Chapter 1

Introduction

The river represents a complex aquatic ecosystem through continuous interaction with other terrestrial, atmospheric, and aquatic sub-systems. Generally, the river originating from plateau orhill area flows along plain and ultimately runs into the sea. The main source of river water is natural ice and precipitation, besides runoff from various other sources. The uniqueness of the riverine ecosystem lies with its unidirectional flow patterns, geomorphologic setup, and variability in physical, chemical, and biological factors in different seasons (Dodds et al., 2018). Rivers may also act as sources of impurities in the watershed, by acting as a sink of a multitudeof discharges of industrial effluents, nutrients, heavy metals, and/or pathogens. The river carries different substances from upper land to downstream before mixing with an estuary, which in the endpoint of a river receiving saline water from the sea.

Freshwater is the best appreciated gift of the environment to mankind that can maintain the livesof all living organisms as well as human beings. Water is distributed as sea water (97%) and the remaining 3% occur as freshwater being the most important natural constituent of the earth (Stolpe and Hassellov et al., 2007). Rivers have been recognized as the main source of water supply for humans and freshwater ecosystems.With increasing population and economic growth, water obstruction is likely to increase rapidly around the world (Pakhira, 2019) coupled with stream flow decline in more regions. There are many factors, such as population, economy, alteration of land-use pattern and climate changes which have imparted their impact in changing the quantity and quality of water (Rajib et al., 2016).

River ecosystems are associated with a number of other water bodies which can be designated as wetland (transitional landscapes in between terrestrial and aquatic ecosystem). Corresponding to tropical evergreen forests, wetlands are one of the most useful ecosystems in the biosphere and play a significant role in the environmental sustainability of a region.

Water is a vital part of human civilization meeting basic needs for life on earth like drinking purpose to climate stabilizers including also maintenance of biodiversity. The values of wetlands though overlapping, like the cultural, economic, and ecological factors are closed together. The wetland diversity depends upon biotic and abiotic factors across continents. The wetlands have various beneficial functions like a recharge of groundwater, water purification, water storage (domestic, agricultural, and industrial usage), sustaining life processes, protection from storm and flood, the storehouse for nutrients, erosion control, and stabilization of local climate (such as temperature and rainfall). Wetlands impart the value of biodiversity and act as habitats for plant, animal, and fish species that can bring many environmental services. Wetlands are still facing the threat of waste material degradation. In Asia, 85% of the wetland was mainly threatened through agricultural and industrial drainage (Xu et al., 2019). Besides wetland, rivers provide temporal, seasonal, and geographical evolution of an ecosystem (Wang et al., 2012).

Rivers bring health and the prosperity of mankind. Till today major industrial complexes and most the cities are established on the riverbanks. The utilization of water in drinking or processing is governed by the physico-chemical such as pH, temperature, alkalinity, etc. and biological parameters i.e. biological oxygen demand (BOD), chemical oxygen demand (COD), bacterial load, etc. Owing to the rapid pace of industrialization coupled with unplanned urbanization has forced the change of uncontrolled land use along the rivers and their basins which all together have led to cause deterioration of environmental qualities of the fluvial ecosystem in a developing country like India. Commonly in the downstream regions, the water quality of the river is deteriorated through drainage of agricultural crop-cultivation or municipality sewage (Amerasinghe et al., 2013). Water quality parameters (physical, chemical, and biological) of rivers are dynamic in nature. Water quality monitoring can help researchers predict and learn from natural processes in the environment and determine human impacts on an ecosystem. The changes in the ecological function because of anthropogenic intervention have resulted in massive loss of not only different biotic components but also alter the overall ecological health of stream (Whiles et al., 2013). The water quality index (WQI) is a very useful tool for the quantitative indication of water quality. WQI has been studded in details and was found to depend upon three parameters such as dissolved oxygen, total dissolved solid (TDS) and turbidity (Bansah et al., 2018). Nowadays, WQI is developed in presence or absence of aquatic organism.

Metal pollution has come to be a vital factor in environmental health. Metal contaminants mainly lead to diminish of the water quality that is directly involved with the morbidity and mortality of population (Koul and Taak, 2018). Water pollution affects not only a single inhabitants or a particular species. They also hampered the ecological balance, which have devastating effects on the environment and a diversity of aquatic organisms (Jiwan and Ajah, 2011). All time in the living bodies the metals are not metabolized and become toxic after being biomagnified. Bio magnification of Pb (II) and Cd (II) along a food chain was studied by several researchers (Pakhira, 2019).

The growing response for irrigation, industrialization and rapidly expanding urbanization, generation of power and huge pollution of both surface and ground water are needed to be addressed with informed interdisciplinary approach (Abdel-Raouf, 2012). Wastewater is mainly comprised of water with moderately minute concentrations of dissolved and suspended inorganic and organic solids. Besides, surface water present in the water bodies like river, estuaries and canals are being constantly polluted by anthropogenic activities (Zhao et al., 2018). Water-borne pathogens are recorded in increasing richness in coastal-estuarine environment posing serious threats to public health (Wang et al., 2018). In estuarine ecosystem higher loads of pathogens are supposed to be owing to the increased human activities, such as substantial recreation, water transportation during eco-tourisms (Paria and Chakraborty, 2019). Several pathogens such as *Vibrio cholerae*, *Salmonella sp.*, *Cryptosporidium sp.*, *Giardia sp.*, and *Campylobacter sp.* were identified in estuaries (Weatherdon et al., 2016). In developing countries water-borne pathogen mediated human diseases are main concern. Especially water quality has imposed serious threat to the human survivality mainly due to inadequate disposal of waste materials, lack of sanitation system, and scarcity of potable water supply (Alrawagh, 2018).

Pollution of both waters (surface water as well as groundwater) has become the major environmental alarm in India. The major sources of water pollution are: (1) discharge of industrial effluents and domestic sewage containing organic, chemical, and biological pollutants including heavy metals, and (2) run-off from agriculture. Agricultural development has been affecting water quality causing deterioration of riverine quality in Indian rivers in two ways. First, excess use of fertilizers and pesticides in agriculture, the run-off from cultivated lands is contaminating the water bodies. Secondly, rivers at many places do not have sufficient water for dilution of domestic sewage, industrial effluents. Thereby the problem of water pollution is gradually increasing. Nearly all riverine water of India has been under the tremendous stresses of pollution mostly by industrial and domestic wastes affecting on aquatic life even human being. According to WHO, BIS, ICMR, CPCB, in India 70% riverine water have been grossly contaminated by heavy metal toxicants and impurities from a different point and non-point sources, which have made the water resources non-suitable for human consumption (Singh, 2016). The common heavy metals acting as a potential pollutant to the aquatic ecosystem are copper (Cu), zinc (Zn), silver (Ag), lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), strontium (Sr), cesium (Cs), and cobalt (Co). Cadmium (Cd) and lead (Pb) are being considered as major water toxicants owing to their high toxicity (Paria et al., 2018). Heavy metals are deposited from lower to higher aquatic organisms (Kumar et al., 2018) and magnified lower to upper trophic levels through the food chain–food web interaction (Chakraborty, 2019). The water quality is affected by chemical nature and the number of heavy metals that are commonly released from anthropogenic activities which act as cytotoxic, mutagenic and carcinogenic agents (Sousa et al., 2017). From a global environmental perspective, water quality cannot be noticed for human needs or environmental and political considerations. It is an integral part in the social, cultural, environmental, and economic fabric of a community. Globally water consumption has been tripled since the 1950's due to expanded irrigation, industrialization, improved standards of living (Carley and Christie, 2017).

More than 80% population in our world have been suffering from freshwater scarcity (Hirich et al., 2014). At least one-fifth of city dwellers and three-quarters of rural people in developing countries lack access to resonable safe supplies of water due to scarcity of water supply and heavy metal pollution. The water quality problems such as eutrophication, acidification, heavy metals in biota and fish, nitrates in ground water, microbial contamination of drinking water, and pesticides accumulating throughout the food chains are new threats and contaminants.

According to WHO, 12% of the human population in our world, lacks freely available, clean drinking water whereas 159 million people are completely dependent on surface water (Chen et al., 2017). WHO proposed that 2 billion global people use contaminated drinking water facilitating the transmission of waterborne diseases such as diarrhea, cholera and dysentery etc. (Pal et al., 2018). The untreated wastewater discharged from purification plant of Paris municipality into lower Seine River, the dissolved oxygen level significantly dropped in the downstream at 100 km segment (Iqbal et al., 2019). In China, the water quality of the Pearl River estuary is maintained regulating the sewage release and run-off from urban areas.

In developing countries like India, water pollution is a growing task, which tries to accomplish quick economic development without adequate environmental management facilities. Now, the polluting materials discharged by different sectors i.e. domestic, industrial and agriculture have increased, sometimes beyond the carrying capacity of the environment. Freshwater sources such as rivers, lakes and aquifers are polluted by contamination that effects on health and livelihoodof people also the physical deterioration of the aquatic ecosystem (Lada, 2014).

In nineteen century, about 70% of water is polluted, out of which 8-16% is by industrial waste and 84-92% by sewage disposal in India (Starling et al., 2019). India is a river-based country which is covered by many large and small rivers. Among them, the Ganga river is the most important river. Several major and minor rivers besides their abundant tributaries make up the waterway system of India. The largest rivers basin system discharges its waters into the Bay of Bengal. However, some of the rivers whose courses take them to complete the western part of the country and towards the east of the state of Himachal Pradesh to the Arabian Sea. Parts of Ladakh northern parts of the Aravalli range and the arid parts of the Thar Desert have inland drainage (Valdiya, 2016). Thamirabarani river basin in South India originated from the Western Ghats and contaminated by heavy metals considerably by the release from agricultural runoff (Allen, 2017). Khan et al., (2016) applied cluster analysis (CA) to hydrochemical data to assess spatial variability in the water quality of Ramganga River and its tributaries (Ganga basin, India). Ganga Rivers in Uttarakhand applied correlation analysis and cluster analysis (CA) components for finding possible pollution causes, studying the seasonal differences. The microbial load in the riverine system including catchments and watersheds is found to be an increasing function of several organic and inorganic pollutants contents as has been noted in Gola, Uppanar, and Narmada rivers, India (Annalakshmi, 2017). The maximum flow of 76% pollutants was also measured in Uttar Pradesh. In Uttar Pradesh, Chhoyia, Permiya and Sisamau, nallahs are the main polluting drains contributing maximum to the river's pollution. For the determination of WQI, twenty-two (22) water quality parameters were measured in Varanasi, India (Chaurasia et al., 2018). In terms of the number of industrial units, the tannery sector dominated, whereas in terms of wastewater generation by chemical, sugar industries, pulp and paper mill. It is also observed that GPIs in Bihar generate 19% minimum wastewater in terms of water consumed whereas GPIs in West Bengal generates a maximum of 75.5 % waste water in terms of water consumed, followed by Uttarakhand (56.7 %) and Uttar Pradesh (39 %) (Singh et al., 2015).

The changing physical, chemical and biological features of water and their interactions influence the aquatic ecosystems of rivers. Experimental evidence associated with the ill effects of the degrading aquatic environmental conditions have been distinguished from different rivers around the globe. Several rivers of West Bengal have been originated from the north Himalayan and the west part of Chhota Nagpur plateau and flow south-eastern part of the state. The rivers in the western plains, at any other time of the year especially in the summer except monsoon accommodate the least amount of water (Miyan, 2015). In the last few decades rapid urbanization and industrialization, intensive agriculture, and growing demands for energy has affected the physicochemical parameters and biological attributes of the ground and surface water (Soni et al., 2015).

Central pollution control board (CPCB) of India also has prepared a list of the138 drains flowing in the Ganga river catchment (Zornes, 2007) pointing out the occurrence of the maximum number of point sources were in West Bengal, India. The research study also found that BOD levels were under prescribed limits from the river's origin at Gomukh to Rishikesh and in few region of Bihar. However, in the stretch of Rishikesh, downstream to Garhmukteshwar, and Kannauj upstream to Trighat, numerous sites in West Bengal such as Dakshineshwar, Uluberia, Diamond Harbour etc. record of water quality parameters (i.e., BOD and COD level) were high (Mariya et al., 2019). The pH level however fluctuates within the permissible level almost all the monitoring while fecal coliform is far in excess of the approved standard at most of the monitoring locations from Kanpur downstream up to Diamond Harbour (Srinivas et al., 2019). After the period of the festivals are over, the idols are immersed in the Ganga or any nearby water body, which cause drastic deterioration of water quality. In addition to the Ganges, there are numerous other rivers in West Bengal that are extra polluted and one of them is Subarnarekha, Damodar, Haldi, Kansai, Rupnarayan, Silaboti etc. Subarnarekha river water is served as several purposes such as recreation, drinking, agriculture, and industries but this water are contaminated by different heavy metals including arsenic (Parthasarathy and Raja, 2018).

The Subarnarekha is a rain-fed river basin among major river basins of India. The catchment area of the Subarnarekha River basin extends over 19,296 km^2 and accounts for 0.6% of the geographical area of India (Singh and Giri, 2018). Subarnarekha is a main transboundary river to satisfy the irrigation, industrial, and municipal water demands of West Bengal, Jharkhand and Odisha states. The upstream of the Subarnarekha basin harbors some extensive mineral deposits and thus a number of industries have been established along the bank of the river. The mineral resources of the Subarnarekha basin are mainly comprised of heavy metals (Cd, Pb, Hg, Cu, Fe, Cr, Al, U etc.) industrial material including asbestos, barites, apatite, china clay, limestone, dolomite and building stones (Giri et al., 2015). The upper part of the river passes through an industrial belt area of Jharkhand and Odisha. Subarnarekha River has four major industrial areas along the bank viz. (i) Ranchi-Hatia industrial area, (ii) Alumina processing plant at Muri, (iii) Jaduguda-Ghatshila mining and industrial complex. Besides these, there is a large number of medium and small industries like Tata Steel, Uranium Corporation of India, Usha Martin Industries, Hindustan Copper Limited, Steel Authority of India (SAIL) and TELCO (Singh and Giri, 2018). The water quality of the Subarnarekha river mainly affected by the discharge of untreated, mining, domestic and industrial effluent at different sites of the river bank.

Heavy metals such as lead (Pb), cadmium (Cd) and aluminium (Al) show extreme toxicity (Embaby and Redwan, 2019). There is a necessity for immediate actions to arrest water shortage especially in developing countries like Sub-Saharan including Nigeria in Africa with an epidemic of waterborne diseases viz. diarrhoea, cholera, shigella, typhoid, etc. due to a shortage of clean water. In Nigeria, more than 66 million people suffer from pure water for drinking purpose (Ayandiran et al., 2018).

Lotic and lentic water contaminated by different kinds of harmful bacteria, heavy metals, benthic fauna and flora but fungi play a dominant role as detrivores in aquatic system. Fungi grow in totally the ecological niches that belong to roots of plants as mycorrhizal to most food crops and animal as a useful agent, even act as a bioremediation agent. Within the domain eukaryote, fungi belongs to their own kingdom like plants, animals and protista (Bardele, 1997). The total number of 1.5 Million fungal species is evaluated, among them only 7% of species have been labelled (Lücking and Hawksworth, 2018). Among all the living organisms, fungi can play numerous roles in nature, the economy, environment, food science and health. Since fungi have to continue as inhabitants of environmental niches adjusting to constantly changing parameters. These niches are highly dynamic and can be composed of both biotic and abiotic factors (Schulze et al.,2019).

Fungal species are adapted to complete their life cycles in the aquatic system. The zygomycetes are mostly absent from aquatic habitats. About 3,000 fungal species and 138 non-fungal oomycetes have been informed to be existent in aquatic habitats (Shearer et al., 2007). According to Goh and Hyde (1996) over 600 freshwater species, consisting of 300 mitosporic fungi, 300 ascomycetes, a number of chytridiomycetes and non-fungal oomycetes were identified. (Ittner et al., 2018). Most of the fungal species in freshwater habitats are ascomycetes, basidiomycetes, chytridiomycetes, and glomeromycetes (Shearer et al., 2007).

Among aquatic organisms, fungi are more versatile group of microbes. They can grow under high temperatures and incompatible pH, those live as a prevailing group in Subarnarekha river (Liu et al., 2015) and they can also act as decomposers of the waste matter of the food web (Crotty et al., 2014) for its nourishment of soil biota. In an ideal ecosystem, a group of organisms belongs to different kingdoms that have shown maximal bio-degradation rate at the time of good supply of most essential nutrients (e.g. N, P, and K) in soil (Pathak, 2016). In the polluted riverine flows, microbes have shown to obvious different ways to cope up with deteriorating ecological condition and also to survive in the ecologically stressed environment by accepting various detoxifying appliances viz. bio-sorption, bioaccumulation, biotransformation and bio- mineralization (Dar and Bhat, 2020). Those scientific values behind such mechanisms of microbes can be employed and exploited for bioremediation either by exsitu or in -situ mechanisms (Tomei and Daugulis, 2019). Benthic microbial biomass such as bacteria and fungi can play regulatory roles in nutrient cycling (Locke and Bircher, 2016). Previous studies have revealed the higher an abundance of fungi in coarse sand fractions whereas bacteria were recorded in higher densities in silt and clay fractions of riverine sediment (Bernasconi et al., 2011).

Besides nutrient cycling, fungi are capable to yield a high amount of biomass and they have strong heavy metal removal efficacy (Qian et al., 2015). During the degradation of metals by white-rot fungi or isolated enzymes, heavy metals interfere with both the activity of extracellular enzymes involved in the process and colonization of fungi. The huge amount of metals is also stored in the mycorrhizal structures in the root and in the spores of fungi. It is noted that fungi almost accumulate 100 mg/kg of Zn and 300 mg/kg of Cd present in the metal rich soils (Vaishalya et al., 2015). Hence, it is necessary to remove these heavy metals from wastewater through low-cost technology before the use of natural water for irrigation purposes and even for drinking. Most of the heavy metal salts are water-soluble that cannot be separated by physical separation methods (Hussein et al., 2004). The present studies have been designed to isolate and characterize metal tolerant fungal strains for bimetallic absorption ability from Subarnarekha estuary. Among detrivores, fungi have adaptable metabolisms allowing them to quickly adapt to altering ecological conditions. The cellular event of morphogenesis is often accompanied by changes in pathways of catabolic and anabolic biochemical reactions. Fungi have both harmful and beneficial effects on the environment. The most important role in agriculture is to increasethe water-holding capability of soil owing to increase soil texture. Fungi can recapitulate soil alkalinity, increasing soil erosion and crop production when crop production falls due to ofbacterial metabolites, excessive use of chemical fertilizer, herbicide and insecticide. Fungi areused in the fermentation industry e.g. citric acid, ethanol, antibiotics, vitamins etc. (Singh et al., 2017). They play vital role in composting of organic waste substances that grow in spoilage food, leather and wood. On the other hand, they can accumulate some inorganic the chemical in their cell. Even they can participate in the conversion of high molecular weight chemical compounds to low molecular weight, comparatively less harmful components. Fungi also help to remove a wide group of toxins from polluted environments or wastewater by the environmentally sound way (Hyde et al., 2016). A filamentous fungus (yeasts) has been used as a model eukaryotic organism for biochemical and molecular biological study. From an ecological perspective, toxic metals, metalloids, radionuclides and organometallics can accelerate pollution of the natural environment. For that reason different types of fungi are grown in metal-polluted habitats for their uptake, translocation and detoxify toxic metals (Vaishaly, 2015). Fungi act as a bio indicator or biomarker of the freshwater ecosystem (Pascoal et al., 2005; Sole et al., 2008). Fungi are generally used as bio-sorbents for the removal of toxic metals with excellent capacities from the aqueous systems (Melgar et al., 2007). *Penicillium sp., Aspergillus sp., Pseudomonas sp., Sporophyticus sp., Bacillus sp., Phanerochaete sp.* etc. species are to be found very useful for the removal of heavy metals (Congeevaram et al., 2007). Different species of *Aspergillus* have also been reported as efficient heavy metals reducers (Abd El Hameed et al., 2015). The *Aspergillus sp.* can remove chromium from tannery wastewater *(*Srivastava et al., 2006). Dead fungal biomass of *Aspergillus niger, Rhizopus oryzae, Penicillium chrysogenum* and *Saccharomyces cerevisiae* could be used to convert more toxic Cr (VI) to less toxic or nontoxic Cr (III). Luna et al. (2016) also observed that *Candida sphaerica* produces bio-surfactants with 95 %, 90 %, and 79 % removal efficiency for iron (Fe), zinc (Zn), and lead (Pb) respectively. These surfactants could make complexes with metal ions and interrelate directly with heavy metals before detaching from the soil. *Candida sp*. that can accumulate substantial 57–71% nickel (Ni) and 52– 68 % copper (Cu) (Dönmez and Aksu, 2001).

Fresh surface water is the best appreciated gift of the nature to human kind supporting the lives of all living organisms. The rising demand for urbanization, industrialization, irrigation and generation of power and huge pollution of surface and ground water are essential to be addressedwith informed interdisciplinary method. Currently both surface and ground water are now great threats because of the increasing incidence of heavy metal discharges from multifarious sources out of human activities like leakage from acid batteries, vehicular emission, industrialization, fertilizers different causes of metal containing paints etc. (Sanyal et al., 2015; Hussein et al., 2004). The physico-chemical approaches have become acted to be ineffective but expensive when the concentration of heavy metals is very low in the water. In such a context, the searchand development for new technologies have been focused on to the application of bio- sorption based technologies which in contrast have appeared to be more acceptable to the environmental managers in contrast to applied physicochemical remediation methods. Bio-accumulation or bio- absorption means removals of heavy metals utilizing the underlying scientific principles of several biophysical processes (Moosavian and Moazezi, 2016) such as solvent extraction, ion exchange, and reverse osmosis, coagulation by lime and precipitation by specific chemical. Among the flora and fauna, fungi are able to produce high amount of biomass and they have strong heavy metal removal efficacy (Gruszecka et al., 2017; Dhankhar and Hooda, 2011). Bioremediation of heavy metals or the environmental management has looked to be the great challenge in view of rising expenditure and also unavailability of user-friendly and eco- sustainable technologies. Heavy metals being very toxic and persistent pollutants (Edwards et al., 2013) tend to accumulate in ecosystems by several sources such as manufacture of electrical apparatus, mining of metals, industrial wastes, use of pesticides and colors, chemical fertilizers and municipal sewage disposal etc. causing deleterious effects on not only to flora and fauna isolated but jeopardize the trophic relationship by way of bioaccumulation and bio- magnification.

Many conventional methods such as adsorption, dialysis, coagulation, and filtration etc. were used for heavy metals bioremediation (Kanakaraju et al., 2019). Microorganisms i.e. fungi, bacteria and algae provide a good option for remediation of heavy metals, dyes and other contaminants from waste water (Mishra et al., 2014; Geva et al., 2016; Gola et al., 2017).Various fungal genera such as *Penicillium sp.,Aspergillus sp. and Rhizopus sp* . are being used as potential microbial agents to remove of heavy metals from aqueous solutions (More et al., 2010). Xiao et al., 2010 has described a novel technology, with the use of hyper accumulator which had proved to be more efficient and convenient method in contrast to the existing traditional one for obtaining highly efficient bio-sorbents from endophytes (Xiao et al., 2010). Usually bacterial pollution are decreased by addition of antibiotics (Bayrock et al., 2003) but previous report mentioned that some of bacteria identified from the bottom sediments of Indian rivers can resist broad-spectrum antibiotics (Kristiansson et al., 2011). In such context, a cost-effective but eco- sustainable alternative waste water management programme is certainly the need of the hour not only for the human health but also to ensure survivality of different components of ecosystem.

Bio-sorption can be made by dead biomass or living cells as passive uptake onto the cell wall and surface layers through surface complexation (Fomina and Gadd, 2014). Bioaccumulation depends on a variability of chemical, physical, and biological factors and these factors are intracellular and extracellular processes (Ayangbenro and Babalola, 2017). Intracellular sequestration is the complexation of metal ions by numerous compounds in the cytoplasm of cell. The concentration of metals within microbial cells can effect from interaction with surface ligands followed by slow transport into the cell. The ability of bacterial cells to accumulate heavy metals intracellular has been exploited in practices, predominantly in the treatment of effluent treatment. Cadmium-tolerant *P. putida* strain possessed the ability of intracellular sequestration of copper, cadmium, and zinc ions with the help of cysteine-rich low molecular weight proteins (Igiri et al., 2018). Also, intracellular sequestration of cadmium ions by glutathione was revealed in *Rhizobium leguminosarum* cells (Lima et al., 2006).

The outer cell wall of fungi is made up of mainly chitin, polysaccharides, polyphosphates, proteins and mineral ions. The outside of the cell wall of fungi acts like a ligand used for labelling metal ions and brings about the elimination of inorganic metals (Igiri et al., 2018).

Extracellular polymeric substances (EPS) are of immense importance to the bioremediation process because of their involvement in the flocculation and binding of metal ions from solution (Nouha et al., 2018). The biosorption of EPS seems to be more cost-effective, safe and unconventional to chemical methods like coagulation, precipitation and ion exchange etc. EPSs are potential conventional chemical polymers due to their high efficiency, nontoxic features and biodegradability but deficiency of secondary pollution production (Nollet, 2016). The chemical hydrolysis of EPSs recovered with 2 M tri-fluoro-acetic acid (TFA) shown a complex sugar arrangement (Caruso et al., 2018). At present-day, a significant number of fungi including higher basidiomycetes and lower filamentous fungi from different ecological places were recognized for their ability to synthesize EPS. Very little evidence is available regarding the biosynthesis of EPSs from fungi. Some fungal EPS biosynthesis pathways have been considered, such as EPS production by *G. lucidum* (Freitas et al., 2017). In particular, the microbial EPS is produced by *Winogradskyella sp*. possess strong emulsifying activity (Wang et al., 2019). The fungal EPSs structure varies from pure sugars to sugars conjugated with protein, phosphate, sulphate, or amine. Different types of sugar unite were found in fungal EPSs such as glucose, galactose, fucose, mannose, xylose and rhamnose. It was also observed that EPSs composed of the same monosaccharide units with a different molecular weight that was synthesized by different fungi. This is caused by differing chain length or branching patterns. The general way of microbial polysaccharide production depicted in Figure 1.1. Microbes take up nutrients from the media, in the proper way. They are able to synthesize polysaccharide that ultimately releases from cells as extra-cellular polymeric substance.

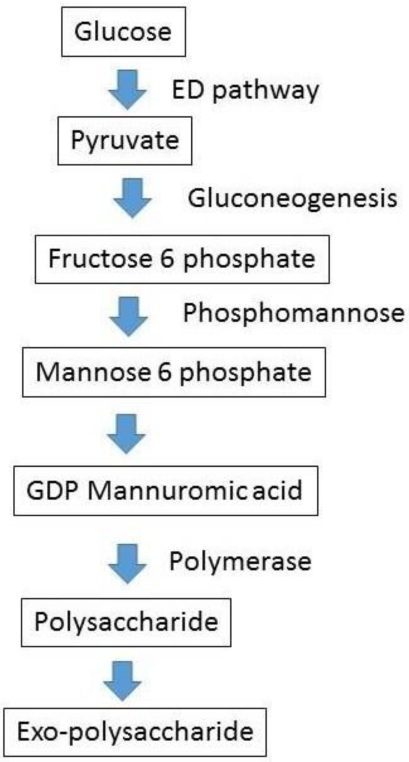

Figure 1.1: Microbial Exopolysaccharide (EPS) production

Biomonitoring change lies at the core of ecosystem conservation, restoration and management. Biomonitoring has become a vital tool for studying professional and environmental experience to various chemicals. Biomonitoring capacities deliver an estimation of the quantity of a chemical absorbed into the body from all conduits of contact and thus give a growing estimate of the chemical load that a person conveys in their body. From the last few decades microbial EPSs have increased importance in different applications that not only indicates the alternative source of plant or seaweed polysaccharides but also have some new and interesting bio applicability beside bio-remediation those indicated in Figure 1.2 (La Barre and Bates, 2018).

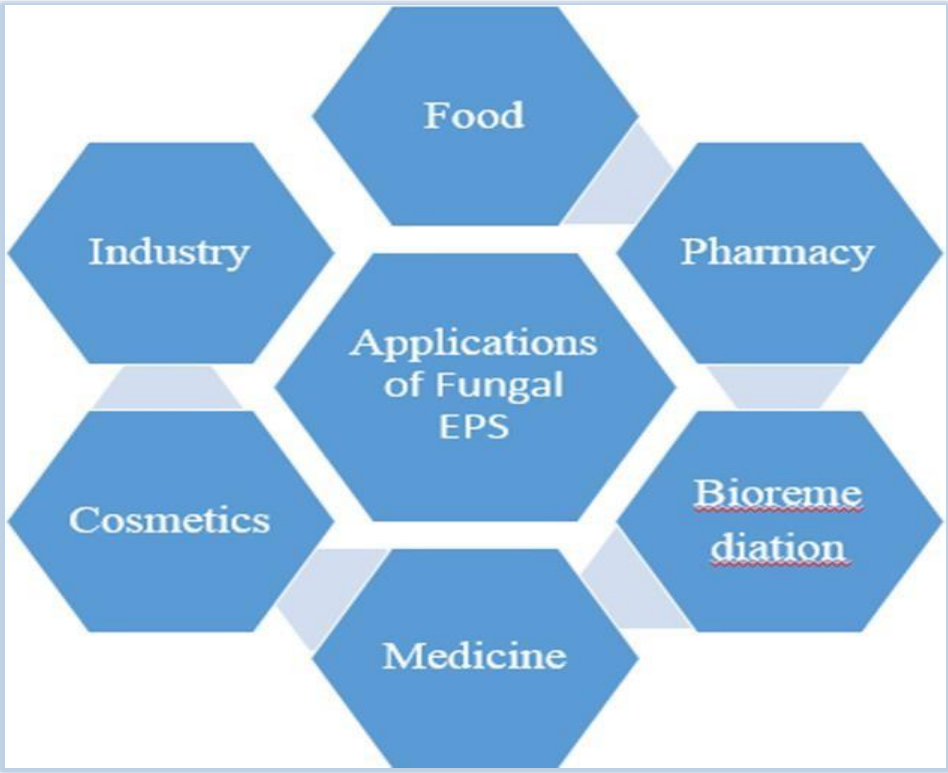

Figure 1.2: Various application of fungal EPS

Extracellular sequestration is built of metal ions by cellular constituents in the periplasm or complexation of metal ions as insoluble compounds. Copper-resistant *Pseudomonas syringae* strains produced copper-inducible periplasmic proteins i.e. Cop A, Cop B and outer membrane protein i.e. Cop C that binds copper ions and microbial colonies (Igiri 2018). Bacteria can discharge metal ions from the cytoplasm to sequester the metal within the periplasm. Zinc ions can cross from the cytoplasm by the efflux system where they are accumulated in the periplasm of *Synechocystis* PCC 6803 strain (Fosso-Kankeu, 2018).

Metal precipitation is an extracellular sequestration. Sulphur reducing bacterium like *Desulfuromonas sp* and iron reducing bacterium such as *Geobacter sp*. are able to reduce harmful metals to less or nontoxic metals (Igiri, 2018). *G. metallireducens* and *G. sulfurreducens* have the ability to decrease chromium (Cr) from the very lethal Cr (VI) to less toxic Cr (III) (Pratush, 2018). Sulfate-reducing bacteria generate large amounts of hydrogen sulphide causing precipitation of metal cations (Najib et al., 2017). *Klebsiella planticola* strain generates hydrogen sulphide from thiosulfate under anaerobic environments and precipitated cadmium ions as unsolvable sulphides. Also, cadmium was precipitated by *P. aeruginosa* strain under aerobic conditions (Chakraborty and Das, 2014).

The microbial cell wall and plasma membrane could prevent metal ions from inward the cell. Bacteria can adsorb metal ions by ionizable groups i.e. amino, carboxyl, phosphate, and hydroxyl of the cell wall (Kushwaha, 2018). The *Pseudomonas aeruginosa* show higher resistance to ions of copper, lead, and zinc than planktonic cells, while cells located at the periphery of the biofilm was killed. Extracellular polymers of biofilm accumulated metal ions and then protect bacterial cells inside the biofilm (Flemming, 2016). The present long term study was planned and undertaken spanning a period of several years (March, 2011- February, 2019) for highlighting of biomonitoring, bioremediation and antibacterial activities of fungal strain of Subarnarekha river estuary, India. The entire work intended to record the following on-

(a) The effectiveness in removing pollutants;

(b) The availability of the absorbent;

(c) The cost of the absorbent;

(d) The regeneration of the absorbent; and

(e) The ease with which the absorbent can be used.

Fungal cells are relatively small with low density, low mechanical strength and rigidity. The use of immobilized biomass systems offers a practical approach to the treatment of metal bearing wastewaters. Various techniques are available for the immobilization of fungal biomass (Vijayaraghavan and Balasubramanian, 2015).

Ecosystem management is a technique that targets to save main ecological facilities and return natural properties. It is a holistic approach that requires an important alteration in how identified the natural environments. Eco-restoration is an important role of the ecosystem approach that is the negotiation of land using patterns and development of healthy ecological systems. Restoration of Ecology deals with management and research experiment to regulate the mechanisms that control and rescue degraded ecosystems, and to discover for safely re-establishing corrupted ecosystems in the natural environment. Wetlands restoration requires water quality and hydrological dynamics; the quality of water is obligatory for good wetland systems. Ecological restoration involves in management actions designed to accelerate the recovery of degraded ecosystems by complementing or reinforcing natural processes.