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Review Article

Microbiology for health care

A Comprehensive Review on Waste Water Treatment Technologies with Special Emphasize on Biological Treatments

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Abstract: Rapid urbanization is essential for growth and economic viability at global level, promoting the extensive industrialization. Rapid industrialization also comes with more water demand with higher water pollution. Industrial wastewater may contain heavy metal, carcinogens, mutagens and radioactive materials which must be prevented to be incorporated into the food chain. Therefore, treatments of wastewater for removal of these toxicants are a necessary and unavoidable measure. There are various modes of treatments for removal of toxicants depending on the type of contaminants. It includes physical, chemical and biological treatment alone or in combination. Here a review is carried to identify major sources of industrial wastewaters with their major pollutants. Various studies are also considered in the review for determination of the hazardous effect of wastewater on ecosystems and biological systems. Details about treatments of wastewater based on the sources were also included. More emphasis has been given on the role of microorganisms for removal of pollutants. Not limited to this, details of methods for biological removal contaminations and treatability studies are also discussed in detail. Based on the review it is found that generation of wastewater from industries must be pretreated with suitable methods before discharging into the environment to protect life on mother earth.

Key words: Industrial wastewater, sources, treatments, microorganisms, treatability studies

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1. INTRODUCTION

The continuously rising human population has led to expansion of agricultural and industrial sectors. Both of them require a higher amount of water, which is a primary need of all the living beings on the earth. Rivers, lakes and groundwater are the major sources of water for irrigation, industrialization and human as well as animal consumption[1, 2]. In certain parts of the world, droughts and floods are observed frequently due to climate change [3, 4]. Over and above all these, pollution due to industries, municipalities and agriculture has significantly contributed to reduction in quality and quantity of potable safe water [5-7]. It becomes very much essential to treat wastewater before disseminating it into water bodies. Polluted water or contaminated water may be defined as water containing excessive hazardous substances or compounds which makes it unsuitable for cooking, drinking, bathing and other uses [8-10]. Pollution of water is mainly caused by human activity and release of the pollutants from industrial dumps, oil spillages, chemical waste, pesticides, sewage leakages, heavy metals, animal wastes, worn sediments, littering, chemical fertilizers, herbicides *etc* [11-15]. Wastewater discharged from various sectors can be broadly classified into many different types like domestic wastewater, agricultural wastewater, sewage wastewater, storm run-off wastewater, and industrial wastewater. In the present study, more emphasis is given on water pollution caused due to rapid industrialization. As per the AQUASTAT database, around 3900 km^3 of total freshwater is utilized every year for various purposes and 22% (860 km^3) of this is used by various industries. Industrial effluents lead to irreversible damage to the ecosystem [16]. Inadequate treatment and straight release of hazardous containing effluents in the sewerage drains leads to pollution into the groundwater and other major water bodies, which may cause harmful effects on the health of animals and aquatic life[17,18]. Not limited to water pollution, untreated effluents also cause air pollution, land surface pollution and soil pollution [19-21]. Careless disposal of industrial wastewater when used for irrigation of crops leads to serious damage to the quality of the crops as well as food chain. As precautionary steps, several countries have now implemented policies for control of water quality. The parameters are being set based on the quantity of pollutants which can be safely incorporated in specific water bodies. For example, Integrated Pollution Prevention and Control (IPPC) in Europe, the total maximum daily load (TMDL) in US Clean Water Act, and the Central Pollution Control Board (CPCB) in India, have set minimum acceptable standards for the disposal of industrial and municipal wastes[11-16]. To minimize the pollution many treatment plants are also developed where use of chemical, electrochemical, biological and physical processes converts the water into potable water [22, 23].

2. INDUSTRIAL WASTEWATER

Industrial wastewater can be defined as water having substances released from various industries during manufacturing, cleaning and other activities. Mining industries, food industries, oil and gas industries, steel and other metal industries are few examples of the wastewater producing industries. Types of the substances present in industrial wastewater highly depend on the type of the industry and the factory. Heavy metals, pesticides, chemicals and pharmaceutical molecules are the major contaminants [21, 24]. It is very difficult to set up a common treatment plant for IWW. Based on the specific requirement, a different set up can be established at industry level.

2.1. Wastewater Production and Treatment in India

India has different rate of wastewater production depending on the industrial development. India has class I cities and class II cities depending on the population and development, which produces around 35,560 MLD and 2,7000 MLD wastewater respectively. Both the types of cities have sewage treatment plants of around 11,500 MLD and 230 MLD. So around 26,530 MLD wastewater cannot be recycled for reuse. According to reports Maharashtra, Gujarat, Uttar Pradesh, Delhi and West Bengal are among the leading cities of wastewater producers [25, 26]. UNESCO has also indicated that Indian industrial water use productivity is very less as compared to Japan, Korea and other developed countries. It is estimated that by the year 2050 around 48 BCM wastewater will be generated by India. India has around 240 sewage treatment plants, most of which are located in the cities and near the river. These STPs are generally used for treatment of wastewater generated from domestic activities. According to a report, only 27% of wastewater and 19% of sewage water is treated in India. Rest is disposed of directly without any treatment. Majority of cities have only basic facilities for wastewater treatment. Around 49 cities have basic as well as advanced level treatment facilities. Majority of plants have oxidative ponds or activated sludge treatment as primary treatment followed by anaerobic sludge blanket technology or similar technology as secondary treatment [26, 27].

2.2. Necessity of Wastewater Treatment and Applications of Treated Water

On the earth the sources of usable water are limited and its use is being increased day by day. To meet the daily requirement of water it must be reused after treatment. But as mentioned earlier, a large amount of wastewater is being discharged untreated into the environment. This leads to many consequences in the environment. Wastewater is contaminated with many toxic elements, which spread the pollution to the entire area where it is being released. Such pollutants may have adverse effects on the life of that particular environment. For example, wastewater with high organic load if discharged in the aquatic system then its digestion requires more oxygen, which results in lowering the dissolved oxygen. Reduction of dissolved oxygen concentration may harm living beings of that aquatic system. If untreated wastewater is discharged into the land, then it may destroy the fertility of soil. Many times, nutrient rich wastewater leads to eutrophication by promoting growth of aquatic plants and algae. Contamination of freshwater with wastewater may lead to many health issues as it has many pathogenic microorganisms. Not limited to soil and water but certain volatile compounds also polluted the atmosphere[21, 27, 28]. Decomposition of many organic molecules may produce gasses which add into the existing air pollution. So in order to protect the environment and conservative use of available water it becomes very much important to treat the water. Treated wastewater can be used for many applications for domestic and industrial purposes. For domestic purposes, it can be used for irrigation of plants, air coolers and flushing of toilets. Industries can be used for cooling, washing and cleaning purposes. It is very rarely used for making food and food products for safety reasons [29-32].

3. MAJOR POLLUTANTS OF INDUSTRIAL WASTEWATER

Pollutants present in wastewater and released by industries are very toxic and can have adverse effects on human and aquatic life. It may also affect agriculture. Heavy metals like lead (Pb), copper (Cu), chromium (Cr), zinc (Zn), cadmium (Cd), nickel (Ni), iron (Fe), arsenic (As) and mercury (Hg) are among the most ubiquitous metals. [33] Majority of such pollutants are released by pharmaceutical, paper, textile and dye industries. In addition to these metals, phenol and phenolic compounds are also found in significant amounts in industrial wastewater. Bulk drug manufacturers, oil refineries and resin forming industries mainly released phonic compounds in the water [34, 35]. Other compounds like aniline, naphthalene acid, olefins, nitrobenzene, alkanes, hydrocarbons, sulfides and chloroalkanes produced in the petrochemical industries also spoil water quality [36-38]. The major problem with this kind of water is the biological decomposition of petrochemical wastes, as the majority of these compounds are very complex and highly stable. It was also seen that, if these kinds of compounds are treated through biological routes even then their secondary metabolite forms are also toxic. Removal of these kinds of compounds needs chemical oxidants which form inorganic end products resulting in a low ratio of biological oxygen demand (BOD) to chemical oxygen demand (COD)[39, 40]. Paper and pulp industries mainly produce suspended solids and other organic materials. The property of effluent depends on the quality of paper to be produced and processing of pulp. In the effluents components like biocides, resin acids, tannins, sterols, lignin, colours and phenolics may be present [10, 41]. Textile industries engaged with printing and dyeing mainly produce urea, ammonium nitrogen (NH_4–N) and other similar nitrogenous as well as phosphorus wastes. Textile industries also produce chromium, surfactants, hydrogen peroxide, chlorine, AOX, silicate and other alkaline bases. Textile industry also produces perfluorooctane sulfonate (PFOS) and another compound similar to PFOS, namely perfluorooctanoic acid (PFOA) is produced by fluoropolymer producing industries. Both these perfluoroalkyl acids (PFAAs) are known to have potential health risks [20, 41, 42]. High salinity of wastewater sometimes may also have adverse effects on life forms. Hence it becomes very essential to remove salt from wastewater. Wastewater with high salinity is generated by leather, food, petroleum and agro-based industries [34, 43]. Below table provides information about industrial sectors and their respective major water pollutants produced by them.

Table 1: Industrial sector and their major water pollutants

Industry	Major water pollutants	Reference
Agriculture	Pesticides, Insecticides, Fertilizers	44-49
Paper and pulp	Suspended solids, lignin, tannins, organic and chlorophenolic compounds, AOX, sterols, colour	50-53
Plastic	Lead, mercury, cadmium, PFOA,	54-57
Paint manufacturing	Lead, chromium, zinc, volatile organic compounds (VOCs)	58-63
Petrochemical	Phenolic, petroleum hydrocarbons, alkanes, chloroalkanes, nitrobenzene, high salt	64-66
Pharmaceutical	Phenolics, cadmium, nickel,	30, 46, 67-72
Textile	Urea, iron, chromium, hydrogen peroxide	20, 41, 42, 73-75
Metal/Ion	Ammonium nitrogen, PFOS, phenol, cyanide, oil	33, 76-81

4. HAZARDOUS EFFECT OF INDUSTRIAL WASTEWATER

As mentioned earlier, fast industrialization in the last few years has significantly added to the pollutants in the environment. It was proved that release of hazardous industrial wastes without any treatment into water bodies have created toxic effects on all the living forms either directly or indirectly. These pollutants reach human and other living beings in multiple ways (Figure 1). Among all the major pollutants, heavy metals are the most persistent and non-biodegradable. Such toxic heavy metals are often taken by aquatic fauna and cause detrimental health problems in aquatic animals. This is one of the modes for the entry of pollutants in the food chain [40, 43, 66]. These heavy metals can be carcinogenic and teratogenic which can cause organ damage, nervous system dysfunction, oxidative stress and reduced growth and development [4, 52]. Phenolic compounds are another major pollutant produced by chemical industries. Their presence in water inhibits the growth of normal microflora and their function. This affects biological treatment processes significantly. Consumption of such water may lead to sweating, cyanosis, low body temperature and respiratory failure [36, 66, 69]. Tannins, resins and other organic chlorinated compounds are mainly produced by paper and pulp industries which are known to cause mutagenicity and genotoxicity/ Lignin and its derivatives also produced from paper and pulp industries are poorly degradable and biological treatment can convert them into toxic compounds [51, 52]. Chromium based compounds and oily scum produced by textile industries forms a colloidal layer on the top which acts as a barrier and prevents the entry of sunlight from entering the water body, resulting in lower dissolved oxygen [77, 82]. Chlorine-bound organic colorants used by textile industries are carcinogenic [20, 42]. Due to all these adverse effects, it is highly recommended to have strategies to efficiently remove these toxic pollutants before draining them into water bodies.

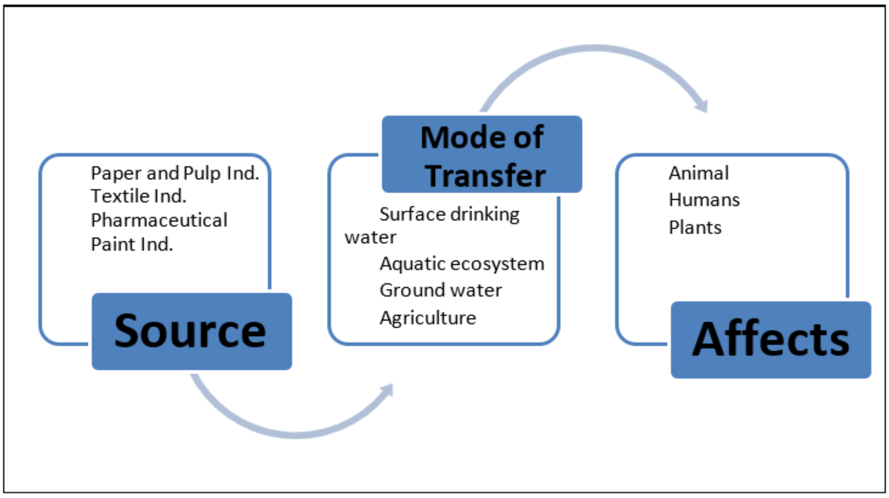

Fig 1: Image showing the entry of pollutants in food chain

5. TREATMENT OF INDUSTRIAL WASTEWATER

Based on the types of pollution and compounds, different types of strategies and technologies are developed and used for removal of contamination from wastewater [27, 83]. Here is the brief information of various strategies developed and applied for treatment of wastewater producing industries (Figure 2). For different types of toxic waste different approaches should be applied for better removal of waste compounds. A schematic representation of best approach for a suitable method for toxic compound is shown in figure 3.

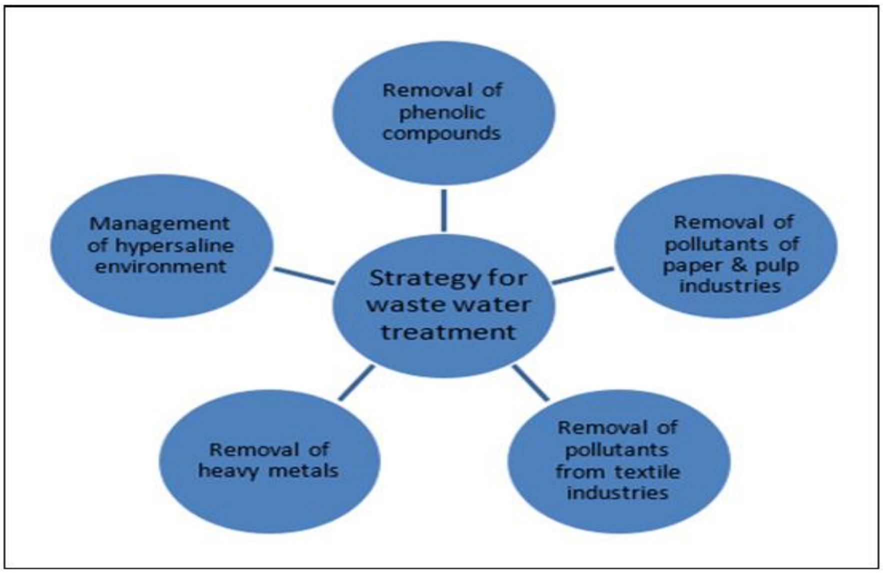

Fig 2: Types of Treatment of Industrial Wastewater

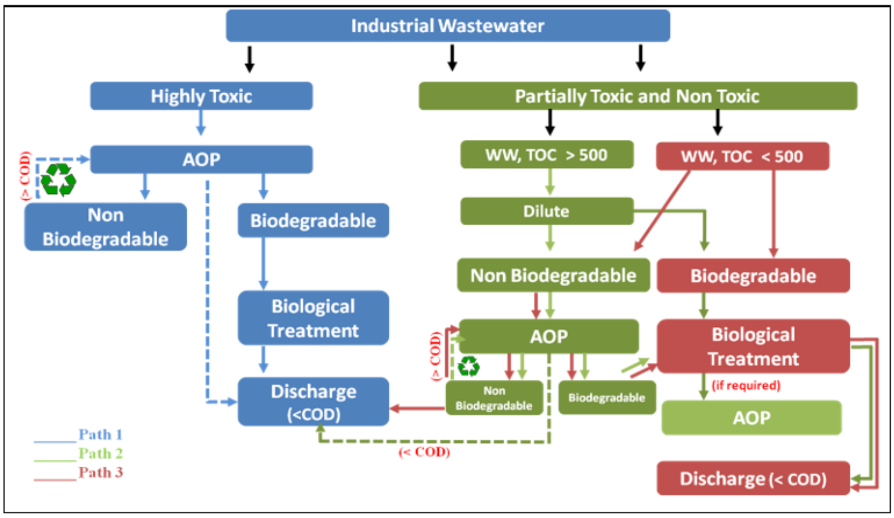

Fig 3: Approach for treatment of wastewater with different toxicity

5.1. Removal of Heavy Metals

Chemical industries are one of the producers of heavy metals and many of them are using conventional strategies like ion-exchange, chemical precipitation and electro thermal decomposition method for removal of metals from the effluent. Synthetic anion and cation ion-exchange matrices are used for ion-exchange. lime and limestone are used for chemical precipitation. There are certain drawbacks associated with these methods. They are not highly efficient in complete removal of metals and they also require very high energy inputs. As an alternative to these, economic and more efficient technologies like membrane filtration, electrodialysis, photocatalysis and adsorption are developed. Zeolites and clinoptilolite are among the most widely used adsorbents which are natural and low cost. Industrial by-products like fly ash, slags of iron and titanium oxide are also good alternatives for removal of heavy metals. Biological and agricultural wastes can be used for biosorption. Orange peel, nut shells, maize husk, rice husk inactive biomass, pecan shells and cob are good bio absorptive materials. Modification of starch, chitosan, chitin and hydrogels enhances their efficiency for the removal of heavy metals. Membrane filtration is an efficient technique for removal of heavy metals from inorganic solutions. It was also seen that reverse osmosis can remove 98% copper and 99% cadmium. In addition to this nano-filtration and polymer based ultrafiltration are also widely used for removal of heavy metals. In the electrodialysis method, an ion-exchange membrane is used and ions are passed through the membrane and separation takes place under applied electric voltage. This method is effective for the removal of heavy metal ions like Ni, Co and Cd. In the photocatalysis, titanium dioxide is used for reduction of Cu^{2+}, Cr^{3+} and Cr^{4+} heavy metal [77, 80].

5.2. Removal of Phenolic Compounds

Phenol and phenolic wastes can be removed by physical, chemical, electrochemical and anaerobic biological methods. Among all the methods, the electrochemical method is considered as one of the most efficient methods. Electrons are the main elements which are used for breaking down of the pollutants by directly or indirectly oxidative processes. Anodes like graphite, Ti-Pt, Ti-Pt-Ir, Ti-SnO_2–PdO_2–RuO_2 and TiO_2–RuO_2–IrO_2 are good electrodes used for the electrochemical treatment of resorcinol, cresol, tannery wastewater and landfill leachate. Nevertheless, electrochemical processes also increase the concentrations of AOX in effluents and that is why, these effluents must be treated with activated charcoal before voiding into the environment [65, 66, 80].

5.3. Removal of Pollutants Produced by Paper and Pulp Industry

The paper and pulp industries are considered as one of most water consuming and highly polluting industrial areas. Not limited to water, these industries also produce large quantities of solid as well as gaseous waste. Multiple treatments are available to treat the contaminated water due to the paper and pulp industries. Vibration separation enhanced processing (VSEP) method - a membrane separation system can be used for treatment of the black liquor produced. It can also be treated with biological treatment. Concentration of AOXs can be reduced by oxygen bleaching and heavy metals can be removed by sedimentation and anaerobic digestion followed by pyrolysis. Primary and secondary bio sludge can be treated by incineration. It will also help in production of biochar and biogas. Lignin can also be removed by this method. In addition to these techniques other techniques like ozonation, gasification, advanced oxidation can also be employed. It was found that a coagulant made from composite with polymeric ferric aluminum sulfate chloride (PFASC) and polyacrylamide (PAM) works well for treatment of wastewater produced by paper industries. It can reduce color liberation from paper upto 71.2% and also bring the COD level near to 65.3%. Higher concentration of products with high BOD and COD can be treated by aerobic granulation, which also removes tannin and lignin. Agro-industries based bio absorbents and other activated carbon can also reduce the color libration rate. Use of microbial fuel cells is comparatively a new approach. It has added advantage of electrical energy production and barring the aeration process which is conventionally used for several other dissolved gasses. Use of enzymes like xylanase and laccase provides and eco-friendly approach in place of chlorine bleaching for reduction of AOX and other organic chlorinated pollutants [51, 52].

5.4. Removal of Pollutants Produced by Textile Industry

Large amount of freshwater is needed by the textile and fabric industries. Multiple processes depending on the freshwater produce huge quantities of wastewater. Among all the other pollutants, dyes especially azo dyes are the key elements which contribute to colourization of the wastewater. It can be treated with physical, chemical and microbial processes. Adsorption, membrane-based separation techniques and ion-exchange methods as mentioned earlier can also be used here. Carbon, silicon, and kaolin polymers can efficiently remove dyes. Reactive dyes can be removed by reverse osmosis and nanofiltration whereas ionic dyes can be removed by ion-exchange method. Ozonation can also be used for toxic non-biodegradable components. Photochemical methods can only be applied to the elements which are UV sensitive. Cucurbituril is a polymer of formaldehyde and glycoluril which is able to completely degrade all types of dyes like basic, acidic, reactive and disperse dyes. In addition to these, biological treatment with different bacteria, fungi, algae and plants are also used for removal of pollutants. Studies have shown that these methods are also very effective in the degradation of highly stable chemical dyes. Certain species of *Pseudomonas, Staphylococcus* and *Citrobacter* sp. are able to break the azo linkage anaerobically, whereas species of *Geobacillus, Micrococcus* sp, and *Staphylococcus* can convert this azo group into nontoxic form with the help of azo-reductases. In a more aggressive and effective approach for biodegradation of the pollutants consortia prepared with more than one potential bacteria is used. Enzymes like lacase, ligninase and peroxides produced by certain fungi are able to break the azo group. Algae uses the nitrogen of azo dye for its growth and development and also contributes in prevention of eutrophication of water bodies. Bioadsorption and biodegradation can be effectively carried out by microalgae to remove the compounds of effluents released by the textile industries. Phytoremediation is a process where plants are used for removal of contamination. Phytostabilization, phytotransformation, phytovolatilization, phytoaccumulation, phytostimulation, rhizofiltration are various approaches using plants for the treatment of textile effluents[41, 42].

5.5. Management of Hypersaline Effluents

Physico-chemical methods are the most common methods for management of hypersaline by some industries. These methods also involve multiple effect evaporators which use thermal techniques to treat the hypersaline water. Thermal technique brings down the volume of effluent and enables separation of a solid salt. Combination of coagulation–flocculation can also be used as a pre-treatment for removal of the colloidal COD fraction of hypersaline effluents. In addition to these, membrane filtration, reverse osmosis, electrodialysis and ion exchange methods are also in use [34, 40, 47, 80].

5.6. Role of Microorganisms in Treatment of Wastewater

Bioremediation is a method for removal of hazardous substances from the environment. In order to destroy the harmful chemicals and hazardous waste naturally occurring living organisms are used. Each of them have different modes of action and different efficacy (Figure 4). Though it is a green and economically viable treatment, it has different efficacy in different environments. For each location, types and concentration of microorganisms need to be optimized. Previous studies have shown that bacteria, fungi, and plants have efficiency to degrade and detoxify harmful substances from water[84-86].

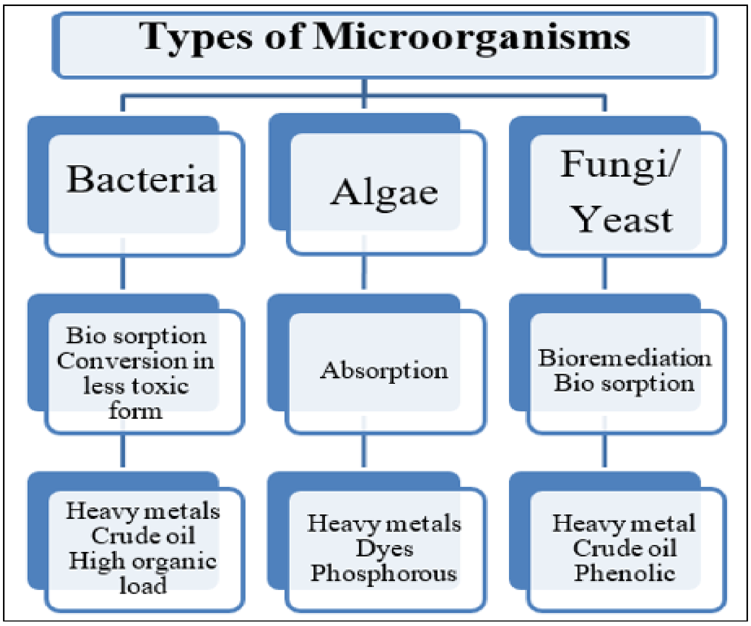

Fig 4: Possible mode of action of microorganisms

Two mechanisms, namely biosorption and bioaccumulation can be used for wastewater treatment. Both these methods are part of bioremediation. Biosorption involves rapid adsorption of material without utilizing energy. It is also a reversible process. For biosorption living as well as dead biomass can be used. This method is very economical. Not limited to this, biomass can be regenerated and reused for multiple times of wastewater treatment. In the bioaccumulation accumulation or concentration of toxins takes place by increased uptake of substance from the surrounding environment. Bioaccumulation can be performed by living biomass only. This approach may be costly and cannot be reused aggressively as biosorption due to the limited life cycle of living organisms[18, 87, 88]. Bacteria have vast diversity and they also have vast potential for bioremediation. Here are a few examples of microorganisms with their possible mode of treatment or removal of waste in industrial water. Selected species of *Arthrobacter, Pseudomonas sp., Bacillus sp., Cellulomonas spp., Desulfovibrio vulgaris, Serratia marcescens, Ochrobactrum sp. Acinetobacter,* and *Ochrobactrum*, are known to have potential to reduce highly soluble and toxic Cr (VI) form into less soluble and toxic Cr (III) form. Arthrobacter psychrolactophilus Sp 313 can decrease the concentration of protein which is highly used for disposal of sewage produced by industries.Many other microorganisms like Bacillus, endophytes and pseudomonas also contribute in this process. Studies have shown that cyanobacteria can remove heavy metals, pesticides, colour particles and crude oil by biosorption. Being nitrogen metabolism an essential part, cyanobacteria is highly preferred for removal of nitrates. *Synechococcus* sp strain and *Synechocystis minima* are examples of such cyanobacterial species. Removal of phosphorus and nitrogen can be effectively extracted by the *Phormidium tenue* and *Phormodium bohneri*. In addition to cyanobacteria *Anabaena oryzae, Anabaena variabilis,* and *Tolypothrix ceytonica* are highly used in treatment of industrial and domestic wastewater mixture. High organic load can be reduced by *A. variabilis and A. oryzae* whereas *T. ceytonica* and *A. variabilis* can remove solid particles. It was seen that *A. subcylindrica* and *N. muscorum* can accumulate heavy metal like copper, manganese, cobalt manganese from sewage wastewater. Species of *Aphanocapsu sp, Terenbans* and *Oscillatoria salina* are capable of degrading crude oil. Pesticides can be effectively degraded by *Anabaena sp.* and *Nostoc ellipsosporum*. Dyes from textile industries can be removed by *O. formosa*. Phosphorus can be removed by *R. sphaeroides* [36, 44]. Algae is considered as a vital part for the natural purification process of water. They absorb poisonous and radioactive metal ions which can be recovered. Many times it may have gold as well as silver. Since they can grow rapidly and absorb more nutrients from wastewater, they can be helpful in the remediation of certain nutrients. It can be an economic alternative technology for environmental treatment of sewage wastewater. Wastewater from textile industries is rich in the nutrients required for algae cultivation and hence can be used for removal of contaminants and dyes from textile wastewater. *C. vulgaris* is known to control the production of diluted alcohol and citric acid from the wastewater. It can also promote the decrease in effluent values of BOD as well as COD. *C. vulgaris* and *S. quadricauda* both are found efficient in removal of nitrate. *C. vulgaris* can also remove phosphate by utilizing phosphorus for its own growth through remediation. Algae-based biosorption methods for removal of heavy metal and ions from wastewater are considered as environmentally safe, economic, and more effective modes. In a study, non-viable biomass of *Spirogyra* was used as biosorbent for the removal of reactive dye present in textile wastewater, which has shown significant removal of the dye from the wastewater. Living algae like *C. Lentillifera* and *C. scalpelliformis* were found to remove basic dyes through biosorption. Algae like *Phormidium*is known to convert textile dyes to their milder form by bioconversion [34, 44]. Heavy metals like Fe, Ni, Ag, Zn, Cd, Pb, Th, Ra and U are taken up by filamentous fungi for their growth and other metabolic activities. Fungi biomass can be used as biosorbents to remove heavy metals and other radionuclides from industrial wastewaters. Species of *Rhizopus, Mucor, Penicillium, Aspergillus, Saccharomyces,* and *Fusarium* are known to have the ability of heavy metal absorption. White rot fungi were found to degrade phenolic compounds present in wastewater. C. versicolor, F. trogii, P. chrysosporium and P. pulmonarius are able to decolorize the molasses and are able to reduce the chemical oxygen demand (COD). *F. ventricosum, P. chrysosporium, A. terreus, C. oxysporum, M. thermohyalospora,* and *T. harzianum* were found to be capable of degrading endosulfan molecules. Fungi belongs to class *zygomycetes* and species *P. chrysogenum, S. apiospermum, P. digitatum,* and *F. solani* are able to degrade polychlorinated biphenyls (PCB). For removal of cadmium, a combination of *Pinus* with *S. bovines* and *R. is* used. Not limited to this, some plant associated fungi like T. Hirsuta, T. viride, A. nidulans, B. adusta, F. trogii, I. lacteus, P. ostreatus, are also popularly used for decolorization of wastewater produced by the textile industry. Yeast like *T. cutaneum, C. tropicalis,* and *Saccharomyces sp.* are highly used in bioremediation of oil wastewater. They are known to lower COD levels and alongwith efficient removal of mono and polyphenols. They can also convert toxic chromophore compounds produced by textile industries into simple forms[83, 85, 89].

6. METHODS OF BIODEGRADATION

Aerobic biodegradation is a degradation process which requires the presence of oxygen. Here enzymes namely oxygenase and peroxidase are involved in digestion of molecules [13, 18]. These enzymes are produced by bacteria as well as fungi. There are two main types of reactors which work on the aerobic principle of digestion - triggered sludge reactor and the membrane bioreactor [86, 90]. In the activated sludge reactor air and a biological floc having protozoans and bacteria are used to treat commercial, domestic, and sewage wastewater. This method was invented by Ardern and Lockett[18]. By this method, organic matter, nitrogenous compounds, and phosphates present in the wastewater are removed. This system is commonly used as secondary treatment for wastewater. In the detailed procedure, contaminants are removed using activated sludge, which is composed of active bacterial biomass. It is carried out in two different stages of aeration and settlement (Figure 5). In the first step, primary treated wastewater is added to the aeration tank, where they mix with air or oxygen-containing microbes. Upon incubation, microbes will grow and form flocks of nitrobacter, saprotrophic, and denitrifying bacteria which reduces the organic load of wastewater. The suspension of bacterial biomass which is known as activated sludge, decomposes the organic pollutant present in wastewater. This activated sludge settles at the tank and separates biological sludge from clarified effluent, which can be discharged as the final effluent [86, 90]. Membrane bioreactor is a newly developed technology for the treatment of wastewater (Figure 6). This technology uses a combination of the membrane with biologically activated sludge, microfiltration, ultrafiltration and biological reactions to clear the urban and industrial wastewater. The porous membrane has pores with a diameter of 0.02 to 0.4 μm which can isolate treated water and microorganisms [38]. Anaerobic degradation is carried out in the absence of oxygen. The following steps are involved in the anaerobic degradation: Breaking down of insoluble organic pollutants into soluble substances (to make them available for microorganisms), convert sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acid by microorganisms and conversion of organic acids into acetic acid, ammonia, hydrogen. However, anaerobic digestion is comparatively a very slow and less efficient method as compared to aerobic digestion. But studies have shown that compounds like lignin and PAH can be efficiently broken down through anaerobic bacteria [39, 90]. Hence these can be used for treatment of wastewater produced by sugar industries, food industry and paper industries where organic pollutant loads are very high. There are two types of methods: an upflow sludge anaerobic blanket (USAB) and anaerobic filter are employed for treatment of wastewater. USAB was developed by Lettinga in 1890 [2, 80, 91-93]. This reactor is a type of suspended growth reactor which helps in maintaining a high microbial biomass concentration. It produces methane and a blanket of granular sludge. There are three zones of UASB, the lower sludge blanket zone, the middle dead zone, and the upper gas zone. At the bottom, a sludge layer is dispersed evenly whereas in the middle layer anaerobic granules degrade the organic matter. The produced gas comes out from the top of the tank. Anaerobic biofilters were first developed in 1960. They are also known as fixed-film anaerobic reactors. This reactor has a fixed bed with a bacterial biofilm. The fixed bed is composed of various inert materials like crushed rock, a stone of pumice, pumice, gravel, etc. These materials have a typical size range of 12-55 mm. These materials are responsible for providing support to anaerobic bacteria to grow. Pollutants present in the wastewater when it flows through the fixed bed, it will get decomposed or destroyed and then methane gas is emitted from the top of the system [18, 88]. Biosorption is a new biotechnological process to remove heavy metals from industrial waste. As mentioned earlier, it is economical, efficient, accurate, chemical friendly and eco-friendly approach. It is proven as a better alternative strategy over the traditional methods to remove heavy metals from wastewater. It utilizes biological materials as biosorbents. Its efficiency is highly dependent on the temperature, pH, dye concentration, and dosage[77, 91, 94].

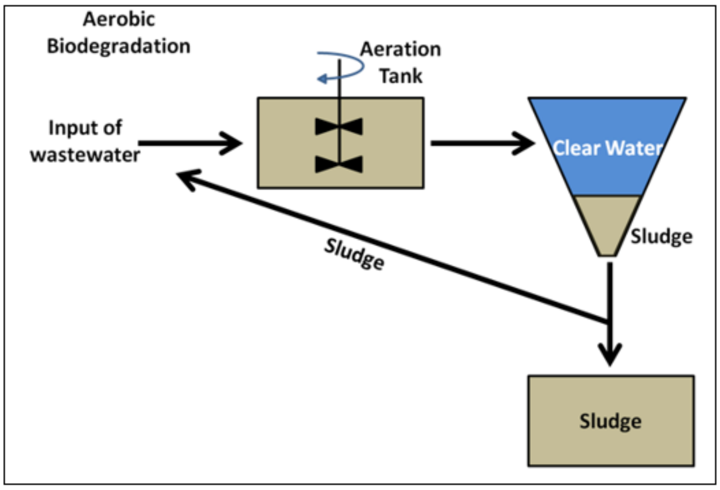

Fig 5: Aerobic biodegradation

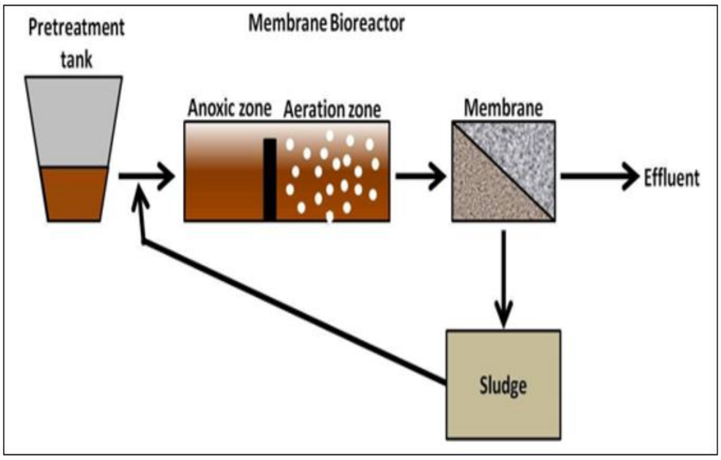

Fig 6: Membrane bioreactor

In situ bioremediation by plants is referred to as phytoremediation. This is an emerging technology which makes use of certain microorganisms which are associated with some higher living plants for extracting pollutants from water [95, 96]. The word "phytoremediation" was first coined in 1991. Rooted plants and trees are used for accumulation, metabolism, degradation and detoxification of organic and inorganic contaminants. Phytoremediation technologies can be used for treatment of wastewater contaminated with heavy metals, chlorinated compounds, aromatic hydrocarbons, hydrocarbons, crude oil, pesticides, explosives, and other pollutants. In the phytoremediation, different types of plants are used to extract, stabilize, shift, and/or destroy water pollutants. Phytoremediation was proven to be the most preferred technique where the field is very large and not feasible to treat with any other method. It is also an eco-friendly and effective approach. Aquatic plants were also found to consume excess contaminants present in agricultural, domestic, and industrial wastewater [41, 44, 91]. Salvinia molesta and Pistia stratiotes are among the most common aquatic plants used in the treatment of this wastewater [96-98]. Phytoremediation techniques also involve phytoextraction, phytodegradation, phytovolatilization, and rhizofiltration. In phytoextraction or phytoaccumulation, plants accumulate contaminants in their roots, shoots or leaves. Heavy metals are most commonly extracted by this method. Phytotransformation or photodegradation transform the pollutant into more stable, less mobile, and less toxic forms. Phytovolatilization converts certain molecules into volatile forms and releases them into the atmosphere. Rhizofiltration minimizes pollution from flowing water into freshwater. [96] Hyacinth, water lily and duckweed are the most common plants used in this technique [18]. A combination of advanced oxidation process (AOP) and biological process also proven to be very helpful in wastewater treatment. The key factor which affects the rate of treatment is doses of oxidant used. It was found that higher concentration of oxidant potentially damages the microorganisms. Not only this, it also increases the operation cost. Addition of less oxidant may result in insufficient treatment of wastewater [99-101]. In the study of Scott and Ollis, it was found that wastewater containing bio-resistant or recalcitrant compounds can be best treated with a combination of AOP and bio-treatment [102]. For bio resistance compounds, various treatments are applied depending on the type of compound. Pesticides can be best treated with photo fenton and aerobic biological treatment. This method can degrade up to 95% with 50% reduction in toxicity [100, 102]. Not only pesticides, but some tannery effluents can also be a fenton based method. Fenton based methods were found to reduce the COD and BOD of wastewater and make them more biodegradable. Not only pesticides, but waste of pharmaceuticals, personal care products and fluorinated compounds can also effectively biodegrade in combination with AOP [68].

7. TREATABILITY STUDIES FOR WASTEWATER TREATMENTS

Treatability studies can be defined as laboratory or pilot scale studies, carried out to optimize physical, chemical, and biochemical parameters in specific environmental media which will help to direct the selection, designing, and operation of complete large scale wastewater treatment units [99, 103]. Treatability studies also contribute significantly in identifying the specific fate of any chemical or treatment in treatment systems. Knowing the significance of treatability studies, the environmental protection agency (EPA) has designed manuals based on various treatability studies. Many different types of treatability tests can be done. Each of them has different mechanisms and applications [104-106]. Treatment screening studies play a vital role in narrowing down the potential treatment alternatives for a specific type wastewater treatment. Based on actual size, small scale or pilot study is designed and optimized which can be easily scaled up for actual operation. The study is comparatively simple and fast. For coagulation, flocculation and precipitation tests, jar tests are the most popular test. In case of characterization of the sorption process either jar or column test can be carried out[83, 105]. For biological treatment, batch or continuous reactors are used. Technology evaluation or verification testing is another kind of study which helps in evaluation of the performance of a specific treatment under a specific set of operating conditions. It is carried out to find out comparative performance of various agencies or to affirm the performance as claimed by the agency. Similar to technology evaluation, design support testing is carried out to determine various criteria for development of a full-scale treatment process and its operation. Fate and effect testing is considered as one of the important and critical tests for the wastewaters having different chemicals. It is carried out to determine the possible effect of a specific chemical, drug or compound present in the stream after treatment. Not limited to this, it will also allow it to evaluate its fates within the process. Liability/litigation support testing is depending on the various practices carried out in the past. Based on the previous carried out survey it will help in prediction whether the proposed treatment may work or may not. At a time, multiple approaches for treatability studies may be carried for better optimization of parameters for wastewater treatments[104-106]. To design an effective treatability study is not a simple task. To determine the applicability and viability of treatability study certain recommendations have been made earlier [28, 107]. The first recommendation is to check whether the study warrants desired output or not. If desired output is not achieved, further modifications must be done. Second recommendations include phase wise or stage wise approach. Though wastewater may be treated with continuous technology, phase wise evaluation should be carried out to determine the efficiency of technology at each stage. Stage wise improvisation leads to a better mode of treatment. On site or venue study with actual samples is given more emphasis over laboratory samples. One must consider all the possible variations and trends of wastewater before initiating the treatment. Especially when biological treatment using active microorganisms are involved, viability of seed culture on the site or venue must be determined. In addition to these parameters, other minor recommendations are there which includes the duration of treatment, cost effectiveness, minimum efficiency etc. An accurate treatability study enables scale up a faster, economic and more efficient technology with least chances of rejection[99, 103].

8. BIOLOGICAL TREATMENT OF WASTEWATER

Currently biological wastewater treatment is more used as compared to chemical treatments. It can be used for treatment of suspended solids, colloids, organic molecules and other soluble. It can also control the phosphorus and nitrogen level. There are two approaches for biological treatment. One is the use of activated sludge, belonging to the suspended growth category. It is one the most widely used processes. Another method is moving bed biofilm reactors (MBBR). Here the microorganisms remain attached and grow. It also acts similar to activated sludge but at a lower (Figure 7). The first MBBR was installed in 1989 at Steinsholt, Norway. Nowadays, MBBR technology is gaining more popularity due to their flexibility in various applications [50, 108]. Use of activated sludge is an old and conventional method for biological wastewater treatment. Till date It has been used widely in its native form as well as modified forms. Activated sludge process has three major parts: (1) a biological reactor fortified with relevant microorganisms responsible for treatment are kept in suspension and constantly kept aerated (2) a separator for segregation of liquid-solids and (3) a last recycle system to return solids after removal of liquid-solids separation. This process is proven efficient in production of good quality effluent but it is also sensitive to accumulation of toxic elements. Major drawbacks of activated sludge treatments include instability of biomass, bulking of sludge, and undesired contamination [89, 103, 109]. In the MBBR, a biofilm is prepared on an inert surface mostly made up of plastic. Biofilm along with media remain retained with sieves of the reactor. During the process, a very small portion of microbial film exits from the MBBR tank with the liquid. Hence, sludge recycling in an MBBR system is not required [108].

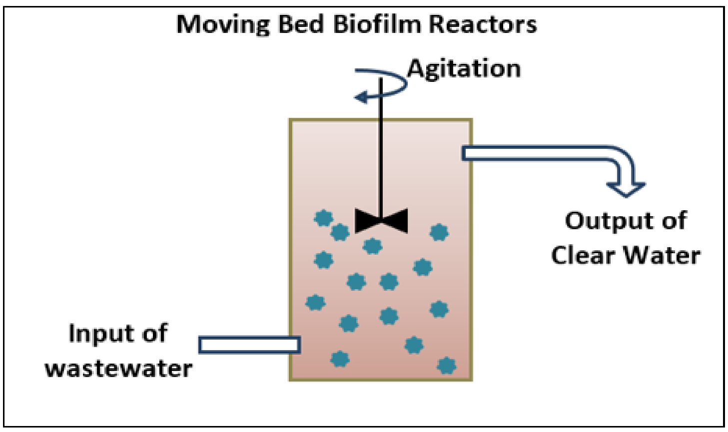

Fig 7: Representative figure of moving bed biofilm reactor

Selection of appropriate biological methods depends on a number of various factors. Among all the major factors, type of wastewater and sources of generation plays a vital role in determining the microorganisms for the treatment. Based on all technical and economic factors an appropriate method is selected. It is highly recommended to carry out a pilot scale study for better treatability. In addition to the characteristics of wastewater, biochemical oxygen demand, concentration of nutrients and toxicants also need to be considered. In case of presence of higher concentration of toxic elements, lower loading rate with multiple stages of treatment can be applied [105, 106].

9. ECONOMIC OF THE WASTEWATER TREATMENT

Economics of wastewater depend on many factors. Type of pollutants and their concentration are among the major factors affecting the economy. It is proposed to make a kinetic model for each type of treatment plant for determination of cost effectivity and output efficiency [100]. It is also recommended to consider total carbon concentrations, biochemical oxygen demand and chemical oxygen demand of wastewater to be treated. This will give a better idea about the required aerobic oxidation process and possible biological treatment. Design of an ideal kinetic model requires efficient designing and combination of chemical and biological processes. In the initial reports it was found that the steady state approach for biodegradation was less efficient as compared to multi-reactor configurations. Not only this type of waste produced and its elimination is also a rate limiting step in designing an economic wastewater treatment model. In addition to all the processes, manufacturing cost and other necessary modification as per requirement may also affect the economics. Many plants do not require any additional changes whereas in many cases installations of specialized sensors, UV lights, O3 supply etc. are required which need additional cost. Based on many previous studies, it was found that for each type of wastewater treatment, specialized plants should be prepared for optimum removal of contaminants [7, 8, 38].

10. CONCLUSION

Based on the entire review, it was found that utilization of water is essential for growth and development of any country but it also becomes essential to minimize the production of wastewater. For the protection of the food chain and food web, produced wastewater must be treated appropriately for removal of toxicants. Use of microorganisms is an eco-friendly and economic way for treatment of wastewater. Treatability study enables standard important parameters for large scale operations.

11. AUTHORS CONTRIBUTION STATEMENT

Jagruti Patel has carried out all the literature surveys required for this review and has prepared the manuscript. Rita N Kumar has guided the preparation of the manuscript. He has also provided kind support in literature surveys and guided for necessary changes in the review.

12. CONFLICT OF INTEREST

Conflict of interest declared none.

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