Toxicology International, *Vol 28(2), 165-176, 2021, DOI: 10.18311/ti/2021/v28i2/26798*

Review Article
ISSN (Print): 0971-6580
ISSN (Online): 0976-5131

Adverse Impact of Textile Dyes on the Aquatic Environment as well as on Human Beings

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History: Received 2021-01-21; Accepted 2021-03-16; Published 2021-05-31

Abstract

Dyeing stages involved in textile processing are considered to be one of the major contributors to aquatic pollution. Dyes being highly persistent due to the chemical composition are considered to be one of the most detrimental groups. Textile dyes essentially affect the exquisite aspect of aquatic bodies by enhancing biochemical as well as chemical oxygen demand. It also attenuates photosynthesis, hinders the growth of plants and invades the food chain. The bioaccumulating potential promotes toxicity, carcinogenicity and mutagenicity. Therefore, the present review article aims to focus on the predominant effects of textile dye on in the aquatic environment particularly on algae, fish and ultimately on humans being.

Keywords: Accumulation, Carcinogenesis, Textile Dyes, Toxicity

1. Background

A rapid increase in industrialization has led to an imminent boost in anthropogenic interference proceeding towards a huge imbalance in the integrity of the ecosystem leading to environmental pollution[1]. Waste water pollution has been on the top of the concerned areas as it is considered to be a cause of dreadful diseases including skin irritation, kidney failure, intestinal tract infection and cancer[2]. Textile, printing and pharmaceutical industrial discharge are the main sources of water pollution[3]. The textile industry is one of the largest in the world with a massive raw material and textiles manufacturing base. Our economy is largely dependent on the textile manufacturing and trade in addition to other major industries[4]. Despite of its evident value, this sector has become one of the biggest global polluters and it consumes high amounts of fuels and chemicals[5]. The attention is mainly placed on the excessive consumption of drinking water in several processes such as washing, bleaching, dyeing etc.[6]. Recently several studies revealed about 7 x 10^5 tons/year of worldwide consumption of dyes and pigments and only the textile sector is reported to consume about two-thirds of dyes and pigments[7,8]. The utilization of dyes involves modification of property of coloration of different substrates such as fabric, paper, leather, etc.[3].

Every year, a number of novel-colored compounds hit the market having several applications[9]. A study performed by Guaratini and Zanoni[10], revealed 26,500 tons of annual consumption of dyes which is correlated to 3.8% of global dyes production. Dyeing and finishing stages involved in textile processing are considered to be one of the major contributors to aquatic pollution. Chequer *et al.*[11] revealed that use of synthetic complex dyes as coloring materials increased remarkably and out of which 12% of textile dyes are lost during manufacturing and processing. However, 20% of lost dyes are known to be present in industrial effluents having a serious impact on plants by interrupting photosynthesis, on the environment by altering physiochemical parameters, on humans as well as on aquatic fauna[12]. Textile dye residues causes extreme water contamination that are either released directly into

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environment or omitted by wastewater treatment systems of industries especially in areas nearby to textile industries[13,14].

2. Classification of Dyes

Dyes are soluble organic compounds and have three essential groups in their molecules: The chromophore (imparts color), the auxochrome (for fixation of the dyes) (Table 1) and the matrix (rest of the atoms of the molecule)[15,16]. Based on their origin dyes classified as natural and synthetic dyes. Natural dyes are further divided based on their origin which can be plants, animals and minerals. Whereas synthetic dyes are divided based on their chemical structure such as azo, phthalocyanine, indigo, anthraquinone, aryl methane and heterocyclic dyes. Dyes may also be classified based on their solubility in water, chromophore, and industrial application[15,17,18] (Figure 1). Acid, direct, mordant, basic, metal complex and reactive dyes are examples of water-soluble dyes whereas azoic, disperse dyes, vat, and sulfur are water-insoluble dyes[19].

Table 1. Auxochrom and chromophor groups of textile dyes

Auxochrom Groups		Chromophor groups	
Alkoxyl	(-OR)	Azo	(-N=N-)
Amino	($-NH_2$)	Alkenes	(-C=C-)
Aldehyde	(-CHO)	Carbonyl	(>C=O)
Carboxyl group	(-COOH)	Ethylenic	(>C=C<)
Dimethylamino	($-N(CH_3)_2$)	Ketone-imine	(>C=NH)
Halogens	Cl, Br, I, At	Sulphide	(>C=S)
Hydroxyl	(-OH)	Nitro	($-NO_2$ or =NO–OH)
Methylamino	($-NHCH_3$)	Nitroso	(-NO or –N-OH)
Methyl mercaptan	($-SCH_3$)	Polymethine	(=HC-HC = CH–CH =)
Sulfonate	($-SO_3H$)		

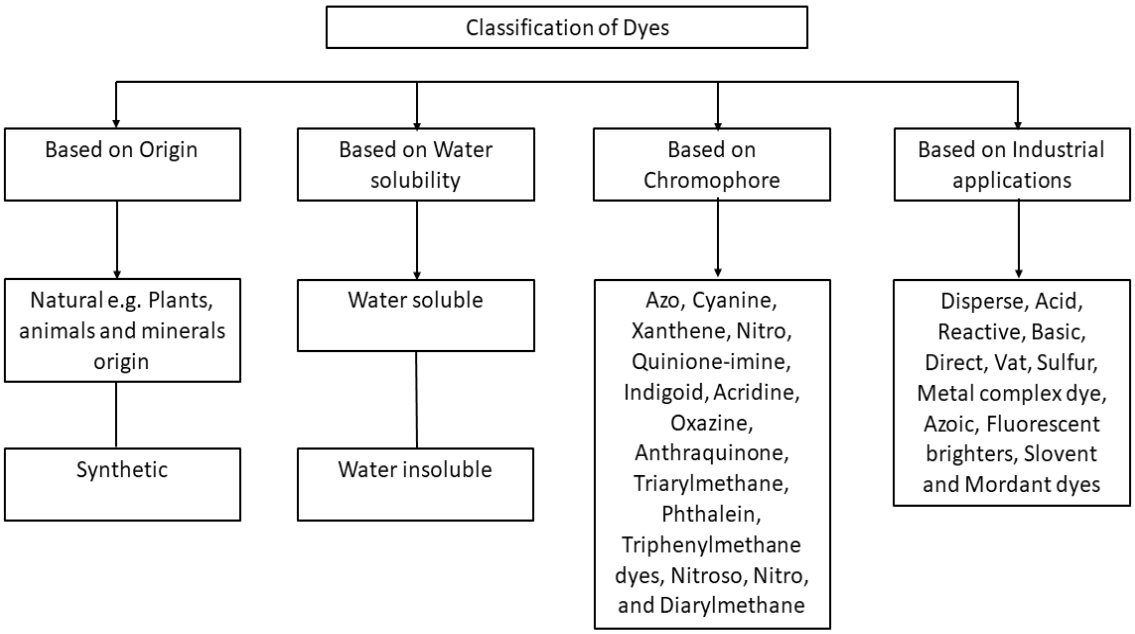


Figure 1. Classifications of dye.

3. How Dyes are Affecting the Food Chain

During the dyeing process, the color released damages the aquatic bodies[20] by hindering the penetration of sunlight to water which thus leads to a drop in photosynthesis[21] and water oxygen levels thus affecting aquatic fauna and flora[22]. Light absorption primarily diminishes the photosynthetic activity of algae and seriously influences the food chain as the algae are the base of the food chain, thus affecting every organism above it. The Remazol Red Brilliant dye and Indigo dye effluents were reported to affect the food chain in aquatic environments therefore causing an ecological imbalance[23,24]. The scarcity of algae is one of the main reasons that aquatic life suffers in areas where dyes are discharged, and another is the toxicity of the dyes themselves. These textile dyes are also observed to be toxic, mutagenic, and carcinogenic in nature[25,26]. Studies performed reported that these dyes act as persistent pollutants and thus enter into the food chains leading to biomagnification[27] such that animals at higher trophic levels have a greater level of contamination as compared to animals at low trophic level[28–30].

4. Impact of Textile Dyes on the Aquatic Environment

The major complication of the textile effluent is color, due to the abundant use of synthetic organic compounds as dyes[31]. Studies reported that up to 200000 tons are lost in the industrial discharge due to their less binding efficiency and depending upon their chemical structure the amount of dye lost varies from 2% to 50%[32]. Dyes lead to several environmental hazards due to their high thermal and photo stability that resist biodegradation and increases persistent in the environment. The potential of absorbing and reflecting sunlight entering the water of dyes decrease photosynthetic efficiency of aquatic producers and consequently affects the food chain. Moreover, high textile dyes concentration in water bodies hampers the oxygenation potential of water received, therefore hinders biological activity in aquatic life[21]. A study performed by Khan and Malik[32], reported that the effluent discharged from the textile industries carries compounds having a hydrosulfide group also blocks the passage of light through the water body thus causing an imbalance in Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). A study performed by Setiadi *et al.*[21] also reported enhanced levels of BOD and COD in the residual textile industrial water. Moreover, oxidative stress, provided by chromium of textile dyes, is another problem associated with a recalcitrant character, offering considerable damage to the growth and development of plants, especially to photosynthesis and CO_2 assimilation[33]. After disruption in the processes of oxygenation of water bodies and photosynthesis, another polluting effect of dyes on the environment is the recalcitrant property which leads to the accumulation of these toxic dyes and their intermediates in sediments and aquatic organisms which may promote toxicity, mutagenicity, and carcinogenicity. A study done by Tkacz and Maguire[33], indicated the presence of 15 dyes including C.I. Disperse Red 60, C.I. Disperse Blue 79 and C.I. Disperse Blue 26 in water and sediments of a river in Canada. A similar study conducted by Oliveria[34], reported that C.I. Disperse Blue 373 and C.I. Disperse Orange 37 were present to be about 1 µg and 10 µg, respectively for each 1 g of sediment samples of two different locations. One sample was taken from a collection site at the entrance of the water treatment station for public supply and other was immediately below the discharge of the effluent of the textile industry indicating the accumulative potential of dyes. Generally, water pollution is caused by a massive amount of non-biodegradable organic compounds especially dyes and their intermediates[35]. Being non-biodegradable, it tends to enter the food chain and after uptake through any route, these xenobiotics tend to accumulate in fatty tissues of aquatic/terrestrial organisms. The primary recipient of such toxic contaminants released from textile dyeing industries includes the fishes and algae[36,37]. The algae are the one of main primary producers in the aquatic ecosystem and any alternation in water quality parameters can affect the balance of the entire aquatic ecosystem[38]. Whereas, fish have an important position in the aquatic food chain both as primary and secondary consumers depending upon feeding habit. Fish also serve as reliable and sensitive bioindicator of aquatic pollution and form an important link in the food chain of humans[29]. Therefore, the present review includes the impact of textile dyes on algae, fishes and ultimately on human has been discussed.

4.1 Impact on Algae

Algae are fast and easy growing and they have high sensitivity towards chemical stressors. Thus, microalgae have been used to evaluate environmental perturbations as indicators of water quality. Recently, studies reported that the microalgae have been used for assessment of the toxicity of dyes besides chemical pollutants as metals, herbicides and insecticides[38]. The indigo dye effluent was reported to reduce the growth and biomass production of a freshwater microalga *Scenedesmus quadricauda* ABU12 significantly. The results revealed morphological changes in coenobium structure such as a decrease in the number of cells per coenobium that indicated the impact of environmental stress. The high concentration of indigo dye effluent was observed to be adversely affecting chlorophyll a, cell density and dry weight production[24]. The increasing concentration

(25-100 mg/l) of Congo Red, Metanil Yellow and Mordant Green dyes were also reported to reduce the growth of algae *Spirulina platensis* and its nutrient level[39].

In a study[40], the aquatic toxicity of 42 commercial dye formulations with different color index and different chemical classifications, using the application of *in silico* tools and ecological bioassays was investigated on algae (*Raphidocelis subcapitata*) and daphnids (*Daphnia magna*). Acute and long-term ecotoxicological assays with algae were applied to evaluate the potential impact of these products, according to the OECD guidelines 201 and 202. The results showed 30 formulations were toxic at lower than 100 mg/L for algae suggesting algae were more sensitive to dye toxicity, particularly when the effects on cell number were considered. The effects of azo dye Direct blue 15 (DB15) exposure to a battery of bioassays was reported[38]. The primary producer microalga: *Pseudokirchneriella subcapitata*, a primary consumer: *Ceriodaphnia dubia*, and a secondary consumer: *Danio rerio* representing a food chain were used in the study. The results revealed that P. subcapitata (IC_{50} = 15.99 mg L^{-1}) was more sensitive than C. dubia (LC_{50} = 450 mg L^{-1}). In microalga *P. subcapitata*, the concentration of chlorophyll-a and -b was higher than that in control whereas carotenoids were reduced. Additionally, the concentrations of protein, carbohydrates, and lipids per cell were increased in *P. subcapitata* exposed to DB15. In the case of *C. dubia*, the start of reproduction was impeded and consequently survival, total progeny, and the number of released clutches were significantly decreased. There is the development of yolk sac edema, curved tail, and skeletal deformations in embryos of *D. rerio* exposed to DB15 and after 144 hpf, as the concentration of dye raised, DB15 produced a significant increase in embryos without a heartbeat. The toxic effects of the different extent on microalgae, cladocerans and zebrafish embryos suggests that its discharge needs to be regulated[38].

In another study, the toxicity of three textile dyes—Drimarene blue, Optilan yellow and Lanasyn brown, was studied in a green alga *Chlorella vulgaris* at graded concentrations (10, 20, 30, 40, 50 ppm) for 96 h. The EC50 founded to be 34.13 ppm (Drimarene blue), 36.27 ppm (Lanasyn brown), to 46.40 ppm (Optilan yellow). The green alga *C. vulgaris* showed a concentration-dependent decrease in specific growth rate, pigments and also a significant decrease in the number of elements (C, H, N, S) after exposure to the dyes. These results suggest that exposure to dyes inhibited the growth, pigment and elemental composition of the algal cells[12]. Recently, the toxicity of Textile Dyeing Effluents (TDE) was observed on the alga *Scenedesmus obliquus* at the physiological (algal growth), biochemical (chlorophyll-*a*) synthesis and Superoxide Dismutase (SOD) activity and structural (cell membrane integrity) level. There was an imbalance in the antioxidant system of the algal cells suggested by the stimulation rate of SOD activity that increased from day 3 (57.25%~83.02%) to day 6 (57.25%~103.81%), and then decreased on day 15 (-4.23%~-32.96%). The algal cells are suggested to be stimulating to produce excessive reactive oxygen species, which would cause peroxidation in the cells, thereby destroying chloroplasts, inhibiting chlorophyll synthesis and reducing photosynthesis. The rate of Chlorophyll-*a* synthesis inhibition increased gradually, reaching 19.70%~79.39% on day 15, while the rate of growth inhibition increased from day 3 (-12.90% ~10.16%) to day 15 (21.27%~72.46%) and with increasing exposure time, irreversible damage to algae can lead to death[41].

4.2 Impact on Fish

Fish have great sensitivity and response towards the changes in aquatic environment and any undesirable change might be reflected in the biochemical, physiological and histological parameters of fish. The toxicity of textile effluents poses threat to fish biota, both directly and indirectly as the direct accumulation of pollutants and the rise in physical parameters like colour, turbidity, temperature and total solids makes light a limiting factor that alters food chain of fish[42]. The study performed by Kaur *et al.*[43] showed alterations in behavioral responses of Cirrhinus *mrigala* such as gulping air on the surface or jumping out of water, erratic movements and fast opercular movements was observed when exposed to sublethal concentrations (24.48%, 12.24% and 6.12%) of dyeing industry effluent. Similarly, Amwele *et al.*[44] reported behavioural change in fish *Oreochromis niloticus* after exposure to the metal complex dark green azo acid dye. The alternations such as fish descended to bottom with minimal activity after 90-min exposure to the metal complex dark green azo acid dye. Fish show increased air gulping likely a response to chemical inhibition of respiration. Also, subchronic toxicity indicated fluctuations in a number of erythrocytes, leukocytes and thrombocytes in all chemical treatments. Barot and Bahadur[45], also reported behavioural changes such as loss of balance, erratic swimming and severe mucus secretion over the gills in Labeo rohita fingerlings after exposure to three sublethal concentrations of C.I. Acid Orange 7 (AO 7) for 5, 10 and 15 days.

Further several studies performed revealed that dyes are also involved in irreversible structural modification in the DNA of fish that appear even at those levels of toxins which are otherwise safe for survival[46,47]. The study performed by Parmar and Barot[48], showed the significantly higher number of Micronuclei (MN) in peripheral erythrocyte and

gill cells of Catla catla exposed to C.I. Reactive Red 120 (RR 120) azo dye suggesting its genotoxic potential. In a similar study, Parmar and Shah[49], reported cytotoxicity of the azo dye Reactive Red 120 (RR120) at sublethal concentrations (0.35, 0.7, 3.5 mg/L) for 10, 20 and 30 days on fish *Catla catla* using DNA damage in gill cells and blood cells. Rishin *et al.*[50] also reported genetic damage in peripheral erythrocytes of the fish, *Anabas testudineus* exposed to acid orange 7. The nuclear abnormalities such as irregular, notched and blebbed nucleus were observed.

A comparative analysis of the toxicity of treated and untreated textile industrial wastewater performed on freshwater fish *Gambusia affinis* showed high mortality and cytotoxic effects on blood cells as compared to treated water[51]. Another report performed on *Mastacembelus armatus* showed the toxic effects of textile dyeing effluent which includes alteration in ionic regulations of various tissues[36]. A similar study conducted on the impact of the textile dyeing industry on *Oreochroomis mossambicus* and *Spiralothelphusa hydrodroma* respectively showed toxic effects inside the organisms[52,53]. The increased level of liver cytochrome P4501A (CYPlA) monooxygenase activity was in caging tilapia (*Oreochromis niloticus*) and mudfish (*Clarias anguillaris*) suggesting that the textile mill effluent contains some highly potent inducers of biotransformation enzymes[54]. A study performed by Belpaire *et al.*[55] revealed the presence of residues of sixteen dyes used in textile industries: triarylmethanes (Malachite Green (MG) and Leuco Malachite Green (LMG), Crystal Violet (CV) and Leuco Crystal Violet (LCV), Brilliant Green (BG), Ethyl Violet, Pararosaniline HCL, Victoria Blue R, Victoria Blue B and Victoria Pure Blue BO), xanthenes (Rhodamine 6G and Rhodamine B), phenothiazines and phenoxazines (Methylene Blue, New Methylene Blue, Azure B and Nile Blue A) and their metabolites. The residues were analyzed in muscle tissue samples of European eels (*Anguilla anguilla*) collected from 91 locations in Belgian rivers, canals, and lakes sampled between 2000 and 2009. The results suggested that the edible fish become unfit for human consumption after being exposed to such toxic dyes.

5. Impact of Textile Dyes on the Humans

The poor quality of water directly affects the health of different groups of organisms, which range from the simplest life form to complex organisms, including mammals[56]. Humans are also highly susceptible to the toxic effects of dyes released in textile effluents. Usage of dye-carrying textile wastewater for soil irrigation is a common practice performed in developing countries[57–61]. Thus, a huge number of dyes gets accumulated into the soil surface around textile processing plants. A study performed by Zhou[60], stated that approximately 12.3 to 456.2 mg of dyes per kg of soil were present in surface soil near these industrial units. Dyes get stabilized in soil within a short time but have the potential to retain in the soil for a longer duration[62]. Thus, humans might be affected by these dyes in two ways that are: Either human directly eats contaminated food fish or consume crops cultivated in the soil in which toxic dyes or their degraded forms are accumulated. Thus, by entering the food chain these contaminants can reach the human organs causing a series of pathologies[63].

The property of recalcitrance leads to their bioaccumulation in soil and sediments and transporting them to public water supply routes[64]. Certain azo dyes lead to partially degraded or fully degraded compounds including aromatic amines[65] which are considered toxic contaminants of the environment. The structural composition of dyes results in an imbalance of the structure and function of the ecosystem[66]. Long-term exposures of complexes of metal dyes on human health have been reported by Ito *et al.*[64] indicating the harmful impact of industrial effluents on humans. The dyes mainly used in textile industries carry nickel[67], cobalt, copper, and chromium[68] as heavy metal cations which after being released into the water bodies are reported to be accumulated in various tissues of fishes[69] ultimately affecting human after being entered into the food chain. Synthetic dyes invaded in the late nineteenth century before that natural dye was in use[70]. Along with synthetic dyes, intermediates compounds including benzidine and 2-naphthylamine are also generated which are also reported to cause bladder cancer[71]. In general, studies showed that disorders caused by textile dyes range from dermatitis to disorders of the central nervous system[63] or caused by inactivation of the enzymatic activities resulted from the substitution of enzymatic cofactors[72,73].

The acute exposure of textile dyes leads to toxicity after oral ingestion and inhalation of dust[74] which leads to the emergence of irritation in the eyes and skin[71]. The workers who are involved in the production or handling of reactive dyes are more susceptible to diseases such as dermatitis, allergic conjunctivitis, rhinitis, occupational asthma and other allergic reactions[75]. These reactive dyes are reported to act as antigens after forming conjugate between human serum albumin and the reactive dye leading to the production of Immunoglobulin E (IgE) antibodies which get combined with histamine. In case of occupational asthma, the reactive dyes were found to be responsible due to their chromogen that help in binding dye to hydroxyl groups on cellulose fibres that in turn elicit immune response by acting as haptens. Long term exposure to textile dyes also presents their genotoxic potential[71,74,75].

Table 2. Specific dyes reported to be toxic

Dye	Comments
Azure B	- reported to penetrate lipid bilayer[75]. - intercalate with deoxyribonucleic acid and ribonucleic acid[76]. - a reversible inhibitor of monoamine oxidase A (MAO-A) as suggested by in vitro studies[77]. -an inhibitor of human glutathione reductase and related enzymes[78].
Amido Black 10B	- toxic by ingestion, inhalation, and may cause skin and eye irritation and damage to respiratory track[79]. -symptoms may include coughing, shortness of breath with development of burns, rashes with redness and pain[79].
The Disperse Red 1	- observed to be mutagenic in the study performed by Chequer et al[80]. - increases the frequency of micronuclei in human lymphocyte, human hepatoma (HepG2) cell lines, and hepatocyte imitative cells (in vivo)[81,82]. - formation of DNA adducts[80].
Eriochrome Black T (EBT)	-recalcitrant to biological treatments[83]. -toxic and carcinogen anionic azo dye[84,85].
Methyl orange (MeO)	-toxic to human health and can cause breathing, diarrhoea, vomiting and nausea[86]. -recalcitrant to biological treatments[86].
Sudan, I dye (Solvent Yellow 14)	- After ingestion, it is transformed into carcinogenic aromatic amines[87]. - neoplastic liver nodules occurred due to Sudan I dye[88].
The Basic Red 9 dye	- carcinogenic property[89]. - degraded into carcinogenic aromatic amines in anaerobic conditions and the discharge of these compounds possesses the potential to cause allergic dermatitis, skin irritation, mutations, and cancer[90]. - Pohanish[91], showed the local sarcomas and tumors in rat tissues after the exposure of degraded material of this dye.
The Crystal Violet Dye	- mitotic poisoning[92]. - clastogenic effects seen in ovules of Chinese hamster (in vitro)[93]. - a strong carcinogenic agent[93]. - chemical cystitis, irritation of the skin and digestive tract, respiratory and renal failure, among others[92].
Malachite green	- affect the immune system, reproductive system, and its genotoxic and carcinogenic properties[94–96]. - in body reduced to some extent to leucomalachite green and can accumulate in the body for more than 20 weeks[97].

6. Strategies for the Ecofriendly Environment: Free from Toxic Dyes

- Natural dyes can be considered as a solution to the negative impact of synthetic dyes. These are obtained from renewable products assuring no negative impact on the environment.
- It is critical to remove various toxic dyes from the wastewaters before their release into the aquatic bodies. The crucial step to reduce the cost of wastewater treatment includes reducing the consumption of water or simply reusing the water. The rinsing process

consumes the maximum amount of water[98] as it involves rinsing of products in a series of tanks using progressively cleaner water. Here the water used can be reused by moving the last rinse tank towards the first and reusing it. This water can also be used in processing such as rinsing containers, washing floors, etc.

- The use of eco-friendly products during the manufacturing of garments should be considered as the main priority. Buyers choosing clothes that involve dyes that do not pollute water could be considered as serving society at the consumer level.
- Air dyeing technology should be considered widely as it is a process that involves the use of air rather than water for dyeing, thus contributing to less water consumption. This process is said to consume 95% less water and an 84% reduction in emission of greenhouse gases is also observed[99]. It is much efficient as it requires less energy and should be adopted in both large-scale and small-scale industries.
- Degrading the compound to a nontoxic form before discharging it into the water bodies should be considered. Physical, chemical, and biological methods are adopted for degrading the toxic compound but biological processes being highly accurate to encourage the economic growth inconsistency with the environment and assure the quality of life are considered to be more efficient. Biological processes involve phytoremediation with plants and biodegradation[100] with the help of microorganisms involving fungi, bacteria[101], etc. that are used for discoloration, transformation and mineralize the toxic materials.

7. Conclusion

This context presents a deep unfolding of damage caused by high levels of toxic and recalcitrant dyes released from textile industries generating disastrous effects on the environment and ultimately to human beings. Thus, conclusively this study calls for the urgency in imposing laws and regulations for inducing management strategies for treating industrial waste effluent before its discharge into aquatic bodies.

8. Acknowledgment

The authors are sincerely thankful to CSIR-UGC for awarding fellowship to Sukanya Mehra and Mandeep Singh and UGC SAP (New Delhi) for providing infrastructural facilities.

9. Conflicts of Interest

The authors declare that they have no conflicts of interest.

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