A REVIEW

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Bioremediation: An ecological solution to textile effluents

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Rapid technological advances, speedy growth in urban sector and unplanned human settlement in the cities have resulted in the pollution problem. Industrial and nuclear energy installation produce large quantities of toxic or hazardous wastes, which have the potential to contaminate the environment. Coloring matter, acidic effluents, suspended solids, waxes, unreacted dyes, starch products, heavy metals etc. which are releasing at different stages of textile processing. Water which emerge out after use from industries is termed as 'industrial effluents' and this waste water have high BOD, pH as well as temperature.

All the conventional remediation methods used for polluted environments have specific benefits and limitations. The use of microorganisms and plant species to control and destroy contamination is of increasing interest to minimize some of these pollution problems called 'Bioremediation'. Bioremediation can serve as a prospective method for decontamination and rehabilitation of contaminated sites. Bacteria, algae, fungi and yeast have all been found to absorb and breakdown metal compounds. Certain lichens were used as bio-accumulator of heavy metals.

As compared to the conventional remediation methods, bioremediation is eco-friendly as well as easy to implement. The future of bioremediation, comprise of ongoing research work and have to go through a developmental phase and many technical barriers. Several hyper-accumulator species still need to be highlighted and implemented for successful future of bioremediation programmes.

Key words : BOD, Conventional remediation, Bioremediation, Hyper-accumulator

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INTRODUCTION

The world's ever increasing population and its progressive adoption of an industrial based lifestyle has inevitably led to an increased anthropogenic impact on the biosphere. In textile production, opportunities exist for the release into the ecosystem of potentially hazardous compounds at various stages of the operation. These pollutants are produced in an effort to improve human standard of living and fashion but ironically, their unplanned intrusion into the environment can reverse the same standard of living by impacting negatively on the environment (Asamudo *et al.,* 2005; El Rahim and Moawad, 2010). Speedy growth in urban sector, rapid technological advances and unplanned human settlement in the cities has resulted in the pollution problem (Fersi *et al.*, 2005).

Industries occupy an important place in the economy of India and other developing countries (Textile Ministry, 2005). Textile processing consumes enormous quantity of water and chemical for various operations like washing, dyeing, etc. (Karthikeyan and Venkata Mohan, 1999). The low efficiency of chemical operation and spillage of chemical, cause a significant pollution hazard and a complex problem (Ezeronye and Okerentugba, 1999).

Enormous volumes of effluent are generated at different stages of textile manufacturing, as a result of the use of copious amounts of chemical and dyes. The discharge of these waste residues into the environment eventually poison, damage or affect one or more species in the environment with resultant changes in the ecological balance (Asamudo *et al.*, 2005).

The care free use of chemicals in the past has led to the accumulation of a multitude of pollutants in our environment. Frequently, large accumulations of xenobiotics are discovered in former disposal sites or contaminated soils at former locations of chemical enterprises. They represent a threat of human health (Schroeder, 2000).

Several tons of textiles required to meet up with social demands are produced daily in this industry.

Effluents derived from the textile and dyestuff activities can provoke serious environmental impact in the neighbouring receptor water bodies because of the presence of toxic reactive dyes, chloro-lignin residues and dark coloration (Pandey and Upadhyay, 2011).

Dyes production includes thousands of marketed organic colorants used for coloration of textiles, paper, leather, plastic and in specialized applications such as food, drug, cosmetic and photochemical productions (Zollinger, 1987). Azo dyes, widely used in textile industry, represent the largest and most versatile group whose share in industrial application amounts to some 70 per cent of all dyestuffs consumed (Ollgaard *et al*., 1998).

Anthraquinone dyes are used for coloration of cotton and cellulose fibres as well as of hydrophobic, synthetic materials (Kirk and Othmer, 1993).

The textile processing units release semi-treated or untreated effluents and contain variety of impurities and create pollution problem in many ways. These effluents are directly or indirectly used to grow crop plants and these are accumulating at different trophic levels (Mondal, 2008).

Wastewater discharge from sewage and industries are major component of water pollution, contributing to oxygen demand and nutrient loading of the water bodies, promoting toxic algal blooms and leading to a destabilized aquatic ecosystem (DWAF and WRC, 1995; Morrison *et al*., 2001). High or low pH values in a river have been reported to affect aquatic life and alter toxicity of other pollutant in one form or the other. Low pH values in a river for examples impair recreational uses of water and effect aquatic life. A decrease in pH values could also decrease the solubility of certain essential element such as selenium, while at the same time low pH increases the solubility of many other elements such as Al, B, Cu, Cd, Hg, Mn and Fe (DWAF, 1996 c).

Textile industries discharge effluents into nearby ponds and drains without any treatment, contain highly toxic dyes, bleaching agents, salts, acids and alkalis. Wastewaters have strong impact on the aquatic environment. Due to its complex chemical structure, dye is one of the most difficult constituent in the textile wastewater to treat (Mondal, 2008; Ogugbue and Sawidis, 2011). Heavy metals like chromium, cadmium, copper, zinc and iron are also found in the dye effluents. Textile workers are exposed to such water with no control over the length and frequency of exposure. The untreated effluents are discharged into the environment, cause severe contamination of surface, underground water and adverse effect on flora and fauna (Mathur *et al*., 2004).

Textile effluents have high BOD, pH and temperature. They have bad odour due to dyeing operation and is alkaline in nature. These industrial effluents constitute a major source of metallic pollution of the hydrosphere (Sharma *et al*., 1999).

High nitrate concentrations are frequently encountered in treated wastewater, as a result of ammonium nitrogen. High nitrate levels in wastewater could also contribute to eutrophication effects, particularly in freshwater (OECD, 1982). Many workers have been reported to have potential health risk from nitrate in drinking water above threshold of 45 mg l^{-1}, which may give rise to a condition known as methaemoglobinemia in infants and pregnant women (Speijer, 1996).

In recent years, different approaches have been discussed to tackle man made environmental hazards. Clean technology, eco-mark and green chemistry are some of the most highlighted practices in preventing and/ or reducing the adverse effect on our surroundings. For effluent treatment, plants and microorganisms are the most widely accepted approaches towards achieving environmental safety. Unfortunately, no single treatment methodology is suitable or universally acceptable for any kind of effluent treatment. For instance, in the past, biological treatment systems had been used extensively (Das, 2005).

Safe and cost effective methods are needed for removing effluents from the soil and water (Phillips and Lunda 1995). All conventional remediation methods used for metal polluted environments have specific benefits and limitations (Purohit, 2006). When green plants and microorganisms are used to remove contaminants from the soil and water, the technology is known as "Bioremediation" (Robinson, 1960; Vidali, 2001). Bioremediation can serve as a prospective method for decontamination and rehabilitation of contaminated sites and is of great importance for many countries (Shtangeeva and Ayrault, 2004).

Bioremediation Technologies:

"Remediate" means to solve a problem, and "bio-remediate" means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater (Sasikumar and Papinazath, 2003). It is an aesthetically pleasing mechanism that can reduce remedial costs, restore habitats and clean up contamination in place rather than entombing it in place or transporting the problem to another site (Ensley, 2000; Glass, 2000; Zynda, 2001). In other words it is a technology for removing pollutants from the environment thus restoring the original natural surroundings and preventing further pollution (Sasikumar and Papinazath, 2003).

Bioremediation had been used to clean up the radionuclides, pesticides (e.g. DDT and Simazin), waste water from textile industries (Bansal and Jagetiya, 2001) and heavy metals (Burken and Schnoor, 1996; Ag-west Biotech. Inc., 1999; Gao *et al.*, 2000; Schnabel and White, 2000; Anu *et al.*, 2001; Teerakun *et al.*, 2004; Kshirsagar *et al.*, 2006; Kshirsagar *et al.*, 2006; Panchal *et al.*, 2006; Pandey and Upadhyay, 2011).

Bioremediation allows natural process to clean up harmful chemicals in the environment. Microscopic bugs or microbes that lives in soil and groundwater like to eat certain harmful chemicals, such as those found in gasoline and oil spills (U.S. EPA, 2000). Most often *in situ* bioremediation is applied to the degradation of contaminants in saturated soils and groundwater. "*In Situ"* bioremediation means there is no need to excavate or remove soils or water in order to accomplish remediation (Bonaventura and Johnson, 1997). "*Ex situ*" bioremediation technology uses microorganisms to degrade organic contaminants in excavated soil, sludge, and solids. The microorganisms break down contaminants by using them as a food source and the end products typically are carbon dioxide and water (Bonaventura and Johnson, 1997).

Most bioremediation technology is designed to remove a pollutant once it is generated or released into the environment although certain methods of bioremediation remove chemicals before they become pollutants. Technologies using bioremediation treatment include bioaugmentation, biofilters, bioreactors, biostimulators, bioventing, composting and landfarming (Shmaefsky, 1999; Sasikumar and Papinazath, 2003).

There are following technologies using for bioremediation treatments:

Bioaugmentation:

This is a common term describing the addition of organisms or enzymes to a material to remove unwanted chemicals. Bioaugmentation is used to remove by products from raw materials and potential pollutants from waste. Bacteria are the most common bioaugmentation organisms (Shmaefsky, 1999). Many applications are accomplished using vegetation to remove excess nutrients, metals and pathogenic bacteria. Waste water from human and agricultural effluent is cleaned this way using wetland plants (USA-EPA, 1999).

Biofilters:

The removal of gases (organic) by passing air through compost or soil containing microorganisms capable of degrading the gases. It has been used to remove volatile organic compounds (VOC's) from air. Oxidation products of linseed oil were produced by impinging a stream of air onto the surface of pure linseed oil and injecting the vapor-laden air into soil percolation columns to enrich the population of bacteria capable of degrading linseed oil vapors. As the populations of bacteria increased, the linseed oil vapors were consumed by these organisms, and the air that emerged from the columns was free of linseed oil contaminants (Shmaefsky, 1999).

Bioreactors:

The treatment of a contaminated substance in a large tank containing organisms or enzymes. Bioreactors are commonly used to remove toxic pollutants from solid waste and soil (US EPA, 1990;Shmaefsky, 1999).

Biostimulation:

The use of nutrients or substrates to stimulate the naturally occurring organisms that can perform bioremediation. Fertilizer and growth supplements are the common stimulants. The presence of small amounts of the pollutant can also act as a stimulant by turning on operons for the bioremediation enzymes (Shmaefsky, 1999; Martinez *et al.*, 2008).

Bioventing:

This is similar to biostimulation. It involves the venting of oxygen through soil to stimulate the growth or natural and introduced bioremediation organisms. This is used predominantly for soils contaminated with petroleum products. It is not suitable for removing halogenated gases that contribute to ozone layer damage (Shmaefsky, 1999; Vidali, 2001).

Composting:

This involves mixing contaminated materials with compost containing bioremediation organisms. The mixture incubates under aerobic and warm conditions. The resultant compost can be used as a soil augmentation or be placed in a sanitary landfill (USA-EPA, 1999).

Landfarming:

The use of farming tilling and soil amendment techniques to encourage the growth of bioremediation organisms in a contaminated area. It has been used success fully to remove large petroleum spills in soil (USA-

EPA, 1999).

These technologies are classified as either *in situ* or *ex situ*. *In situ* technologies involve the use of organisms or enzymes to remove pollutants in the location that is polluted. *Ex situ* technologies involve the removal of the contaminated material where, it can be treated using bioremediation (Shmaefsky, 1999).

Bioremediation through microorganisms and plants:

The use of microorganisms to control and destroy contamination is of increasing interest to minimize some of the pollution problems. Bacteria, algae, fungi and yeast have been found to absorb and breakdown metal compounds (Roane *et al*., 1996). Green plants may be used to remove effluents and contamination from soil. This may be called as 'Phytoremediation' (Cosmis, 1996).

Biological dye removal techniques are based on microbial biotransformation of dyes. Many researchers have demonstrated partial or complete biodegradation of dyes by pure and mixed cultures of bacteria, fungi and algae. The metabolic capabilities of microbes were 'all powerful'. The general approaches to bioremediation are to enhance natural biodegradation by native organisms (intrinsic bioremediation), to carry out environmental modification by applying nutrients or aeration (biostimulation) or through addition of microorganisms (bioaugmentation) (Atlas and Unterman, 1999).

Investigations to bacterial dye biotransformation have so far mainly been focused to the most abundant chemical class of dyes *i.e.*, azo dyes. The electron withdrawing nature of the azo linkages obstructs the susceptibility of azo dye molecules to oxidative reactions (Fewson, 1988). Therefore, azo dyes generally resist aerobic bacterial biodegradation. Only bacteria with specialized azo dye reducing enzymes (azoreductase) were found to degrade azo dyes under fully aerobic conditions (Ganesh *et al*., 1994; Pagga and Taeger, 1994; Coughlin *et al*., 1999; Quezada *et al*., 2000).

Fungi are recognized for their superior aptitudes to produce a large variety of extracellular proteins, organic acids and other metabolites, and for their capacities to adapt to severe environmental constraints (Lilly and Barnett, 1951). Fungi have been attracting a growing interest for the biotreatment of wastewater ingredients such as metals, inorganic and organic compounds (Palma *et al*., 1999; Coulibaly, 2002). The degradation of dyes by white-rot fungi was first reported in 1983 (Glenn and Gold, 1983).

Degradation of a number of dyes by algae has been reported in a few studies (Jiang and Bishop, 1994; Semple *et al*., 1999). The degradation pathway is thought to involve reductive cleavage of the azo linkage followed by further degradation of the formed aromatic amines. Hence, algae have been demonstrated to degrade several aromatic amines, even sulphonated ones (Luther and Soeder, 1991; Soeder *et al*., 1987).

Novotony *et al*. (2006), studied on comparative use of bacterial, algal and protozoan tests to study toxicity of azo and anthraquinone dyes. Toxicity of two azo dyes [Reactive orange 16 (RO16); Congo red (CR)] and two anthraquinone dyes [Remazol Brilliant Blue R (RBBR); Disperse Blue 3(DB3)] were compared using bacterium *Vibrio fischeri*, microalga *Selenastrum capricornutum* and ciliate *Tetrahymena pyrifomis*. The following respective endpoints were involved acute toxicity measured as bacterial luminescence inhibition, algal growth inhibition and the effects on the protozoa including viability, growth inhibition, grazing effect and morphometric effects. In addition, mutagenicity of the dyes was determined using Ames test with bacterium *Salmonella typhimurium*. DB3 dye was the most toxic of the all dyes in the bacterial, algal and protozoan tests.

Often bacteria perform important tasks in the absence of a partner. One common bacterium, *Thiobacillus*, flourishes in mud, bogs, sewage, brackish springs and even acid mines. It derives energy from the oxidation of sulphur, compounds such as elemental sulphur, sulphides and thiosulfate converting these toxic compounds into nontoxic sulphates that are useful to other organisms. *Thiobacillus* are extensively used by man for mining and bioremediation purpose (Saier, 2005). Another versatile bacterium *Rhodobacter*, fixes carbon and nitrogen from the air to make biodegradable plastics (Saier, 2005). The bacterium *Deinococcus radiodurans* has been modified to consume and digest toluene and ionic mercury from highly radioactive nuclear waste (Brim *et al.,* 2000). Study was carried out on aerobic bacteria for their degradative abilities are *Pseudomonas, Alcaligenes, Sphinogomonas, Rhodococcus* and *Mycobacterium*. These microbes have often been reported to degrade pesticides and hydrocarbons, both alkanes and polyaromatic compounds (Muller, 1996). Pourbabaee *et al*. (2008), studied on aerobic decolorization and detoxification of a disperse dye in textile effluent by a new isolate of *Bacillus* sp. Efforts to isolate bacterial cultures capable of degrading azo dyes started in 1970s with report of *Bacillus subtilis* (Hortisu *et al*., 1977) then *Aeromonas hydrophilla* (Idaka and Ogawa, 1978), followed by *Bacillus cereus* (Wuhramann *et al*., 1980).

Most of the microbial strains (aerobic/anaerobic) were isolated from different domestic and industrially polluted soil/sludge and water for the treatment of textile dyes and effluents (Kulla *et al*., 1983; Chen *et al*.. 2003; Kapdan and Oztekin, 2003; Maier *et al*., 2004). Decolorization/degradation by these different bacterial strains (live/dead) was mostly carried out on solid and in liquid cultures under static/shaking conditions, besides analyzing the mechanism [enzymatic transformation (Zimmermann *et al*., 1984; Tatarko and Bumpus, 1998; Aksu and Tezer, 2000; Minussi *et al*., 2001; Coulibaly *et al*., 2003); biosorption (Van der Zee, 2002; Rojek *et al*., 2004); bioadsorption (Pagga and Brown, 1986; Lazlo, 1996; Wang and Yu, 1998)] involved.

However, microbial strains are also used in consortium (bacterial or bacterial-fungal) for achieving comprehensive mineralization of dyes and related products (Bhatt *et al*., 2000). Gram-negative bacteria other than *Pseudomonas* were included *Acinetobacter, Alcaligenes*, *Moraxella, Achromobacter* and *Flavobacterium* spp. The Gram-positives most noted were all in the actinomycete line and they were *Mycobacterium*, *Nocardia*, *Rhoodococcus* and *Arthrobacter* spp. (Alexander, 1994). Nigam *et al*. (2004), studied on decolorization of effluents from the textile mill by a microbial consortium. A microbial consortium, PDW was isolated capable of the rapid decolorization of commercially important textile dyes under anaerobic conditions. PDW was capable of dye decolorization when utilizing cheap and readily available carbon sources such as lactose, starch and distillery waste. Study was intended to find out the heavy metal resistance pattern of sponge associated bacteria. The bacteria associated with a marine sponge *Fasciospongia cavernosa, Streptomyces* sp., *Salinobacter* sp., *Roseobacter* sp., *Pseudomonas* sp., *Vibrio* sp., *Micromonosporo* sp. and *Alteromonas* sp. showed resistance against tested heavy metals (Selvin *et al*., 2007).

Ertugal *et al*. (2008), studied on treatment of dye waste water by an immobilized thermophilic cynobacterial strain *Phormidium* sp. The highest colour removal was detected at 45 °C and 50 °C incubation temperatures for all dye concentration. As the temperature decreased, the removal yield of immobilized *Phormidium* sp. also decreased. The removal of Remazol Blue Black B by immobilized thermophilic cynobacterial strain *Phormidium* sp. was investigated under thermophilic conditions in a batch system, in order to determine the optical conditions required for the highest dye removal (Melike *et al*., 2007).

In the world of fungi, *Phanerochaete chrysosporium* has emerged a model system in textile, polycyclic aromatic hydrocarbon, pulps and paper mill effluent remediation. *P. chrysosporium* is a basidiomycete fungus able to degrade complex compounds such as cellulose, starch, pectin, lignin and lignocelluloses, which are characteristics of textile effluents (Daba *et al*., 2005). Ligninolytic fungi have the ability to degrade an extremely diverse range of persistent for toxic environmental pollutants, substrates include straw, sawdust or corn cobs (NRC, 1993). Biodegradation activity was evaluated by two genra, *Flavobacterium* and *Aspergillus*, were identified as the primary microorganisms that degraded hydrocarbons in the polluted soil (Roldon, 2008). Carlos *et al*. (2008), in his study *Aspergillus oryzae* was utilized to remove azo dyes from aqueous solution. The ligninolytic peroxidises were isolated from *Phanerochaete chrysosporium* and are called lignin peroxidise (LiP) (Glenn and Gold., 1983). The ligninolytic system of white-rot fungi (WRF) is directly involved in the degradation of various xenobiotic compounds and dyes (Wesenberg *et al*., 2003). The biosorption abilities of *Aspergillus foetidus* was found to be effective in the decolorization of azo reactive dyes (Sumathi and Manju, 2000). The cell wall of *Myrothecium verrucaria* was shown to bind azo dyes, including Acid Orange II and Acid Red 114 (Laszlo, 1994). Kirby *et al*. (2000), reported that *Phlebia tremellosa* decolorized eight synthetic textile dyes under stationary incubation conditions. *Coriolopis gallica* and *Phanerochaete chrysosporium* were selected for their potential ability to degrade five dyes in an artificial effluent. The results highlight the potential of *C. gallica* for textile dye degradation (Robinson *et al*., 2001).

Davies *et al*. (2005), studied on phytoremediation of textile effluents containing azo dye by using *Phragmites australis* in a vertical flow intermittent feeding constructed wetland.

Ibbini *et al*. (2009), studied on phytoremediation in textile dyes. Experiments were set up with 20-40 mg l^{-1} dye solutions of different colors, they used two week old sunflower seedling and place them into a test tube of known volume dye solution. Among the many dyes tested, Evan‘s Blue proved to be the most readily decolorized azo dye. *Mukhtar et al. (2010)*, conducted a study to evaluate the efficacy of sunflower plant to phytoremediate Pb and Ni contaminated water in the absence and presence of synthetic chelator. Neem sawdust (*Azadirachta indica* A. Juss.) was used as an adsorbent for the removal of malachite green dye from an aqueous solution. The adsorption of dye on neem sawdust was found to follow a gradual process (Khattri and Singh, 2009). Kulkarni *et* *al*. (2006), carried out an investigation on phytoremediation of textile process effluents by water hyacinth, for studying reduction of COD and metals from textile process effluents. It has been observed that there is a reduction of 80 per cent in COD and about 25-45 per cent reduction in metals after 18 days period. Harrelkas *et al*. (2008), studied on phytocatalyticand anaerobic-phytocatalytic treatment of textile dyes. Phytocatalysis was able to remove more than 90 per cent colour from crude as well as autoxidized chemically reduced dye solutions. The end product of phytocatalytic treatment was not toxic toward methanogenic bacteria. Phytotoxity tests on the untreated effluents samples using the seeds of *Lens orientalis*, *Triticum aestivum* and *Triticum boeoticum* indicate that the first one is the most sensitive while the last one is the most resistant.

Moran *et al*. (2009), studied on effects of sewage treatment on textile effluent using three separate samples of effluents, the initial toxicity was tested using the aquatic invertebrate *Daphnia manga*. Result showed relatively good biodegradability but negligible toxicity reduction.

Conventional methods v/s bioremediation:

Bioremediation is an eco-friendly cost effective technology, as compared to physical and chemical technique (Robinson *et al*., 2001; Singh *et al*., 2007). There are more than 100,000 commercially available dye exist and more than 7x105 tonnes per year are produced annually (McMullan *et al*., 2001; Pearce *et al*., 2003). Wastewater containing dyes is very difficult to treat, since the dyes are recalcitrant organic molecules, resistant to aerobic digestion and are stable to light. A synthetic dye in wastewater cannot be efficiently decolorized by traditional methods. This is because of the high cost and disposal problems for treating dye wastewater at large scale in the textile and paper industries (Ghoreishi and Haghighi, 2003).

Chemical methods:

Chemical methods include coagulation or flocculation combined with flotation and filtration, precipitation-flocculation with $Fe(II)/Ca(OH)_2$, electroflotation, electrokinetic coagulation, conventional oxidation methods by oxidizing agents (ozone), irradiation or electrochemical processes. These chemical techniques are often expensive, and although the dyes are removed, accumulation of concentrated sludge creates a disposal problem. There is also the possibility that a secondary pollution problem will arise because of excessive chemical use. Recently, other emerging techniques, known as advanced oxidation processes, which are based on the generation of very powerful oxidizing agents such as hydroxyl radicals, have been applied with success for the pollutant degradation. Although these methods are efficient for the treatment of waters contaminated with pollutants, they are very costly and commercially unattractive. The high electrical energy demand and the consumption of chemical reagents are common problems (Rajendran *et al*., 2011).

Physical methods:

Physical methods are widely used, such as membrane-filtration processes (nanofiltration, reverse osmosis, electrodialysis) and adsorption techniques. The major disadvantages of the membrane processes is that they have a limited lifetime before membrane fouling occurs and the cost of periodic replacement must thus be included in any analysis of their economic viability. In accordance with the very abundant literature data, liquid-phase adsorption is one of the most popular methods for the removal of pollutants from wastewater since proper design of the adsorption process will produce a high-quality treated effluent. This process provides an attractive alternative for the treatment of contaminated waters, especially if the sorbent is inexpensive and does not require an additional pre-treatment step before its application. Adsorption is a well known equilibrium separation process and an effective method for water decontamination applications (Dabrowski, 2001). Adsorption has been found to be superior to other techniques for water re-use in terms of initial cost, flexibility and simplicity of design, ease of operation and insensitivity to toxic pollutants. Decolourisation is a result of two mechanisms- adsorption and ion exchange (Slokar and Majcen Le Marechal, 1998) and is influenced by many physio-chemical factors, such as dye/sorbent interaction, sorbent surface area, particle size, temperature, pH, and contact time (Kumar *et al*., 1998; Pandey and Upadhyay, 2011).

Bioremediation:

Bioremediation or biological remediation is very safe because it relies on microbe that naturally occurs in soil. These microbes are helpful and pose no threat to people at the site or the community. Polluted soil and groundwater can be cleaned at the site without having to move them somewhere else. If right conditions exist or can be created underground, soil and groundwater can be cleaned without having dig or pump it up at all. This allows workers to avoid contact with polluted soil and groundwater. Microbes change the harmful chemicals into water and harmless gases (EPA, 2001). Often, it does not require as much equipment or labour as most other methods. It is usually cheaper and safe.

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