysis.

It enables us to understand and assess the many variables that affect the phenomena, including the impact of pollutant loading rate, contact length, solution pH, temperature, agitation speed, and adsorbent mass. Adsorption in both batch and continuous columns ought to be used as a method for treating industrial wastewater. In continuous adsorption systems, the concentration in the liquid and solid phases varies across time and space. The design and performance of fixed bed columns present specific problems in the absence of a quantitative approximation model.

For instance, in batch and bed column systems, the ability of citrus peel-alginate compound beads to remove methylene blue (MB) dye from an aqueous solution was investigated. To analyze breakthrough curves, a series of continuous adsorption experiments were conducted, considering three different factors: bed height, input feed flow rate, and feed MB dye concentration.

The results of the batch tests showed that dye adsorption is influenced by the pH of the solution. The high MB removal on UCP/A was found to be 93% at pH 7 [42]. On the other hand, nano-hydroxyapatite was incorporated into a starch-graft-poly(acrylamide)/graphene oxide network to create a nano-adsorbent composite for the removal of malachite green dye from aqueous solutions. The following parameters were used to achieve the highest dye adsorption (297 mg/g): agitation for 60 min, n-Hap content of 3 weight percent, solution pH of 10, and initial dye concentration of 100 mg/L [39]. Technology, natural carbohydrate polymeric materials, tunable materials, and sensitive materials would all benefit from another application of biodegradable polymers as adsorbents to efficiently remove toxins from wastewater at a variety of levels [43, 44].

Consequently, the methyl orange anionic color from contaminated water was removed using natural carbohydrate polymeric materials made from rice flour (RF) and graham flour (GF). In this study, the RF and GF adsorbents showed exceptional selectivity, enabling precise, targeted removal of dangerous dye with high efficacy under ideal experimental conditions. Because of the adsorbent charge reactivity, the pH of the solution was significantly altered. The best experimental technique was used to assess the influence of each influencing element and its interactions. According to the kinetic results, RF and GF adsorbents had slower kinetic capabilities than functional nanomaterials and ion exchange fibrous adsorbents [43, 45, 47].

The monolayer coverage adsorption findings showed a high adsorption capacity of 173.24 and 151.27 mg/g of RF and GF adsorbent, respectively, and were closely associated with the Langmuir isotherms. Foreign anions including chloride, nitrate, and sulfate had no impact on the RF and GF adsorbents' ability to bind dye. Additionally, during a few cycles, the adsorbed dye on the RF and GF was completely desorbed with ethanol and reconstituted back into its original form for the following removal process. This was done with no appreciable functional loss [46, 48, 49]. Based on the findings of reactivity, selectivity, and applicability, the RF and GF natural carbohydrate polymeric adsorbents may be employed to remove harmful anionic pollutants [50–52]. Natural carbohydrate polymeric adsorbents RF and GF might be employed in large-scale applications to remove hazardous anionic dyes and other pollutants to start cleaning up wastewater to preserve population well-being [53–55].

6 Conclusion

This study aims to offer an overview of biodegradable polymer-based materials for dye adsorption to combat water pollution. Adsorption removal of contaminants from wastewater is a substantial substitute for cost-effective traditional procedures and the best solution for wastewater treatment as well as for businesses. Dye wastewater-producing enterprises are expanding and discharging more often across the world. Because there is no worldwide norm for wastewater discharge, each country has its own set of guidelines established by its government. Therefore, there are no distinctive, unique, or financially viable solutions to the wastewater curse. Moreover, multiple standard, advanced, and new ways to dye wastewater have been developed and tested. Taking into account neither the rate of dye removal nor the benefits and drawbacks, biodegradable polymers as adsorbents appear to be the most effective and sophisticated for dye removal. The results of this ongoing investigation and numerous model-predicted results demonstrated how toxic dyes are to our health and their influence on the environment, despite their widespread use in industry and other fields. The review also suggests the potential of biodegradable polymer adsorbents as efficient, cheap and environmentally friendly adsorbents for different types of dyes removal from wastewater, as well as how they show a high removal rate and worldwide acceptable that may be used to scale up the procedure to an industrial ecosystem because they performed well in various experiments. Consequently, this study will assist governments and entrepreneurs make the appropriate environmental decisions as it is also relevant to the sixth number of the sustainable development goals (Clean water and Sanitation).

7 Recommendation

Encourage the adoption and utilization of biodegradable polymers as adsorbents in water treatment processes. These polymers offer a more sustainable and environmentally friendly alternative to traditional adsorbents like activated carbon. Collaboration between researchers, policymakers, and industries is crucial to facilitate the implementation and scale-up of biodegradable polymer-based adsorption techniques. Invest in further research and development to explore and optimize the functionalization of biodegradable polymers for enhanced adsorption of dyes. This can include studying different types of biodegradable polymers, their modifications, and their performance under various conditions. Additionally, investigate the use of agricultural waste as a source of biodegradable polymers to reduce costs and promote circular economy principles. The use of sustainable adsorption techniques, including biodegradable polymers, in water treatment processes. Provide incentives and support mechanisms for industries to adopt environmentally friendly practices and invest in.

Acknowledgements The study's investigators would like to express their appreciation to the Science and Technology Development Fund (STDF) for their assistance in contributing the project, No. 41902 (Centre of Excellence in Membrane-based Water Desalination Technology for Testing and Characterization).

References

1. Sahraei R, Sekhavat Pour Z, Ghaemy M (2017) Novel magnetic bio-sorbent hydrogel beads based on modified gum tragacanth/graphene oxide: removal of heavy metals and dyes from water. J Clean Prod 142:2973–2984. https://doi.org/10.1016/j.jclepro.2016.10.170
2. Marni Sandid A, Bassyouni M, Nehari D, Elhenawy Y (2021) Experimental and simulation study of multichannel air gap membrane distillation process with two types of solar collectors. Energy Convers Manag 243:114431. https://doi.org/10.1016/j.enconman.2021.114431
3. Elhenawy Y, Fouad K, Bassyouni M, Majozi T (2023) Design and performance a novel hybrid membrane distillation/humidification–dehumidification system. Energy Convers Manag 286:117039. https://doi.org/10.1016/j.enconman.2023.117039
4. Fouad K, Gar Alalm M, Bassyouni M, Saleh MY (2020) A novel photocatalytic reactor for the extended reuse of W-TiO_2 in the degradation of sulfamethazine. Chemosphere 257:127270. https://doi.org/10.1016/j.chemosphere.2020.127270
5. Elhenawy Y, Bassyouni M, Fouad K, Sandid AM, Abu-Zeid MA-R, Majozi T (2023) Experimental and numerical simulation of solar membrane distillation and humidification—dehumidification water desalination system. Renew Energy 118915. https://doi.org/10.1016/j.renene.2023.118915
6. Elhady S, Bassyouni M, Mansour RA, Elzahar MH, Abdel-Hamid S, Elhenawy Y, Saleh MY (2020) Oily wastewater treatment using polyamide thin film composite membrane technology. Membranes (Basel) 10:84. https://doi.org/10.3390/membranes10050084
7. Eteba A, Bassyouni M, Saleh M (2022) Modified coal fly ash for textile dye removal from industrial wastewater. Energy Environ 1–27. https://doi.org/10.1177/0958305X221130536
8. Eteba A, Bassyouni M, Saleh M (2022) Utilization of chemically modified coal fly ash as cost-effective adsorbent for removal of hazardous organic wastes. Int J Environ Sci Technol. https://doi.org/10.1007/s13762-022-04457-5
9. Malik LA, Bashir A, Qureashi A, Pandith AH (2019) Detection and removal of heavy metal ions: a review. Environ Chem Lett 17:1495–1521. https://doi.org/10.1007/s10311-019-00891-z
10. Eteba A, Bassyouni M, Saleh M (2021) Removal of hazardous organic pollutants using fly ash. Environ Ecol Res 9:196–203. https://doi.org/10.13189/eer.2021.090407
11. Fouad K, Bassyouni M, Alalm MG, Saleh MY (2021) Recent developments in recalcitrant organic pollutants degradation using immobilized photocatalysts. Appl Phys A Mater Sci Process 127:612. https://doi.org/10.1007/s00339-021-04724-1
12. Chai WS, Cheun JY, Kumar PS, Mubashir M, Majeed Z, Banat F, Ho SH, Show PL (2021) A review on conventional and novel materials towards heavy metal adsorption in wastewater treatment application. J Clean Prod 296:126589. https://doi.org/10.1016/j.jclepro.2021.126589
13. Bassyouni M, Zoromba MS, Abdel-Aziz MH, Mosly I (2022) Extraction of nanocellulose for eco-friendly biocomposite adsorbent for wastewater treatment. Polymers (Basel) 14. https://doi.org/10.3390/polym14091852

14. Zoromba MS, Ismail MIM, Bassyouni MI, Abdel-Aziz MH, Salah N, Alshahrie A, Memic A (2017) Fabrication and characterization of poly (aniline-co-o-anthranilic acid)/magnetite nanocomposites and their application in wastewater treatment. Colloids Surfaces A Physicochem Eng Asp 520:121–130. https://doi.org/10.1016/j.colsurfa.2017.01.075
15. Abdel-Aziz MH, Bassyouni M, Soliman MF, Gutub SA, Magram SF (2017) Removal of heavy metals from wastewater using thermally treated sewage sludge adsorbent without chemical activation. J Mater Environ Sci 8:1737–1747
16. Kumar R, Mathur S (2022) Natural reserves of water on earth. In: Handbook of research on water sciences and society. IGI Global, pp 699–721
17. Rashid R, Shafiq I, Akhter P, Iqbal MJ, Hussain M (2021) A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method. Environ Sci Pollut Res 28:9050–9066
18. Periyasamy S, Karthik V, Senthil Kumar P, Isabel JB, Temesgen T, Hunegnaw BM, Melese BB, Mohamed BA, Vo D-VN (2022) Chemical, physical and biological methods to convert lignocellulosic waste into value-added products. A review. Environ Chem Lett 20:1129–1152
19. Fouad K, Gar Alalm M, Bassyouni M, Saleh MY (2021) Optimization of catalytic wet peroxide oxidation of carbofuran by Ti-$LaFeO_3$ dual photocatalyst. Environ Technol Innov 23:101778. https://doi.org/10.1016/j.eti.2021.101778
20. Muhd Julkapli N, Bagheri S, Bee Abd Hamid S (2014) Recent advances in heterogeneous photocatalytic decolorization of synthetic dyes. Sci World J 2014. https://doi.org/10.1155/2014/692307
21. Mateo-Sagasta J, Zadeh SM, Turral H (2018) More people, more food, worse water?: a global review of water pollution from agriculture
22. Singh J, Yadav P, Pal AK, Mishra V (2020) Water pollutants: origin and status. Sensors Water Pollut Monit Role Mater 5–20
23. Borah P, Kumar M, Devi P (2020) Types of inorganic pollutants: metals/metalloids, acids, and organic forms. In: Inorganic pollutants in water. Elsevier, pp 17–31
24. Mekhilef S, Saidur R, Kamalisarvestani M (2012) Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renew Sustain energy Rev 16:2920–2925
25. Uddin F (2021) Environmental hazard in textile dyeing wastewater from local textile industry. Cellulose 28:10715–10739
26. Nur ASM, Sultana M, Mondal A, Islam S, Robel FN, Islam A, Sumi MSA (2022) A review on the development of elemental and codoped TiO_2 photocatalysts for enhanced dye degradation under UV–vis irradiation. J Water Process Eng 47:102728
27. Ayodhya D, Veerabhadram G (2018) A review on recent advances in photodegradation of dyes using doped and heterojunction based semiconductor metal sulfide nanostructures for environmental protection. Mater Today Energy 9:83–113. https://doi.org/10.1016/j.mtener.2018.05.007
28. Al-Tohamy R, Ali SS, Li F, Okasha KM, Mahmoud YA-G, Elsamahy T, Jiao H, Fu Y, Sun J (2022) A critical review on the treatment of dye-containing wastewater: ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. Ecotoxicol Environ Saf 231:113160
29. Yaseen DA, Scholz M (2019) Impact of pH on the treatment of artificial textile wastewater containing azo dyes using pond systems. Int J Environ Res 13:367–385
30. Sharma J, Sharma S, Soni V (2021) Classification and impact of synthetic textile dyes on Aquatic Flora: a review. Reg Stud Mar Sci 45:101802
31. Vikrant K, Giri BS, Raza N, Roy K, Kim K-H, Rai BN, Singh RS (2018) Recent advancements in bioremediation of dye: current status and challenges. Bioresour Technol 253:355–367
32. Kishor R, Purchase D, Saratale GD, Saratale RG, Ferreira LFR, Bilal M, Chandra R, Bharagava RN (2021) Ecotoxicological and health concerns of persistent coloring pollutants of textile industry wastewater and treatment approaches for environmental safety. J Environ Chem Eng 9:105012
33. Samsami S, Mohamadizaniani M, Sarrafzadeh M-H, Rene ER, Firoozbahr M (2020) Recent advances in the treatment of dye-containing wastewater from textile industries: overview and perspectives. Process Saf Environ Prot 143:138–163

34. Katheresan V, Kansedo J, Lau SY (2018) Efficiency of various recent wastewater dye removal methods: a review. J Environ Chem Eng 6:4676–4697
35. Ahmed SF, Mofijur M, Nuzhat S, Chowdhury AT, Rafa N, Uddin MA, Inayat A, Mahlia TMI, Ong HC, Chia WY (2021) Recent developments in physical, biological, chemical, and hybrid treatment techniques for removing emerging contaminants from wastewater. J Hazard Mater 416:125912
36. Shaikh MA, Weiguo S, Shahid MU, Ayaz H, Ali M (2018) An assessment of hazards and occupational health & safety practices for workers in the textile industry: a case study. J Acad Res Bus Soc Sci 8:333–347
37. Shahedi A, Darban AK, Taghipour F, Jamshidi-Zanjani A (2020) A review on industrial wastewater treatment via electrocoagulation processes. Curr Opin Electrochem 22:154–169
38. Taghizadeh A, Taghizadeh M, Jouyandeh M, Yazdi MK, Zarrintaj P, Saeb MR, Lima EC, Gupta VK (2020) Conductive polymers in water treatment: a review. J Mol Liq 312:113447
39. Junlapong K, Maijan P, Chaibundit C, Chantarak S (2020) Effective adsorption of methylene blue by biodegradable superabsorbent cassava starch-based hydrogel. Int J Biol Macromol 158:258–264
40. Kumar V, Rehani V, Kaith BS (2018) Synthesis of a biodegradable interpenetrating polymer network of Av-cl-poly (AA-ipn-AAm) for malachite green dye removal: kinetics and thermodynamic studies. RSC Adv 8:41920–41937
41. Mittal H, Kumar V, Alhassan SM, Ray SS (2018) Modification of gum ghatti via grafting with acrylamide and analysis of its flocculation, adsorption, and biodegradation properties. Int J Biol Macromol 114:283–294
42. Benhouria A, Islam MA, Zaghouane-Boudiaf H, Boutahala M, Hameed BH (2015) Calcium alginate–bentonite-activated carbon composite beads as highly effective adsorbent for methylene blue. Chem Eng J 270:621–630
43. Janarthanan P, Yunus WMZW, Bin AM (2003) Thermal behavior and surface morphology studies on polystyrene grafted sago starch. J Appl Polym Sci 90:2053–2058
44. Yagub MT, Sen TK, Ang HM (2012) Equilibrium, kinetics, and thermodynamics of methylene blue adsorption by pine tree leaves. Water Air Soil Pollut 223:5267–5282
45. Alencar WS, Acayanka E, Lima EC, Royer B, de Souza FE, Lameira J, Alves CN (2012) Application of Mangifera indica (mango) seeds as a biosorbent for removal of Victazol Orange 3R dye from aqueous solution and study of the biosorption mechanism. Chem Eng J 209:577–588
46. Belhouchat N, Zaghouane-Boudiaf H, Viseras C (2017) Removal of anionic and cationic dyes from aqueous solution with activated organo-bentonite/sodium alginate encapsulated beads. Appl Clay Sci 135:9–15
47. Saleh MY, Enany GEL, Elzahar MH, Elshikhipy MZ, Hamouda R (2014) Removal of lead in high rate activated sludge system. Int J Environ Ecol Eng 8:413–418
48. Abdel-Aziz MH, El-Ashtoukhy EZ, Bassyouni M, Al-Hossainy AF, Fawzy EM, Abdel-Hamid SMS, Zoromba MS (2021) DFT and experimental study on adsorption of dyes on activated carbon prepared from apple leaves. Carbon Lett 31:863–878
49. Saleh MY, El Enany G, Elzahar MH, Omran MH (2015) Industrial wastewater treatment improvements using activated carbon. In: International conference on energy, ecology, environment and sustainable development at: Miami, USA
50. Gutub SA, Bassyouni M, Abdel-Hamid SMS (2013) Dissolved solids adsorption of freshwater using synthesized bio-foam composite. Life Sci J 10:464–471
51. Hamdon RS, Salem A, Ahmed HGI, ElZahar MMH (2022) Use of chitosan for enhancing the process of surface water purification in Egypt. Int J Environ Sci Dev 13:26–34
52. Elshikhipy MZ (2014) Use of alum for removal of total dissolved solids and total iron in high rate activated sludge system

53. EL-Dosoky SH, El-Zahar MH, Saleh MY (2019) The usage of date pits for treatment of thickened sludge
54. Saleh M, El Enany G, Elzahar M, Omran M (2017) Industrial wastewater treatment improvements using limestone. J Environ Stud Res 7:910–918
55. Saleh MY, El Enany G, Elzahar MH, Elshikhipy MZ (2014) Industrial wastewater treatment using high rate activated sludge and alum additive. Int J Environ Sci Dev 5:551