IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Phytoremediation of Dyes as Industrial Effluents: A Review

Sanjive Kumar
A. S. (P.G.) College, Mawana, Meerut
IIMT University, Meerut

Abstract

Industrial effluent is one of the major environmental problems facing by world. It contains several types of chemicals including heavy metals, dyes, plastic and other chemical compounds. Among them dye pollutants create severe health problem to animals and human beings as well as in plants. There are several strategies used to overcome dye pollutants that include physical, chemical and biological methods. Phytoremediation is one of the biological methods which is cost effecting, environment friendly and produce no secondary pollutants. These properties make it a good choice for remediation of dye pollutants; however this method is not applicable at industrial level.

Keywords-Industry, dye, pollutant, phytoremediation

1 Introduction

World population is increasing day by day. It increases the need of energy and industrial development. The industrial development is essential for economic development as well as employment generation. These industries prepared several useful products for mankind but they give out several types of chemicals as industrial effluents, which cause serious problem of environmental pollution. Dyes are one of the major pollutants present in industrial effluents.

Dyes are chemical compounds that are used to impart colour to different materials. It is one of the important chemical used in different manufacturing industries like paper, textile, food, leather, plastic and many more. These industries give out several harmful chemicals as industrial effluents and pollute soil as well as water bodies. Dyes are one of the parts of these effluents which cause water pollution and create several problems to the plants, animals as well as for human being.

There are several strategies used to overcome these dye pollutants that includes chemical method, physical methods and biological methods. We can also use combination of more than two methods for remediation of dye pollutants. The chemical methods required costly chemicals which can produce secondary pollutants also. The physical methods do not require chemicals but they are costly and time taking. The biological methods used plants or microorganism for the degradation of dyes, these methods does not require costly

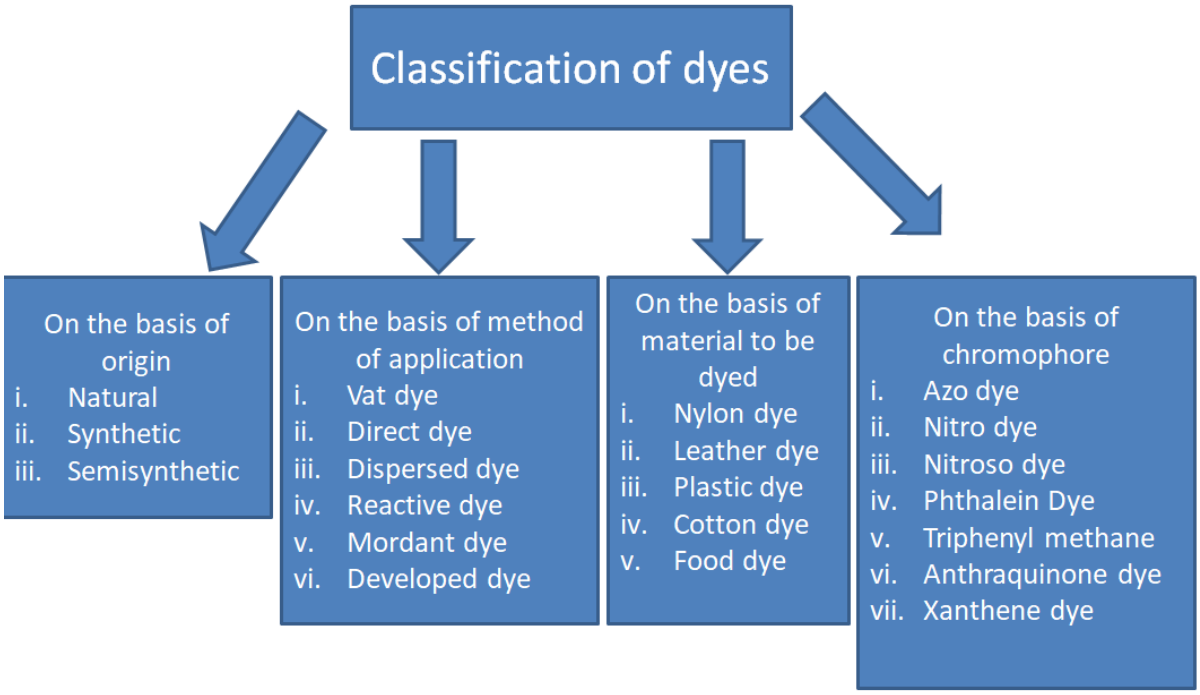
chemicals and machinery. Phytoremediation is one of the biological methods used for dye degradation that used plants for the degradation of dyes by the use of solar energy.

2 Dyes and its classification

Dyes are colored compounds which are used to impart color to the substrate like leather, fiber, clothes, paper, plastic, cosmetic products, food and paint etc. Dyes are also used for printing on paper and clothes. Dyes can be organic or inorganic compound which can absorb the visible range of light due to which they appear colored. There are around one lakh commercially available dyes are present which are producing 10x 10^7 tons of dyed stuff annually in whole world[1]. They are commonly used in textile, leather, paper and food industries. These industries used lots of water for dyeing process according to Kant et. al (2012) the daily water consumption of an average size textile mill is 1.6 million liters. According to a study around 8000 types of chemicals used for the dyeing process and around 80% of dye would remain on the textile fabric while other 20% go up in drains. Beside dyes there are several other compounds like chlorine is used in these industries which are carcinogenic in nature. There are some metal oxides which are called mordant used to fix the color of dyes.

There are several methods of classification of dyes. On the basis of source we can classify them into natural and synthetic dyes. Among them natural dyes are obtained from natural sources like plants and minerals, these dyes are less harmful for environment but they impart less stable color on substrate and it get decolorize by the effect of sunlight, water and air. The synthetic dyes prepared in the laboratory by using chemical compounds, produce stable color which retains more by the effect of sunlight, water and air. But it can produce more harmful effects on environment, human being, animals and plants[2], [3].

The dyes can also be classified on the basis of chromophore present in it. Chromophores are those functional groups which are responsible for the production of color in the dye, it is due to the absorption of visible range of electro-magnetic radiation by the compound.



Picture-1: Classification of dyes on different basis

Table-1: Classification of the dyes on the basis of chromophore

S. No.	Name of dye	Chromophore present	Examples
1.	Azo dyes	-N=N-	Methyl blue, Methyl orange , Congo red, Aniline yellow, Bismark brown
2.	Nitro dyes	$-NO_2$	Picric acid, Martius yellow
3.	Nitroso dye	-N=O	Fast green O, Gambine Y
4.	Phthaleins		Phenolphthalein
5.	Triphenyl methane dye	Ph_3C-	Crystal violet, Malachite green, Rosaniline
6.	Anthraquinone dye	$C_{14}H_8O_2$	Alizarin,
7.	Xanthene dye	$CH_2[C_6H_4]_2O$	Rhodamine B, Eosin

Table-2: Classification of dyes on the basis of their application on fiber

S.No.	Type of dye	Example
1.	**Acid Dye-** Their acidic solution is used for application. They are also called anionic dyes.	Picric acid, Napthol yellow
2.	**Basic Dye-** Their alkaline solution is used for application. They are also called cationic dyes.	Crystal violet, Methyl violet, Methylene blue
3.	**Direct Dye-** Their aqueous solution is used for application. They are also called substantive dyes.	Congo red, Martius yellow
4.	**Developed Dye-** These dyes are produce within the clothes itself by the chemical reaction between two reactants. They are also called ingrain dyes	Azo dyes
5.	**Mordant Dye-**These dyes cannot be applied directly but require a mordant to produce color. They are also called adjective dyes.	Alizarin
6.	**Vat Dye-** These dyes are insoluble in water but their reduced form is soluble which is applied on fiber and color is produce by further oxidation with atmospheric oxygen.	Indigo dye

3 Harmful effects of Dyes

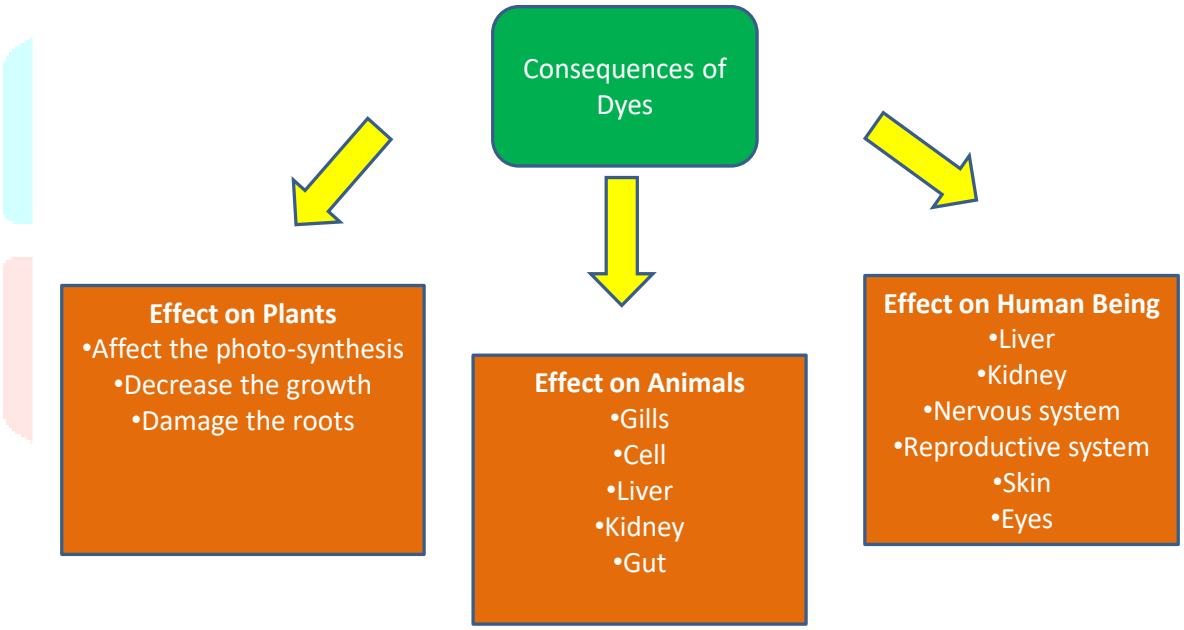
There are several industries based on dyes that includes textile, printing, paint, leather etc. among them textile industry is the major consumer of dyes and also play important role in world economy. These industries used several types of dyes which came out as water effluent into the aquatic environment like rivers, ponds, lakes and other water sources. These effluents create serious problem of water pollution and cause toxic effect on ecosystem.

Dyes are generally organic aromatic compounds but they have also contains several types of heavy metals like Mercury, Chromium, Cadmium, Lead, Arsenic etc., which are used as color pigments in dyeing[2]. When these chemicals enter into water system, they remained there for long time and make the water toxic. These chemicals can enter into plants by irrigation and by consumption of these plants and their products into human being and animals. These chemicals can also enter into human being and animals by consumption of polluted water and cause toxic effect on their health.

4 Harmful effects of Dyes

There are several industries based on dyes that includes textile, printing, paint, leather etc. among them textile industry is the major consumer of dyes and also play important role in world economy. These industries used several types of dyes which came out as water effluent into the aquatic environment like rivers, ponds, lakes and other water sources. These effluents create serious problem of water pollution and cause toxic effect on ecosystem.

Dyes are generally organic aromatic compounds but they have also contains several types of heavy metals like Mercury, Chromium, Cadmium, Lead, Arsenic etc., which are used as color pigments in dyeing[2]. When these chemicals enter into water system, they remained there for long time and make the water toxic. These chemicals can enter into plants by irrigation and by consumption of these plants and their products into human being and animals. These chemicals can also enter into human being and animals by consumption of polluted water and cause toxic effect on their health.



Picture-2: Harmful effects of dyes

3.1. Effect on aquatic plants

The aquatic animals contain algae and macrophytic species. That is playing the role of primary producer in aquatic ecosystem. They are important to provide nutrients, balancing the physical and chemical composition of water and also provide shelter to the aquatic animals. Microalgae are very sensitive towards the chemical composition of water and they are used as an indicator of water quality.

The dyes are coloured compounds and when they are come out as effluent in water sources, it makes the water turbid which resist the penetration of light into the water. That resists the process of photo-synthesis by aquatic plants which decrease the amount of oxygen in water and also disturb the biological activities of water ecosystem. Beside that the chemical compounds present in dyes change the chemical and physical properties of the water ecosystem. It affects the pH, Temperature, BOD, COD, TDS and chemical composition of water. It causes destruction of microalgae and also affects the other aquatic plant species. These aquatic plants are primary producer of water ecosystem so it affect the whole food cycle and cause the destruction of whole ecosystem.

3.2. Effect on Animals and human beings

As we have discussed earlier that dyes cause destruction of aquatic plants which are primary producer of the food chain in water ecosystem, that cause the scarcity of the food for aquatic animals. Beside that dyes also cause restriction of photosynthesis which decreases the concentration of oxygen in water which is essential for respiration in aquatic animals. Dyes are made up of several organic chemicals as well as heavy metals which enter into the aquatic animals through water or aquatic plants and cause several types of toxic effect on them. These dyes affect the cells, gills, lever, gut, kidney and other vital organs of the aquatic animals.

The harmful dyes and other pollutants persist in water sources, aquatic animals and plants for long time. These dyes and chemicals enter into human being either by direct consumption of polluted water or consumption of these plants and animals. The dyes can cause inflammation in eyes and skin by direct contact of polluted water. The most of the compounds which are used as dyes are carcinogenic in nature and cause cancer in several parts of bodies like liver, Kidney, skin, intestine etc. [2], [4]. The dyes can also cause substitution of enzyme co-factor which disturb the balance of enzymes[5]. A study shows that dyes can also affect reproductive system by interfering the ovulation and spermatogenesis[6].

5 Strategies to overcome dyes pollutants

4.1. Chemical methods

Chemical methods are most conventional strategy that used chemical compounds to degrade dyes pollutants. In chemical techniques there are several types of methods are used but the most common techniques are Fenton reagent technique, ozonolysis and photo-catalytic method[7] The problem with the conventional chemical techniques is that they required expensive chemicals and they produce several secondary pollutants which are further harmful of environment.

4.2. Physical Methods

The physical methods include adsorption, ion exchange, filtration, coagulation, flocculation, reverse osmosis etc. These methods are quite easy and nonspecific but the problems with these methods are that they are quite time taking, expensive and also producing sludge as secondary pollutant[8]. Due to which these methods are not applicable at industrial level.

4.3. Biological Method

The biological degradation of dyes can be classified into aerobic and anaerobic biodegradation. Aerobic degradation is catalyzed by specific enzyme like azo reductase enzyme for azo dyes[9]. Then it is treated with some microorganisms which degrade complex dyes into intermediate metabolites which can further degrade by using other micro-organism. Anaerobic degradation is comparative simple and non-specific method[10]. This method is applied in the absence of oxygen and enzymes are used as catalyst to reduce the dyes. These reduction reactions are carried out in the presence of certain co-factors and reduction mediators. In biological degradation several types of microorganisms like bacteria, fungi, yeast, and actinomycetes are used[11], [12]. The biological methods have a problem that they required a specific temperature and pH to work which is quite difficult to maintain.

6 Phytoremediation

This is one of the biological methods used for dye degradation. It is a method that used plants and microbes associated with plants root system to remove pollutants from environment. It has been recognised by several studies that plants grown near polluted areas developed potential to survive and these plants have genetically modified to accumulate pollutants like dyes[13]. Thus plants can work as self-driven bioreactors for remediation of pollutants[14], [15].

Plants have properties to uptake pollutants by their roots which provide large surface area for contact. Then pollutants are converted into several products by different mechanism. On the basis of mechanism applied, phytoremediation can be classified into different categories that involved phytoextraction, phytofiltration, phytostabilization, phyotransformation, rhizodegradation, phytovolatilization etc.

6.1. Phytoextraction

This is one of the processes applied in phytoremediation, this process includes extraction and storage of pollutants including dyes in different parts of plants like roots, stem and leaves. There are several studies carried out related to the phytoextraction of dyes by using several plants.

A study carried out by Kooh et.al.2017 to investigate the potential of *Azolla Pinnata* to remove methyl violet dye by phtoextraction with inclusion of Artificial Neural Network modelling[16]. It was observed that above plant shows 93% efficiency in phytoextraction when dose is 0.8 g (dye volume = 200 mL, initial pH = 6.0, initial dye concentration = 10 mg)[16]. The above study shows the capability of *Azolla Pinnata* in phytoextraction.

Another study carried out by Kooh et.al.2019 to study the phytoextraction capability of *Azolla Pinnata* for removal of Rhodamine B dye from aqueous solution[17]. The results show that *Azolla Pinnata* has 76% efficiency to remove plant dose of 0.4g of Rhodamine B dye at pH 3.0 and growth estimation also show that *Azolla Pinnata* can tolerate Rhodamine B dye concentration upto 20 mg/L[17].

6.2. Phytofiltration

This is another process used in phytoremediation; this process includes removal of dyes from water by the use of roots. The mechanism of this process is based on filtration, sorption and precipitation of the pollutants around the roots of plants[13]. There are several studies carried out on the Phytofiltration capacity of different plants.

A study was carried out by Khandare et.al.2013 to develop a phyto-tunnel system by using *Portulaca grandiflora* for filtration dye containing water[18]. This phyto-tunnel is prepared by using drilled PVC pipe filled with *Portulaca grandiflora* and treated with textile effluent contain dyes. The results shows that effluent and dye mixture get decolorize up to 87% and 90% in 96 and 60 hours respectively[18].

Another study carried out by Badawy et.al.2020 for assessment of phyto-filtration and bio sorption treatment from contaminant from waste water. This study analyse the use of dry leaves of Neem *Azadirachta Indica* and *Azolla Pinnata* in the removal of heavy metals present in aqueous solution[19]. The results proved the phytofiltration capabilities of both plants, however *Azolla Pinnata* have high capabilities of filtration than *Azadirachta Indica* [19].

6.3. Phytostablization

This is another process applied in phytoremediation of dyes that proceed by reduction in the bioavailability and immobilization of pollutants[13]. This process is carried out by sorption, precipitation and complexation of pollutants in rhizosphere[13]. There are several studies that show the phytostabilization capabilities of different plant.

A study was carried out by Balan et.al.2011 to study the Phytostabilization of pollutants present in contaminated soil. The study shows that plantation at contaminated sites reduces leaching and control erosion that creates an aerobic environment around roots that bind the contaminants[20]. The microbial activity around roots can increase the degradation of organic contaminates also[20].

Another study carried out by Mendez et.al.2007 to study phyto-stabilization potential of Quailbush. The study was carried out at abandoned mine tailing sites and results shows that Quailbush is a very good candidate for phytostabilization of mine tailings in semiarid environments[21].

6.4. Phytotransformation

This phytoremediation process involved transformation of pollutants into non harmful materials by the use of metabolic and enzymatic activities of plants. In this process roots of plants absorb the pollutants and convert them into other materials internally or externally[13]. There is several studies show the phyto-transformation of several dyes by using different plants species.

A study carried out by Adki et.al.2012 to study the phyto-transformation potential of cactus for textile dye degradation. This study was carried out for degradation of Red HE7B dye by *Cactaceae Nopalea cochenillifera* cell cultures. The results show that Red HE7B dye is converted into non-hazardous carboxylic and phenolic compounds[22].

Another study carried out by Kagalkar et.al.2011 to study the phytodegradation of Malachite green dye by using cell suspension culture of *Blumea malcolmii* Hook. The enzymatic analysis in this study shows that enzymes such as laccase, veratryl alcohol oxidase and DCIP reductase are involved in the transformation of Malachite green dye[23].

6.5. Rhizodegradation

This is one of the phytoremediation methods that involve degradation of pollutants by soil dwelling microbes present in rhizosphere. The enzymes present in the roots of plants stimulate this transformation process. There are several studies that prove the Rhizodegradation of dyes.

A study was carried out by Watharkar et.al.2013 to study the phytotransformation of Navy Blue RX dye by *Bacillus pumilus*. In this study rhizospheric bacterium isolated from the roots of *Bacillus pumilus* was used to decolorize the Navy Blue RX dye. The results show that the efficiency of *P. grandiflora* Juss. & *B. pumilus* strain PgJ for phytotransformation of above dye is noteworthy and produce less harmful metabolites[24].

Another study carried out by kumar et.al.2011 to study the Rhizo-remediation of azo dyes constructed wetland technology using *Typha latifolia*. The results shows that *Typha latifolia* is one of the most commonly found and widely used macrophyte in constructed wetland and it is very effective against azo dyes[25].

6.6. Phytovolatilization

This is one of the methods used in phytoremediation that involves transformation of pollutants into volatile form and released into the air by the use of plants[13]. This process includes absorption of water soluble pollutants by roots and transformation of pollutants during vascular translocation from roots to leaves[13]. There are several studies carried out in the phyto-volatilization of pollutants.

A study was carried out by Limmer et.al.2016 to study the phyto-volatilization of organic pollutants including dyes. This study shows that plants can show two types of volatilization, direct volatilization that includes transformation of pollutants inside the plant and indirect volatilization that includes transformation of pollutants into volatile substance within the soil by the use of plant enzymes[26].

Another study was carried out by Zhang et.al.2020 to study phyto-volatilization of 2, 4-dibromophenol and 2,4-dibromoanisole by rice plant. The study show that rice plant effectively transform both the compounds into volatile substance , however it is more effectively towards 2,4-dibromoanisole[27].

Table-3: Different Phytoremediation techniques and their description with references

S. No.	Phytoremediation Technique	Basic Description	References
1.	Phytoextraction	Extraction and storage of pollutants in different parts of plants like roots, stem and leaves	[16], [17]
2.	Phytofiltration	filtration, sorption and precipitation of the pollutants around the roots of plants	[18], [19]
3.	Phytostabilization	sorption, precipitation and complexation of pollutants in rhizosphere and reduction in the bioavalibility of pollutants	[20], [21]
4.	Phytotransformation	Transformation of pollutants into non harmful materials by the use of metabolic and enzymatic activities of plants	[22], [23]
5.	Rhizodegradtion	Degradation of pollutants by soil dwelling microbes present in rhizosphere	[24], [25]
6.	Phytovolatalization	Transformation of pollutants into volatile form and released into the air by the use of plants	[26], [27]

7 Conclusion

The above study shows that there are several strategies available to overcome dye pollutants that include physical methods, chemical methods and biological methods. Among them phytoremediation is one of the biological methods that use plants for the remediation of dye pollutants. This method includes several processes on the basis of mechanism applied for degradation that includes phytoextraction, phytofiltration, phytostabilization, phyotransformation, rhizodegradation and phytovolatilization. These methods are cost effective and environment friendly as these methods does not require any harmful and costly chemicals and machinery. These properties make it a very effective tool to overcome dye pollutants. This method has several limitations as it is time taking and can degrade small amount of pollutant which restrict it to use at industrial level, however this method can be used along with other methods used to overcome dye pollutants.

8 References

[1] A. Porto, ‘Selection of Pseudomonas for industrial textile dyes decolourization’, *Int. Biodeterior. Amp Biodegrad.*, Jan. 2009, Accessed: Mar. 08, 2024. [Online]. Available: https://www.academia.edu/23236055/Selection_of_Pseudomonas_for_industrial_textile_dyes_decolourization

[2] R. Al-Tohamy *et al.*, ‘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.*, vol. 231, p. 113160, Feb. 2022, doi: 10.1016/j.ecoenv.2021.113160.

[3] H. S. RAI, M. S. BHATTACHARYYA, J. SINGH, T. K. BANSAL, P. VATS, and U. C. BANERJEE, ‘Removal of Dyes from the Effluent of Textile and Dyestuff Manufacturing Industry: A Review of Emerging Techniques With Reference to Biological Treatment’, *Crit. Rev. Environ. Sci. Technol.*, vol. 35, no. 3, pp. 219–238, Mar. 2005, doi: 10.1080/10643380590917932.

[4] M. Berradi *et al.*, 'Textile finishing dyes and their impact on aquatic environs', *Heliyon*, vol. 5, no. 11, p. e02711, Nov. 2019, doi: 10.1016/j.heliyon.2019.e02711.

[5] L. Wu *et al.*, 'Impacts of an azo food dye tartrazine uptake on intestinal barrier, oxidative stress, inflammatory response and intestinal microbiome in crucian carp (*Carassius auratus*)', *Ecotoxicol. Environ. Saf.*, vol. 223, p. 112551, Oct. 2021, doi: 10.1016/j.ecoenv.2021.112551.

[6] V. Suryavathi *et al.*, 'Acute toxicity of textile dye wastewaters (untreated and treated) of Sanganer on male reproductive systems of albino rats and mice', *Reprod. Toxicol.*, vol. 19, no. 4, pp. 547–556, Mar. 2005, doi: 10.1016/j.reprotox.2004.09.011.

[7] R. V. Kandisa and N. Saibaba KV, 'Dye Removal by Adsorption: A Review', *J. Bioremediation Biodegrad.*, vol. 07, no. 06, 2016, doi: 10.4172/2155-6199.1000371.

[8] K.-T. Chung, 'Azo dyes and human health: A review', *J. Environ. Sci. Health Part C Environ. Carcinog. Ecotoxicol. Rev.*, vol. 34, no. 4, pp. 233–261, Oct. 2016, doi: 10.1080/10590501.2016.1236602.

[9] J. Feng, C. E. Cerniglia, and H. Chen, 'Toxicological significance of azo dye metabolism by human intestinal microbiota', *Front. Biosci. Elite Ed.*, vol. 4, no. 2, pp. 568–586, Jan. 2012, doi: 10.2741/e400.

[10] Y. Gao, B. Yang, and Q. Wang, 'Biodegradation and Decolorization of Dye Wastewater: A Review', *IOP Conf. Ser. Earth Environ. Sci.*, vol. 178, p. 012013, Aug. 2018, doi: 10.1088/1755-1315/178/1/012013.

[11] A. Pandey, P. Singh, and L. Iyengar, 'Bacterial Decolorization and Degradation of Azo Dyes', *Int. Biodeterior. Biodegrad.*, vol. 59, pp. 73–84, Mar. 2007, doi: 10.1016/j.ibiod.2006.08.006.

[12] Y. Patel, U. Chhaya, D. Rudakiya, and S. Joshi, 'Biological Decolorization and Degradation of Synthetic Dyes: A Green Step Toward Sustainable Environment', 2021, pp. 77–110. doi: 10.1007/978-981-15-7455-9_4.

[13] U. Tahir, A. Yasmin, and U. H. Khan, 'Phytoremediation: Potential flora for synthetic dyestuff metabolism', *J. King Saud Univ. - Sci.*, vol. 28, no. 2, pp. 119–130, Apr. 2016, doi: 10.1016/j.jksus.2015.05.009.

[14] 'Enhanced biodegradation of aromatic pollutants in cocultures of anaerobic and aerobic bacterial consortia | Antonie van Leeuwenhoek'. Accessed: Jun. 19, 2024. [Online]. Available: https://link.springer.com/article/10.1007/bf00872195

[15] 'Degradation of azo dyes containing aminonaphthol by Sphingomonas sp strain 1CX | Journal of Industrial Microbiology & Biotechnology'. Accessed: Jun. 19, 2024. [Online]. Available: https://link.springer.com/article/10.1038/sj.jim.2900746

[16] M. R. R. Kooh, L. B. L. Lim, L.-H. Lim, and O. A. Malik, 'Phytoextraction potential of water fern (Azolla pinnata) in the removal of a hazardous dye, methyl violet 2B: Artificial neural network modelling', *Int. J. Phytoremediation*, vol. 20, no. 5, pp. 424–431, Apr. 2018, doi: 10.1080/15226514.2017.1365337.

[17] M. R. R. Kooh, M. K. Dahri, L. B. L. Lim, L. H. Lim, and S. L. Lee, 'Phytoextraction capability of Azolla pinnata in the removal of rhodamine B from aqueous solution: artificial neural network and random forests approaches', *Appl. Water Sci.*, vol. 9, no. 4, p. 80, May 2019, doi: 10.1007/s13201-019-0960-6.

[18] R. V. Khandare, A. D. Watharkar, A. N. Kabra, M. S. Kachole, and S. P. Govindwar, 'Development of a low-cost, phyto-tunnel system using Portulaca grandiflora and its application for the treatment of dye-containing wastewaters', *Biotechnol. Lett.*, vol. 36, no. 1, pp. 47–55, Jan. 2014, doi: 10.1007/s10529-013-1324-1.

[19] R. Badawy, S. Shehata, and Y. Aboulsoud, 'Assessment of phyto-filtration and biosorption treatment on the removal of contaminant form wastewater', *Nat. Sci.*, vol. 18, pp. 16–26, Dec. 2020, doi: 10.7537/marsnsj180220.04.

[20] N. S. Bolan, J. H. Park, B. Robinson, R. Naidu, and K. Y. Huh, 'Chapter four - Phytostabilization: A Green Approach to Contaminant Containment', in *Advances in Agronomy*, vol. 112, D. L. Sparks, Ed., Academic Press, 2011, pp. 145–204. doi: 10.1016/B978-0-12-385538-1.00004-4.

[21] M. O. Mendez, E. P. Glenn, and R. M. Maier, 'Phytostabilization Potential of Quailbush for Mine Tailings', *J. Environ. Qual.*, vol. 36, no. 1, pp. 245–253, 2007, doi: 10.2134/jeq2006.0197.

[22] V. S. Adki, J. P. Jadhav, and V. A. Bapat, 'Exploring the Phytoremediation Potential of Cactus (nopalea Cochenillifera Salm. Dyck.) Cell Cultures for Textile Dye Degradation', *Int. J. Phytoremediation*, vol. 14, no. 6, pp. 554–569, Jul. 2012, doi: 10.1080/15226514.2011.619226.

[23] A. N. Kagalkar, M. U. Jadhav, V. A. Bapat, and S. P. Govindwar, 'Phytodegradation of the triphenylmethane dye Malachite Green mediated by cell suspension cultures of *Blumea malcolmii* Hook.', *Bioresour. Technol.*, vol. 102, no. 22, pp. 10312–10318, Nov. 2011, doi: 10.1016/j.biortech.2011.08.101.

[24] A. D. Watharkar, N. R. Rane, S. M. Patil, R. V. Khandare, and J. P. Jadhav, 'Enhanced phytotransformation of Navy Blue RX dye by *Petunia grandiflora* Juss. with augmentation of rhizospheric *Bacillus pumilus* strain PgJ and subsequent toxicity analysis', *Bioresour. Technol.*, vol. 142, pp. 246–254, Aug. 2013, doi: 10.1016/j.biortech.2013.05.044.

[25] A. A. Kumar, D. Sukumaran, and S. G. T. Vincent, 'Rhizoremediation of Azodyes by Constructed Wetland Technology using Typha latifolia', in *Phytobiont and Ecosystem Restitution*, V. Kumar, M. Kumar, and R. Prasad, Eds., Singapore: Springer, 2018, pp. 253–261. doi: 10.1007/978-981-13-1187-1_13.

[26] M. Limmer and J. Burken, 'Phytovolatilization of Organic Contaminants', *Environ. Sci. Technol.*, vol. 50, no. 13, pp. 6632–6643, Jul. 2016, doi: 10.1021/acs.est.5b04113.

[27] Q. Zhang *et al.*, 'Uptake, phytovolatilization, and interconversion of 2,4-dibromophenol and 2,4-dibromoanisole in rice plants', *Environ. Int.*, vol. 142, p. 105888, Sep. 2020, doi: 10.1016/j.envint.2020.105888.