Effective Role of Microorganism in Waste Management and Environmental Sustainability

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Contents

Abstract

Environmental protection and sustainability is one of the major concerns in present scenario. Continuous release of harmful waste and contaminants due to improper industrialization and unchecked urbanization possesses greatest threat

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to mankind directly in short as well as long term and also puts a tremendous pressure on the natural resources. Unscientific and ill-management of urban and industrial wastes and contaminants has handed over the ecology and environment to the hand of endangered sustainability. So it is the time to make correction and remediate the polluted NR in such a way that brings a sustainable and habitable ecosystem for the future generations. Waste generation has a positive correlation with the economic development which is much observed in the Western countries and also in developing countries like India. Waste generation in India shows different trends, and urbanization plays a significant role in waste generation. In India total solid waste generation is about 42 million tons/year. Hazardous waste treatment requires more effective and green technologies. In this context microorganism plays a promising role. The unique nature of microorganisms can be used effectively for resurrecting the environment. Microorganism can act as magic bullets for bioremediation of contaminated sites and biodegradation purposes. Now a day microorganisms are effectively used together with nanotechnology, termed as nano-bioremediation to clean up radio active wastes. Moreover, the use of genetically modified organisms (GMOs) in combating pollution in extreme polluted condition makes the microorganism a boon to human welfare. This chapter gives an insight into different types of wastes and explains how microorganism can be used effectively for waste management (WM) and sustaining our environment in a greener way.

Keywords
Environment · Industrialization · Microorganism · Sustainability · Urbanization · Waste

Abbreviation

C	Carbon
DDT	Dichlorodiphenyltrichloroethane
GMOs	Genetically modified organisms
HC	Hydrocarbons
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
N	Nitrogen
OC	Organic compounds
OM	Organic matter
PAHs	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PVC	Polyvinyl chloride
TCE	Trichloroethylene
WM	Waste management
WW	Waste water
XC	Xenobiotic compounds

1 Introduction

Rapid urbanization, industrial revolution and tremendous pressure of population on the natural resources put great stress on the global environment. Various unscientific activities of modern civilization generate huge quantity of wastes which lead to pollution (Raj et al. 2018a, b). Moreover increased rate of consumption of raw materials by the large-scale industries results in dumping of huge quantities of chemical contaminants and radioactive wastes in the environment, leads to irreparable damage to the overall biosphere. The generation of waste is the main factor for a loss of materials and energy and raises environmental consequences and cost on society for its collection, treatment, disposal and overall management (Jhariya et al. 2018). Generation of harmful waste in India is directly related to the development of the cities and has a significant variation among the cities. If the rate of industrialization increases it is thought that the amount of wastes will also increase (Sharma and Shah 2005), unless application of scientific waste management.

The scenario of waste management (WM) is significantly different between developed and developing nations because developing nations are lacking of proper collection and disposal mechanism of waste. So, WM has become very critical and receives priority due to progressive concern related to environmental degradation and sustainability (Brewer 2001). Uncontrolled, haphazard and unscientific means of dumping of wastes on the outskirts of towns and periphery of villages results in overflowing landfills, which are not only impossible to return to a suitable condition but also have solemn environmental implications in terms of soil and groundwater pollution and contribution to global warming.

An effective or operative system of WM is the need of the hour and should be economically and environmentally sustainable. There are various popular methods of WM and treatment which are practised regularly such as the following: (1) Incineration method – here wastes and trash materials are treated with high temperature. (2) Sanitary landfills – this method is more useful and practised throughout the world**.** Practically sanitary landfills are the sites where wastes are kept isolated from the environment. (3) Recycling – it means transformation of materials into new form for use. (4) Avoidance and reduction – avoidance means reuse of second-hand products, designing reusable products and, instead of buying new, repairing broken items.

So cleaning of polluted environment in a sustainable way is very much necessary; in this regard the role of microorganism in WM and biodegradation of contaminants has intensified in recent years (Banerjee et al. 2018). Different microorganism based biotechnological tools such as bioremediation, biodegradation, biocomposting and biotransformation have been used to accumulate and degrade huge range of contaminants effectively (Banerjee et al. 2018). Maghraby and Hassan (2018) reported that *Cladophora* sp. (green algae) has high bioaccumulation capability for toxic metals and can be used as potent and alternative WM agent. Moreover, microbial ecology is a major important factor for proper functioning of biological processes of waste water (WW) treatment systems. Martinez et al. (2018) demonstrate that archaea and bacteria are dominant in the bioreactors of

WW treatment system in the polar arctic region in Finland. Nowadays, nanoparticles have been used effectively to enhance the activity of microbes, termed as nanobioremediation. In the USA, *Deinococcus radiodurans* (extremophilic bacteria) is used in radioactive waste removal strategies as it is a radioactive-resistant organism and can withstand radiation naturally (Brim et al. 2000; Varma et al. 2017).

So use of microorganisms with different biotechnologies is the most effective method to treat different wastes, in addition to being eco-friendly, cost-effective and environmentally sustainable method. The main objective of this paper is to propose and promote the application of most affordable and environment-friendly method for treating polluted waste with the use of different microbial agents towards environmental sustainability.

2 What Is Waste?

Waste is generated from human activity mostly**.** Rapid and unplanned development and modification of livelihood all over the world put complexity in the generated waste. Overall biosphere is degraded rapidly due to continuous release of hazardous pollutants from different industries throughout the world. Rapid expension of health-care facilities and modernization of agricultural practices generate large quantity of biomedical and agricultural wastes which brings adverse effect on environmental health. There are three kinds of wastes mainly such as solid waste, liquid waste and gaseous waste.

3 Classification of Waste

Waste can be solid, liquid and gas or waste heat. Waste is classified by its source and by its characteristics. Waste products can be differentiated according to their source and types. Generally there are four sources from where waste can be generated such as industrial, municipal, biomedical and electronic. Waste can be classified on the basis of different criteria such as based on matter, based on degradation feature, based on environmental impact and based on the source. Each category may be of different types which are shown on Fig. 1.

4 What Is Waste Management?

WM is basically the storage, collection and disposal and managing of waste materials. The main aim of WM is to reduce the effects and consequences of wastes on human health and environment. It continues to be a rising challenge with rapid urbanization, industrial revolution and tremendous pressure of population on the NR that put great stress on the global environment. WM has basically four parts – industrial, electronic, municipal and biomedical – and all of these wastes are supervised by particular policies. The concept of 4R theory (refuse, reduce, reuse and

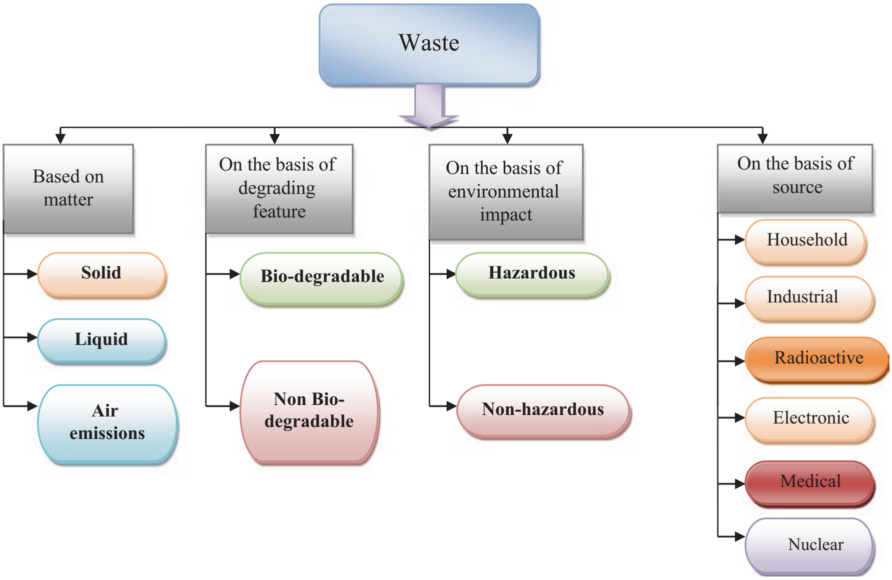

Fig. 1 Different types of waste

recycle) has been applied to the basic principles of WM. In India strategy for WM depends on waste generation, store, collection, transportation, recycle, treatment and disposal. Some of the commonly used WM methods are landfills, incineration, composting and gasification. Schematic view of WM system is shown on Fig. 2.

4.1 Microbes in Waste Management

Microbial biotechnology in WM is the process of utilization of modern scientific tools and techniques which use a wide variety of microorganisms in controlled condition without disturbing the ecosystem. Most common and efficient methods adopted at various level of WM are composting, biodegradation, bioremediation and biotransformation. A wide variety of microorganisms have been used effectively for WM such as *Bacillus* sp., *Corynebacterium* sp., *Staphylococcus* sp., *Streptococcus* sp., *Scenedesmus platydiscus*, *S. quadricauda*, *S. capricornutum*, *Chlorella vulgaris*, etc.

4.1.1 Composting

Composting is an aerobic decomposition process and is facilitated by a diverse population of microorganisms. This process has been widely practised for different types of wastes by means of metabolic activity of microbial consortium. Composting has been used to transform and stabilize organic waste into more safer and stabilized form that can be used in various agricultural practices (Garcıa-Gomez et al. 2005). It is an economically and environmentally appropriate method for handling

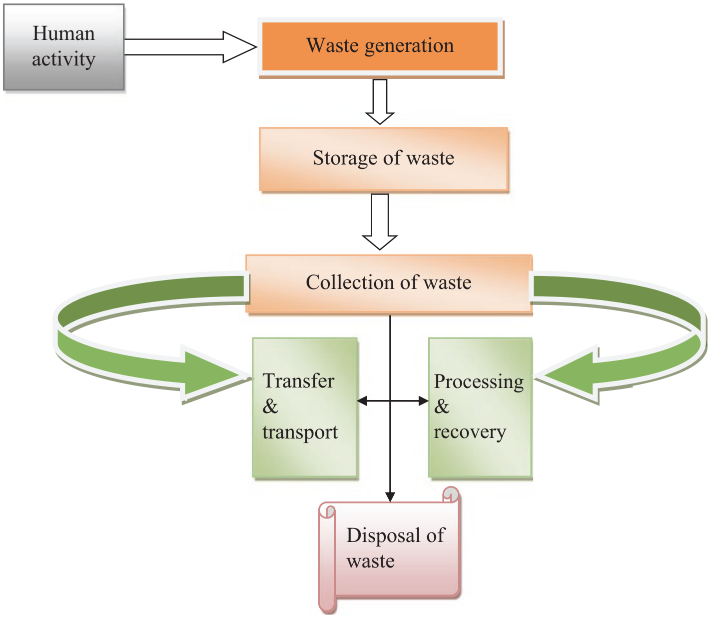

Fig. 2 Schematic view of WM system

waste. The main product of composting is humus and plant nutrients, and carbon dioxide, water and heat are the by-products (Abbasi et al. 2000). Different types of microorganisms such as bacteria, actinomycetes, yeasts and fungi are involved in this process. Composting occurs in three different phases: mesophilic phase, thermophilic phase and cooling and maturation phase. Two factors regulate the duration or length of the composting phases: the types of composting organic matter (OM) and the efficiency or effectiveness of the process ascertain by the degree of aeration and agitation.

Factors Related to Composting

Microorganisms

Several microbes are very much effective to oxidize or decompose different organic compounds (OC) into a more simple and stabilized end products (Atalia et al. 2015). Report suggests that there are certain kinds of microorganisms such as mesophilic bacteria, actinomycetes, fungi and protozoa which colonize a heap of biodegradable solid waste (Gajalakshmi and Abbasi 2008). These microbes can grow in the temperature range between 10 and 45 °C and effectively degrade degradable components (Cooperband 2000; Hellmann et al. 1997). Thermophilic phase is the active phase of composting and can last for several weeks. In the thermophilic phase, most of the OM is degraded (Gajalakshmi and Abbasi 2008; Meena et al. 2018).

Temperature

It has been reported that favourable temperatures for composting to occur is at the range of 52–60 °C (MacGregor et al. 1981). During composting the maximum temperature goes up to 60–70 °C, where most of the microbes are not as much active. Composting process can be paused or significantly steady at the temperature that is below 20 °C. It has also been reported that temperature above 60 °C can reduce the microbial activity, because temperature at that level cross optimum thermophilic borderline of microorganisms (Gajalakshmi and Abbasi 2008).

pH

Composting process is greatly affected and influenced by the pH value. Different composting microorganisms prefer different pH ranges. pH range within 6.0–7.5 is ideal for bacterial development, whereas pH in between 5.5–8.0 is ideal for fungi (Gajalakshmi and Abbasi 2008). If somehow the pH value crosses 7.5, it results in nitrogen (N) loss (Gajalakshmi and Abbasi 2008). pH between 6.5 and 7.5 is probably the favourable temperature for a wide range of microbes (Bharadwaj 1995). It has been reported that bacterial activity is significantly hampered or even inhibited below pH 5.0 (Gajalakshmi and Abbasi 2008).

Moisture Content

To start compost the suitable and ideal moisture content is generally 60–70%. But at the final stages, 50–60% is the optimum moisture content. Moisture content higher than 75% and lower than 30% significantly reduces microbial activities (Bertoldi and Vallini 1983). A proper balance between microbial activity and available oxygen effectively manages the moisture content (Gajalakshmi and Abbasi 2008). Excess moisture creates anaerobic conditions which results in undesirable products and bad odour.

Carbon and Nitrogen Ratio

C and N are both essential for microorganism. C is the principal energy source, and N is important for growth of the microbes. Rapid and entire humification of a substrate basically relies on C/N ratio which is initially in the range of 25 and 35 (Gajalakshmi and Abbasi 2008).

Particle Nature and Size

Nature and the size of particles are very important for composting. Particle size affects oxygen availability into the pile as well as microbial ingress to the substrate. Particles which are smaller in size increase the surface area needed for microbial attack (Atalia et al. 2015; Kumar et al. 2018), and particles which are larger in size minimize the surface area available for microbial attack which leads to slow down or even stop the composting machinery (Zia et al. 2003).

4.1.2 Biodegradation

Biodegradation is a biological way of degradation of chemical compounds (Alexander 1994). In this process living microbial organisms are used to degrade

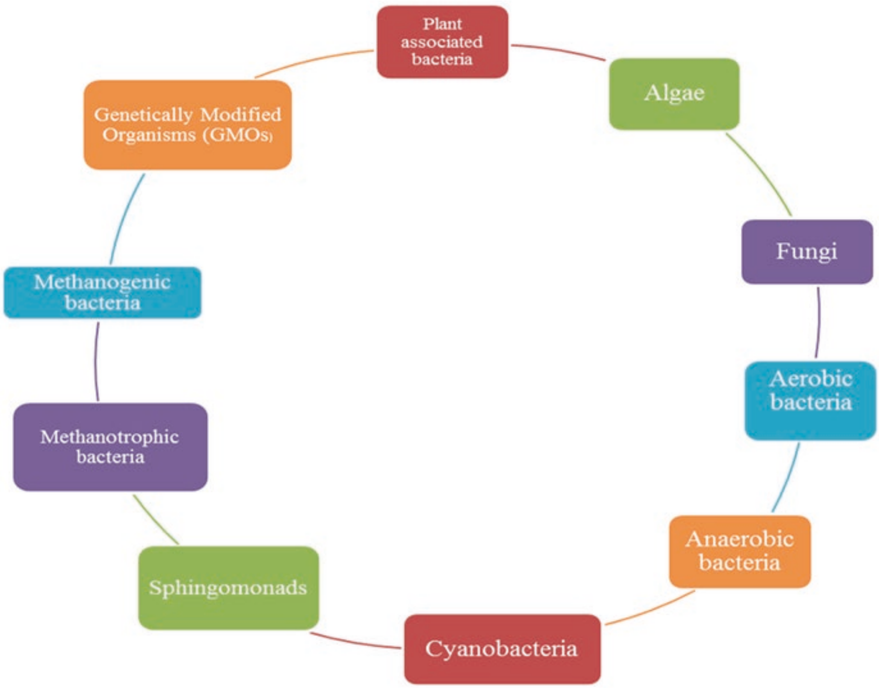

Fig. 3 Different types of microbes involved in biodegradation process

organic substances into smaller compounds (Marinescu et al. 2009). Biodegradation is closely associated with WM and environmental remediation (Marinescu et al. 2009). In terms of microbiology, biodegradation is degradation of OC by a huge diversity of microbial population mainly bacteria, yeast and fungi. Different types of microbes involved in biodegradation process are shown on Fig. 3.

Degradation Capability of Bacteria

Several bacteria have been reported as having hydrocarbon (HC)-degrading ability (Yakimov et al. 2007). This bacterium can biodegrade HC under aerobic and anaerobic conditions, but anaerobic biodegradation is more significant (Wiedemeier et al. 1995). A wide variety of bacteria having HC-degrading ability were extracted from marine environment (Floodgate 1984). Kafilzadeh et al. (2011) isolated different types of bacteria which are good biodegrader of HC; examples are *Bacillus* sp., *Corynebacterium* sp., *Staphylococcus* sp., *Streptococcus* sp., *Shigella* sp., *Alcaligenes* sp., *Acinetobacter* sp., *Escherichia* sp., *Klebsiella* sp. and *Enterobacter* sp. of which *Bacillus* sp. has the best HC-degrading capability. Successful removal of pesticides by the addition of bacteria also has been reported to degrade pesticides from many compounds such as atrazine successfully (Struthers et al. 1998). It has been reported that dichlorodiphenyltrichloroethane (DDT) is degraded by isolates of *Bacillus* sp., *Stenotrophomonas* sp. and *Staphylococcus* sp. from contaminated soil (Kanade et al. 2012).

Degradation by Plant-Associated Bacteria

Bacteria associated with plants such as rhizospheric bacteria and endophytic bacteria are effective biodegrader of toxic compound in contaminated soil (Divya and Deepak Kumar 2011). Plant growth-promoting rhizobacteria are naturally occurring bacteria which are found in the rhizosphere of plant roots and promote growth stimulation in plants (Saharan and Nehra 2011). In most of the cases, the association between plant and bacteria is beneficial for plants as these bacteria help in N fixation and enrich the soil with nutrients (Tank and Saraf 2009; Meena et al. 2015). For example, an important bacterium, *Pseudomonas* spp., has plant growth-promoting rhizobacteria activity and also has the ability to degrade HC (Hontzeas et al. 2004).

Some soil bacteria often promote plant growth, known as plant growth-promoting bacteria. These bacteria are also efficient up-taker of heavy metal from the contaminated soil. Various mechanisms have been applied by this bacterium for metal uptake such as production of organic acid and bio-surfactant and result in reduced toxicity in root and promote plant growth (Wu et al. 2006). Plant growth-promoting bacteria act as a supplement in phytoremediation of metal and can boost plant growth in high metal concentration (Glick 2010).

Microfungi and Mycorrhizal Degradation

Microfungi are aerobic and belong to eukaryotic microorganisms which include unicellular yeasts to mycelial moulds (Rossman 2008). Fungi also have degrading capacities like that of bacteria and OM which are in dissolved state are successfully metabolized by them. Fungi can reproduce and flourish in low moisture content and low pH site which suit them in OM degradation (Spellman 1997). Fungi are considered as the most efficient biodegrader of natural polymeric compounds if they are equipped with extracellular multienzyme complexes. Mycorrhiza is an association between a fungus and roots of a vascular plant. Fungus may be either intracellular or extracellular and play a significant role in soil livelihood.

Different aromatic compounds may be utilized and converted co-metabolically by several yeasts. *Trichosporon cutaneum*, an example of soil yeast, has been reported to have specialized energy-dependent uptake systems for several aromatic compounds (Mörtberg and Neujahr 1985). Alkane-utilizing yeasts such as *Aureobasidium pullulans*, *Rhodotorula aurantiaca*, *Candida lipolytica*, *C. tropicalis* and *C. ernobii* have been reported as an effective diesel degrader (De Cássia et al. 2007). Mucha et al. (2010) reported that *C. methanosorbosa* BP-6 is able to biodegrade aniline. Microfungi are also reported for transformation of different organic pollutants such as biphenyls, polycyclic aromatic hydrocarbons (PAHs) and different pesticides (Fritsche and Hofrichter 2000).

Degradation by Algae

Though algae are also able to biodegrade different kinds of HC, their involvement in HC biodegradation is still not well reported (Das and Chandran 2011). Walker et al. (1975) stated that *Prototheca zopfi* is a good agent for the degradation of different aromatic compounds. Wang and Chen (2006) demonstrate some algae which are capable of up-taking and degrading PAHs. Examples are *Scenedesmus* *platydiscus*, *S. quadricauda*, *S. capricornutum* and *Chlorella vulgaris*. List of microorganism involved in biodegradation process is listed in Table 1.

4.1.3 Biodegradation of Xenobiotic Compounds (XC)

What Are XC?

Xenobiotic (Greek *xenos* = strange, foreign, foreigner) compounds are human-made chemical compounds that are foreign to the nature. They are highly thermodynamically stable, hence are relatively persisting in the environment. The main sources through which XC are released into the environment are chemical and pharmaceutical industries which generate varieties of xenobiotic and synthetic polymers. Modernization of agriculture and mining produces huge quantities of fertilizers and pesticides and releases heavy metals into biogeochemical cycles. Toxic chlorinated compounds released from the pulp and paper industry and accidental oil spillage in large quantity make the situation more catastrophic. The general diagram of probable fate of XC in the environment is provided in Fig. 4.

Impact of XC on Biosphere

Xenobiotic substances are relatively new to the environment, hence not easily removed. XC are toxic and show adverse effect on public health such as disrupting various cellular pathways that are responsible to regulate development and growth. XC can put its adverse effect on lower and higher eukaryotic organisms (Dermatas and Meng 2003; Di Palma et al. 2003; Hrapovic et al. 2005; Huling and Pivetz 2006; Hyman and Dupont 2001; Sihag et al. 2015). The persistent and non-degradative nature of the XC resulted in bioaccumulation or biomagnification and is also able to incorporate into the food chains (Marchiol et al. 2007; Meagher 2000).

Mechanisms Involved in Biodegradation of Xenobiotic

XC is hard to break down and degrade due to its recalcitrant nature. For breaking down such compounds, different microorganisms and their enzymes play a

Table 1 List of microbes involved in biodegradation

Microorganism	Waste compounds	References
Pseudomonas putida	Benzene and xylene	Safiyanu et al. (2015)
Gloeophyllum trabeum, *Trametes versicolor*	Hydrocarbons	Karigar and Rao (2011)
Acinetobacter sp., *Microbacterium* sp.	Aromatic hydrocarbons	Simarro et al. (2013)
Pseudomonas cepacia, *Bacillus cereus*, *Bacillus coagulans*, *Citrobacter koseri*, *Serratia ficaria*	Crude oil	Kehinde and Isaac (2016)
Micrococcus luteus, *Listeria denitrificans*, *Nocardia atlantica*	Textile dyes	Hassan et al. (2013)
Bacillus, *Staphylococcus*	Endosulfan	Mohamed et al. (2011)

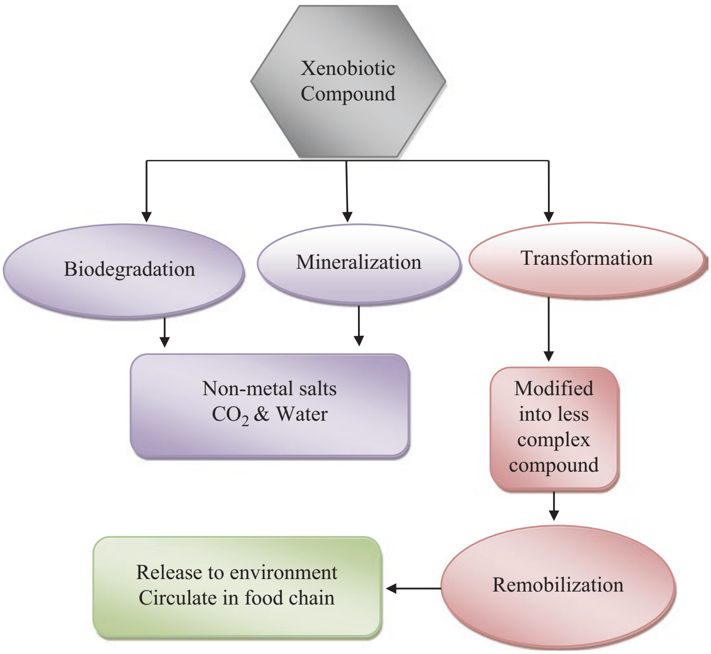

Fig. 4 Probable fate of XC in the environment. (Source: Gren 2012)

significant role. Several studies indicate that in comparison to yeast and fungi, bacteria are the principal microorganisms for xenobiotic detoxification. The role of protozoa and microalgae is very low in xenobiotic degradation. *Pseudomonas* sp. and *Bacillus* sp. are potent and effective in the degradation of xenobiotic among the bacterial group (Janssen et al. 2005; Tropel and Van der Meer 2004).

Among the fungus, *Aspergillus niger*, *Gliocladium deliquescens* and *Penicillium italicum* have the potential to degrade various XC (Ekundayo et al. 2012). Microorganisms degrade different XC aerobically or anaerobically. Petroleum HC, phenol, naphthalene, benzene, toluene etc. are some of the xenobiotic compounds rapidly degraded by the aerobic degradation process, whereas chlorinatedd dioxins and some pesticides like DDT and polychlorinated biphenyl (PCB) are the targets of anaerobic degradation process. The following are some XC and their degrading microbes (Table 2).

Microbial Enzymes Involved in Biodegradation

The major groups of enzymes which assist biodegradation of a wide range of xenobiotics are as follows.

Microbial Oxidoreductases

Oxidoreductases are responsible for oxidization of different types of contaminants and transform them to harmless compound by means of oxidation-reduction

Table 2 List of common microorganism for XC

XC	Microorganisms degrading XC	References
Benzene	*Bacillus* sp.	Lorimor et al. (2001)
PCB	PCB *Rhodococcus* RHA1	Rajan (2005)
Endosulfan compounds	*Mycobacterium* sp.	Sutherland et al. (2002)
Endosulphate compounds	*Arthrobacter* sp.	Weir et al. (2006)
Naphthalene	*Pseudomonas putida*	Muhammad et al. (2007)
Pyrene	*Mycobacterium* PYR-1	Kanaly et al. (2000)

reactions (Karigar and Rao 2011). Oxidoreductases are the potent detoxifier of XC belong to phenolic or anilinic groups with the help of polymerization and binding to humic substances (Park et al. 2006).

Microbial Oxygenase

These enzymes belong to oxidoreductase group (Karigar and Rao 2011). Oxygenase is of two types, monooxygenases and di-oxygenases, based on the number of oxygen atoms for oxidation to happen.

In aerobic biodegradation, oxygenases are the principal enzymes for oxidation reaction. Oxygenases transfer oxygen and use either flavinadenine dinucleotide, nicotinamide adenine dinucleotide or nicotinamide adenine dinucleotide phosphate as the co-substrate for oxidation of the substrates. Various OC are metabolized by oxygenases. These enzymes cleave the aromatic ring of the OC and increase their reactivity and water solubility (Arora et al. 2010). In the bioremediation process, monooxygenases can perform as biocatalysts and have high region selectivity and stereoselectivity on different substrates (Cirino and Arnold 2000; Arora et al. 2010; Yadav et al. 2018). Various reactions are catalysed by monooxygenases such as hydroxylation, de-halogenation, desulphurization, biotransformation and biodegradation of aliphatic and aromatic compounds (Arora et al. 2010).

Monooxygenases catalyse various types of reactions such as biotransformation, hydroxylation, de-halogenation, desulphurization, denitrification, ammonification and biodegradation of various compounds which belong to aliphatic and aromatic family (Arora et al. 2010).

Microbial Dehalogenases

Chlorinated pollutants are the primary target of these enzymes (Copley 1998). Some anaerobic microorganisms are known to use substrates like halogenated compounds as electron acceptors and convert perchloroethylene either dichloroethylene, ethylene or ethane into other forms through this mechanism (Wohlfarth and Diekert 1997; Scholz-Muramatsu et al. 1995; Schumacher and Holliger 1996). Magnuson et al. (1998) partially purified two reductive dehalogenases (perchloroethylene reductive dehalogenase and trichloroethylene reductive dehalogenase) from *Dehalococcoides ethenogenes* strain. The initial enzyme reduces perchloroethylene to trichloroethylene, and the second enzyme is able to reduce trichloroethylene and vinyl chloride.

Phosphotriesterases

These enzymes hydrolyse phosphoesterase bond and mainly act on organophosphate pesticides. Phosphotriesterases decrease the ability of organophosphate pesticides by hydrolysing and reducing toxicity (Theriot and Grunden 2010).

4.1.4 Biodegradation of Plastic Wastes

Plastics are chemically synthesized synthetic polymeric material prepared for human use and having very much similarity to natural resins in many ways. In all aspects of every day's life, it has made its presence due to the versatile nature. Plastics are used for manufacturing different types of products as it is durable, strong, lightweight and cheap (Laist 1987; Pruter 1987). In spite of its vast utility, it creates major environmental hazards due to some unique characteristics such as its buoyant nature, dispersing over long distances, nondegradable and may be sustained in the environment for years (Ryan 1987; Hansen 1990; Goldberg 1995, 1997).

Types of Plastics

Plastics are not only stable and durable but also have suitable thermal and mechanical properties which made its excessive and widespread application in daily life (Rivard et al. 1995). Plastics are generated from monomeric HC. Mostly plastics are produced by chemical alternation of natural materials or raw materials which may be organic or inorganic. Plastics are basically of three types such as thermosetting, elastomers and thermoplastics or thermo-softening plastic based on their physical nature and can be differentiated on the basis of molecular structure. Most of the plastics are thermoplastic type which can be softened and hardened by heating and cooling to give structure. Thermosetting plastics cannot be remodified by heating. Elastomers have the elastic properties of rubber.

Later extensive research work has been started to find out to make biodegradable plastics that could be prototyped for availability to microbial attack in a suitable environment. Biodegradable plastics come up with new possibilities for rejuvenated means of WM approach, as these plastics are formulated to degrade under certain environmental conditions or in biological way of waste treatment equipment (Augusta et al. 1992; Witt et al. 1997). Biodegradable plastics are developed successfully for the past few decades due to its similarity with synthetic plastics. The most significant biodegradable plastic is polyhydroxyalkanoates and polyhydroxybutyrate. Polyhydroxyalkanoates are manufactured from renewable substances, and it is biodegradable and biocompatible in nature. The different types of plastics with features commonly used and their application are shown in Tables 3, 4 and 5, respectively.

Hazards of Plastics

Plastics are almost nondegradable and vastly dumped after being used. Because of this, extensive application of plastic can cause severe environmental hazard to different ecosystems. Terrestrial and marine habitats are significantly hampered due to the accumulation of plastic materials. Disposal of plastic is a major concern due its high production and wide usage. Groundwater ecosystem is also hampered by the

Table 3 Different types of plastics with features

Plastic types	Characteristics
Thermosetting	These are hard plastics and have a branched structure. Thermosets can be shaped only once
Thermoplastics/ thermo-softening	Thermoplastics are high molecular weight plastics and flexible at ordinary temperatures. These types of plastics melt to a liquid form upon heating
Elastomers	Elastomers have viscoelasticity properties and less cross-linked structure. Elastomers are capable of recovering original shape if stretched

Table 4 Synthetic plastics and its use

Synthetic plastic	Use
Polypropylene terephthalate	Used in making soft drink and water bottles, etc.
High-density polyethylene	Preparation of water and milk bottles and grocery bags
Polyvinyl chloride	Used to prepare raincoat, shoe soles and electricity pipes
Low-density polyethylene	Preparation of squeezable bottles and lids of flexible container
Polypropylene	Making of disposable syringes, medicine bottles, car batteries and lid of bottles
Polystyrene	Making of disposable plates and cups, laboratory wares, etc.
Polycarbonate	Used in the preparation of beverage bottles and electric casing

Table 5 Biodegradable plastic types and their general application

Biodegradable plastics types	General application
Polyglycolic acid	Used in subcutaneous sutures, surgeries of thoracic and abdominal region
Polyhydroxybutyrate	Use in making of disposable razors and utensils and also have wide medicinal applications like making of bone plate and wound dressings
Polylactic acid	Used in making of paper coatings, packaging materials and compost bags
Polycaprolactone	Used in drug encapsulation, root canal filling and also in tissue engineering
Polyhydroxyalkanoates	Used for wound dressings, spinal fusion cages, sutures, orthopaedic pins, cardiovascular patches, implant materials etc.
Polyhydroxyvalerate	Used in therapeutic drug delivery for cattle and release vehicle for pharmaceutical drugs
Polyvinyl alcohol	Used in laundry detergent, pesticides, etc.
Polyvinyl acetate	Used as adhesives, paper lamination and remoisten tags

adverse effect of chlorinated plastics. Plastic degradation releases a very fatal greenhouse gas, methane, which brings global warming (Hester and Harrison 2011). Marine ecosystem is also effected by plastic pollution as it can cause morbidity to many marine animals. Different studies indicate that many marine animals including sea turtles, cetaceans, zooplankton and sea bird often ingest plastics which are continuously dumped in the aquatic system. When polyvinyl chloride (PVC) is burned, it releases dioxins which are a potent carcinogen and also an immune and reproductive system disrupter. Some plastic-made bottles have bisphenol as a constituent which is demonstrated as a carcinogen and also hamper physiological system of human. For example, bisphenol can initiate diabetes and preterm puberty (Hester and Harrison 2011).

Plastic Biodegradation and Role of Microorganism

Plastics are considered as major solid waste. Disposal of plastic wastes is a major problem nowadays. Plastic is a polymer, and degradation of polymer can be performed in various ways such as thermal, photo-oxidative, mechanochemical, catalytic and biodegradation, based on the nature of the causing agents. Among these biodegradation process has a great potential due to its effectiveness and environment-friendly manner.

Biodegradation is the natural capability of microorganism to initiate degradation process through enzymatic activity (Albertsson et al. 1987). Microorganisms have significant role in degradation and decaying of synthetic and natural plastics (Gu et al. 2000; Meena et al. 2017). The degradation of plastics happens in a slow manner, and different environmental factors are needed in this process such as temperature and pH. Bacteria and fungi are the main degraders of plastics. The biodegradation of plastic involves various subsequent steps, induced by enzymatic reactions; among them hydrolysis is the most important (Schink et al. 1992). Generally biodegradation of polymeric substances is influenced by different factors such as availability of microbial enzymes and suitable abiotic factors.

Microorganisms use the contaminants for their growth, nutrition and reproduction. This is the main reason behind microbial transformation of different contaminants which are organic in nature. Microorganisms get C from OC. C is essential for microorganisms as it acts as a building block for new cell. C is also a source of energy utilized by the microorganisms (Chapelle 1993). Microorganisms responsible for the degradation of various types of plastics are shown in Tables 6, 7 and 8

Factors Affecting Microbial Degradation

The efficiency of microorganism relies upon several factors such as the chemical nature and concentration of the contaminants and pollutants, their accessibility to microbes and most importantly environmental characteristics (Kaplan and Kitts 2004). Significant factors that affect the rate of microbial degradation are of two types: biological factors and environmental factors.

Table 6 Bacteria used in plastic degradation

Sl. no.	Plastic	Bacteria	Reference
1	Polyurethane	*Corynebacterium* sp., *Pseudomonas* sp., *Arthrobacter globiformis*, *Bacillus* sp.	Kay et al. (1991), El-Sayed et al.(1996), Blake and Howard (1998) and Howard et al. (2012)
2	Low-density polyethylene (LDPE)	*Rhodococcus ruber* C208, *Brevibacillus borstelensis* 707, *Rhodococcus ruber* C208, *Staphylococcus epidermidis*, *Bacillus cereus* C1	Chandra and Rustgi (1997), Sharma and Sharma (2004), Hadad et al. (2005), Sivan et al. (2006) and Chatterjee et al. (2010)
3	High-density polyethylene (HDPE)	*Bacillus* sp., *Micrococcus* sp., *Vibrio* sp., *Arthrobacter* sp., *Pseudomonas* sp.	Kumar et al. (2007), Fontanella et al. (2009) and Balasubramanian et al. (2010)
4	Degradable polyethylene	*Rhodococcus rhodochrous* ATCC 29672. *Nocardia steroids* GK 911, *Bacillus mycoides*	Bonhomme et al. (2003) and Seneviratne et al. (2006)
5	Polyethylene bags	*Pseudomonas aeruginosa, Pseudomonas putida*, *Bacillus subtilis*	Nwachukwu et al. (2010)
6	Polyethylene carry bags	*Serratia marcescens*, *Bacillus cereus*, *Pseudomonas aeruginosa*, *Streptococcus aureus*, *Micrococcus lylae*	Aswale and Ade (2009)
7	Degradable plastic	*Pseudomonas* sp., *Micrococcus luteus*, *Bacillus subtilis*, *Streptococcus lactis*, *Proteus vulgaris*	Priyanka and Archana (2011)

4.2 Bioremediation

Bioremediation is a natural process which makes the use of microorganism to remove waste or pollutant from the water and soil. This is an environment-friendly and sustainable method as it involves eco-friendly microbes in treating the solid waste (Kensa 2011). It is of two types:

(1) *In Situ Bioremediation*: Here removal of water or soil is without excavation and transport of contaminants. Biological treatment on surface of the waste is carried out by bacteria. It is the alternative method of treatment of soil and groundwater. In this technique, non-toxic microbes are applied. This type of bioremediation is of three types:
   (a) *Biosparging*
      It is a waste treatment process of the sites having petroleum products like diesel, gasoline and lubricating oil. In this method the concentration of oxygen is increased by injecting the air below groundwater under pressure. The air pressure has to be controlled in a proper way to avoid the liberation of volatile particles to the atmosphere, which leads to air pollution.

Table 7 Fungi in plastic degradation

Sl. no.	Plastic	Fungi	References
1	Polyurethane	*Chaetomium globosum*, *Aspergillus terreus*, *Curvularia senegalensis*, *Fusarium solani*	Boubendir (1993) and Crabbe et al. (1994)
2	Degradable plastic	*Phanerochaete chrysosporium*, *Penicillium* sp., *Aspergillus* sp.	Lee et al. (1991) and Priyanka and Archana (2011)
3	LDPE	*Aspergillus niger, Penicillium* sp., *Chaetomium globosum*, *Pullularia pullulans*, *Fusarium* sp. AF4, *Aspergillus oryzae*	Gilan et al. (2004) and Shah et al. (2009) and Konduri et al. (2011)
4	HDPE	*Aspergillus terreus* MF12, *Trametes* sp.	Balasubramanian et al. (2014) and Iiyoshi et al. (1998)
5	PVC	*Polyporus versicolor*, *Phanerochaete chrysosporium*, *Pleurotus sapidus*, *P. eryngii*, *P. florida*	Kirbas et al. (1999)
6	Disposable plastic films	*Aspergillus flavus*, *Mucor rouxii*	El-Shafei et al. (1998)
7	Polyethylene carry bags	*Phanerochaete chrysosporium, Aspergillus niger*, *A. glaucus*, *Pleurotus ostreatus*	Aswale and Ade (2009)
8	PVC films	*Phanerochaete chrysosporium*, *Lentinus tigrinus*, *Aspergillus niger*, *A. sydowii*	Ali (2011)

Table 8 Actinomycetes used in plastic degradation

Sl. no.	Plastic	Actinomycetes	Reference
1	Polyurethane	*Acinetobacter calcoaceticus*, *A. gerneri*	Howard et al. (2012)
2	Polyethylene	*Streptomyces* sp., *Sporichthya* sp. *Actinoplanes* sp.	Sathya et al. (2012)
3	Disposable plastic films	*Streptomyces* sp.	El-Shafei et al. (1998)
4	LDPE powder	*Streptomyces* KU5, *Streptomyces* KU1, *Streptomyces* KU6	Usha et al. (2011)

(b) *Bioventing*

It is the process in which waste compounds are degraded aerobically. Bioventing is used to treat different solid wastes generated from oil reservoirs during extraction of gasoline and petroleum. In this process the contaminated site is injected by oxygen and nutrients like phosphorus and N to increase the rate of removal process.

(c) *Bioaugmentation*

Here cultured microorganisms are added at the polluted site for the purpose of biodegradation of contaminants of specific environment. This process makes sure that the microorganisms also break down contaminants present in the groundwater and soil to non-toxic compound.

(2) *Ex Situ Bioremediation*: It describes the removal of the contaminated soil or water for remedy process. The following are the types of ex situ bioremediation:
   (i) *Composting*: Composting is an aerobic method where contaminated soil is combined with harmless organic amendments. Organic amendments help to grow microbial population in high quantity.
   (ii) *Land farming*: It is a bioremediation technology wherein contaminated soil is mixed with soil amendments, and after that the mixture are tilled into the earth. The main target is to enhance indigenous biodegradative microorganisms for degradation of contaminants aerobically.
   (iii) *Bio-piling*: It is a hybrid technology using both land farming and composting. This technique gives a suitable environment for growing both aerobic and anaerobic microorganisms. Bio-piles are applied to eliminate petroleum constituents' concentrations with the help of biodegradation.

4.2.1 Heavy Metal Bioremediation

Heavy metals are generally considered as metals having relatively high densities and atomic weight. Few heavy metals like silver (Ag), copper (Cu), cadmium (Cd), lead (Pb), zinc (Zn) and chromium (Cr) are considered as heavy metals because of their toxicity properties. The existence of heavy metals in the environment can contaminate the soil and groundwater through the process of leaching. Toxic metals may enter feeding relationships among organisms through water engendering inauspicious consequences on the overall living things. Various microorganisms like bacteria, algae and fungi act as a bio-absorbent in degradation of the metals. Yeasts have been reported of having a significant role in toxic heavy metal elimination from the environment. Some pioneer research work indicate that yeasts are efficient and superior heavy metal accumulator such as Cu(II), Ni(II), Co(II), Cd(II) and Mg(II) compared to certain bacteria (Wang and Chen 2006). Bahafid et al. (2011, 2012) reported that *Pichia anomala* is able to eliminate Cr (VI) and cells (live or dead) of three yeasts species: *Cyberlindnera, Tropicalis*, *Cyberlindnera fabianii* and *Wickerhamomyces anomalus* are good bio-absorbers of Cr(VI).

Ksheminska et al. (2006) reported that *Saccharomyces cerevisiae*, *P. guilliermondii*, *Rhodotorula pilimanae*, *Yarrowia lipolytica* and *Hansenula polymorpha* are able to remove Cr(VI) to Cr(III). Several studies have reported that the immobilized cell of yeast *Schizosaccharomyces pombe* is efficient to remove copper (SaiSubhashini et al. 2011). Several species of *Chlorella* sp., *Anabaena* sp., *Westiellopsis prolifica*, *Stigeoclonium tenue* and marine algae have been used for heavy metal removal, and more importantly these organisms have effective heavy metal tolerance ability (Dwivedi 2012). Algae apply adsorption mechanism for metal uptake. Brown algae are also considered for heavy metal biosorption by a number of cell wall components such as alginate and fucoidan. The continuous cultures of microalga *Scenedesmus incrassatulus* has been demonstrated for Cr(VI),

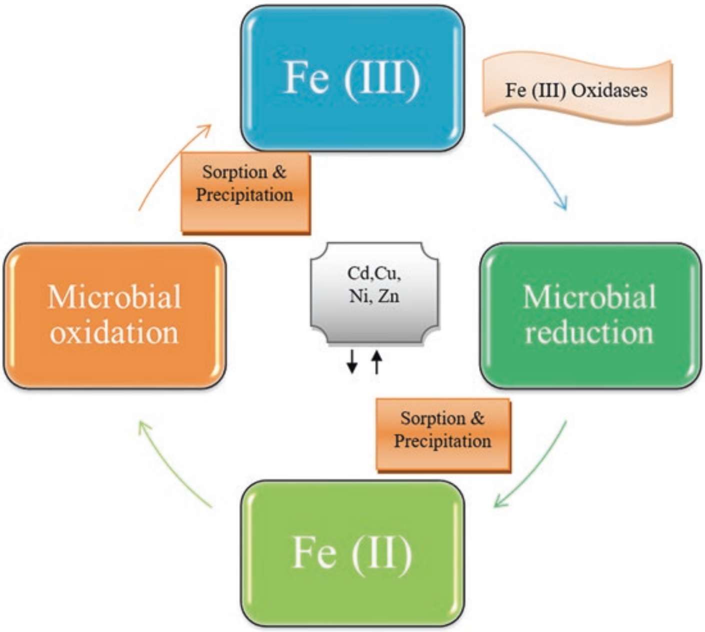

Fig. 5 Schematic view of heavy metal bioremediation. (Source: https://water.usgs.gov/nrp/microbiology)

Cd(II) and Cu(II) removal (Peňa-Castro et al. 2004). Green algae *Chlorella sorokiniana* have also been reported as bioremediator of Cr(III) (Akhtar et al. 2008). Schematic view of bioremediation of heavy metals is shown in Fig. 5.

Microorganisms have developed various ways by which they are able to protect themselves from the toxic effect of heavy metals. Some of those ways are oxidation, reduction, adsorption, uptake and methylation. For example, bacterial species such as *Alcaligenes faecalis*, *Bacillus pumilus*, *Bacillus* sp. and *Pseudomonas aeruginosa* utilize bio-methylation to form methylmercury from mercury, Hg (II) (De Jaysankar et al. 2008; Ashoka et al. 2017). In addition to methylation reactions, acidophilic bacteria *Acidithiobacillus ferrooxidans* (Takeuchi and Sugio 2006) and sulphur-oxidizing bacteria (White et al. 1998) have been reported to leach high concentrations of heavy metals like As, Cd, Cu, Co and Zn from polluted site.

4.2.2 Rubber Waste Bioremediation

Rubber is considered as a solid waste and consists of synthetic material. Unscientific method of disposing rubber is by burning it. Burning of rubber generates huge quantity of hazardous elements like C monoxide which has devastating effect on the environment (Adhikari et al. 2000). Due to its physical composition, it can neither degrade nor recycle easily (Conesa et al. 2004). Naturally rubber is degraded very slowly because rubber has zinc oxides which are responsible for the inhibition of growth of naturally evolved bacteria and sulphur-oxidizing bacteria (Zabaniotou and Stavropoulos 2003). To overcome this problem, *Recinicium bicolour* (fungi) is used to eliminate the entire harmful and environmentally unfriendly ingredient of rubber, and thereafter the rubber can be treated with sulphur-reducing or sulphur-oxidizing bacteria like *Pyrococcus furiosus* and *Thiobacillus ferrooxidans* for devulcanization. After these treatments the rubbers can be easily recycled (Keri et al. 2008). So by regulated kindling, effective management of rubber waster can be achieved (Conesa et al. 2004).

4.2.3 Bioremediation of Agricultural Waste

Agricultural wastes are outputs of production and processing of various agricultural products which are beneficial to human. Economic values of these products are less valuable than the cost of collection, transportation and processing to make them beneficial for use. Generally, agricultural wastes are produced from a number of sources such as cultivation, livestock and aquaculture. Effective disposal mechanism and environment-favourable operation mechanism of the wastes have received a prime concern globally. Hence a lot of attention has been put forward to devolve potential and cost-effective machinery to metamorphose these wholesome wastes into valuable products for achieving endurable environments and development. In this regard microorganism plays a significant role in OM degradation, and the role of earthworm is also considerable as it propels the procedure and transmutes the organic activity (Dominguez 2004).

4.3 Biotransformation

Biotransformation is a transformation of toxic compounds into less persistence and less toxic form. Bacteria and fungi are the major groups of microorganisms, and their enzymes are involved in this process. Microorganism cells are crucial for biotransformation due to some causes such as:

- *Surface-volume ratio*: Surface-volume ratio is high in case of microorganism-mediated biotransformation.
- *Rate of microbial cell growth*: Microbial cells have high growth rate which minimizes biomass transformation duration.
- *Rate of metabolism*: Rate of metabolism in microorganism is very high which is needed for efficient transformation.
- *Sterile condition*: In order to make effective biotransformation, it is necessary to maintain sterile condition of the microorganism (Hegazy et al. 2015).

4.3.1 Biotransformation of Pollutants

In the present day, use of microorganism in biotransformation of different pollutants have harvest much interest to mitigate the polluted environment (Pajouhesh and George 2005). The bacterial genera which have been associated potentially with biotransformation process of varieties of contaminated wastes can be aerobic or anaerobic types. Examples of aerobic types are *Escherichia* sp., *Micrococcus* sp., *Pseudomonas* sp., *Bacillus* sp., *Rhodococcus* sp., *Gordonia* sp. and *Moraxella* sp., whereas *Methanosaeta* sp., *Methanospirillum* sp., *Desulfotomaculum* sp., *Pelatomaculum* sp., *Syntrophus* sp., *Syntrophobacter* sp. and *Desulfovibrio* sp. belong to anaerobic types (Chowdhury et al. 2008). *Mycobacterium vaccae* has been reported to catabolize benzene, ethylbenzene, propylbenzene, acetone, cyclohexane and dioxane. On the other hand *Pseudomonas* sp. and *Bacillus* sp. have been reported to degrade PCB effectively. Some strains of bacteria such as *Pseudomonas* sp., *Acetobacter* sp. and *Klebsiella* sp. are able to biofix carcinogenic azo compounds. Studies suggest that two strains of *Pseudomonas* such as BCb12/1 and BCb12/3 are exceptionally degrading low-ethoxylated nonylphenol polyethoxylates (DiGioia et al. 2008).

Several methanogens such as *Syntrophobacter fumaroxidens* and *Methanospirillum hungatei* which are anaerobic in nature have been reported to degrade phthalate compound (Qu et al. 2004; Zhang and Bennet 2005). A promising research reported that pollutants which have the pentafluorosulfanyl (SF_5) functional group have been bio-transformed by *Pseudomonas knackmussii* and *P. pseudoalcaligenes* KF707 and *Cunninghamella elegans* (Kavanagh et al. 2014).

4.3.2 Biotransformation of Petroleum

Petroleum is the principal means of propulsion in industry and livelihood (Mathew 2012). However, HC contamination related to the petrochemical industry has a place in the foremost environmental issues right now (Das and Chandran 2011; Dadhich et al. 2015). Soil and water are polluted due to leaks and accidental release of contaminants. Petroleum is a potent carcinogenic and neurotoxic to all biota (O Peter 2011).

In order to remediate the contaminated soil and water, various chemical and mechanical methods are available, but utilization of microorganism in biotransformation process is the most effective method for detoxification of the pollutants as it is environment-friendly and cost-effective, and the most important part is that it leads to complete mineralization. Many aquatic and marine microfloras have been reported in the oil spill biodegradation (McGenity et al. 2012). Bacteria, yeast and fungi are the principal microorganisms for petroleum biotransformation (Atlas 1981). *Sphingomonas* sp. has been reported to degrade polyaromatic HC (Daugulis and McCracken 2003).

Some bacterial genera such as *Mycobacterium* sp., *Arthrobacter* sp., *Rhodococcus* sp. and *Pseudomonas* sp. have been reported to degrade petroleum HC very effectively. Several other microorganisms such as *Gordonia* sp., *Brevibacterium* sp., *Corynebacterium* sp., *Flavobacterium* sp., *Pseudomonas fluorescens*, *P. aeruginosa*, *Actinocorallia* sp., *Klebsiella* sp., Rhizobium sp., *Bacillus* sp. and *Alcaligenes* sp., *Aeromicrobium* sp., *Dietzia* sp., *Burkholderia* sp. and *Mycobacterium* sp. have been extracted from petroleum-polluted zone and are reported to degrade HC very efficiently (Chaillan et al. 2004). *Cephalosporium* sp., *Aspergillus* sp., *Penicillium* sp., *Neosartorya* sp., *Talaromyces* sp. and *Amorphoteca* sp. are the fungal microorganisms found in petroleum-contaminated sites and have been reported in oil spill bioremediation (Koul and Fulekar 2013).

4.3.3 Microorganism and Waste Water Management

WW management chemical and biological are the two principal treatment methods to clean up WW impurities. In comparison with chemical treatment, biological treatment has obtained more potentiality due to many reasons such as biological treatment is more cost-effective and environmentally sustainable. Microorganisms are of major importance in different WW treatments like industrial, agricultural and in aquaculture. Microbes efficiently eliminate and degrade different toxic materials such as ammonia, nitrite, hydrogen sulphide, etc. The role of microorganisms particularly bacteria and protozoa in WW treatment system is very significant as these organism are potent degrader of N and phosphorus.

5 Roles of Microorganisms in Wastewater Treatment Systems

Bacteria

Bacteria are of greatest importance in the treatment of WW. Most of them are facultatively living in either aerobic or anaerobic conditions (Spellman 1997; Absar 2005). In WW treatment systems, both autotrophic and heterotrophic bacteria are found, but predominant ones are the heterotrophic bacteria. Generally, heterotrophic bacteria use the carbonaceous OM as their energy source in WW effluent. The obtained energy is utilized for new progeny cell production and energy release by the conversion of organic substances and water. *Achromobacter* sp., *Alcaligenes* sp., *Arthrobacter* sp., *Citramonas* sp., *Flavobacterium* sp., *Pseudomonas* sp., *Zoogloe* sp. and *Acinetobacter* sp. are some important bacteria found in WW treatment system (Oehmen et al. 2007; EPA 1996). Bacteria are the key microorganisms which are able to stabilize influent wastes in WW treatment systems. The interesting thing is that majority of the bacteria are known to form peculiar body mass that are clump of bacteria that degrade waste and serve as absorption site of waste also. Filaments of filamentous bacteria help the peculiar body to grow and prevent the splinter action in the treatment process. When filamentous bacteria are found in excessive quantity or stretch, they can cause settlement problems (Paillard et al. 2005).

Alga

Some types of algae that can be found in WW include *Euglena* sp., *Chlamydomonas* sp. and *Oscillatoria* sp. Algae is a potent organism to purify WW biologically as they are able to accumulate heavy metals, pesticides and organic and inorganic pollutants. Over the years, microalgae have gained a lot of importance in the treatment of WW (Lloyd and Frederick 2000).

Fungi

Fungi are also found in WW treatment systems. Fungi are multicellular creatures that are also an integral part of the sewage treatment. If fungi are cultured with bacteria under some environmental criteria, they can compete with bacteria and also able to metabolize compounds that are organic in nature. Few types of fungi are able to oxidize ammonia to nitrite. *Sphaerotilus natans* and *Zoogloea* sp. are the most common sewage fungus organisms (Painter 1970; LeChevallier and Au 2004). Varieties of filamentous fungi are found naturally in WW treatment systems which can also metabolize organic substances. Different types of fungi species, like *Aspergillus* sp., *Penicillium* sp., *Fusarium* sp. and *Absidia* sp., have been used to remove C and nutrient sources in WW (Akpor et al. 2013). Some fungi are also demonstrated to have the capacity to break down OM present in the sludge system effectively. In a system with low pH, the main role of the fungi is the breakdown of OM where bacterial growth is inhibited. Moreover, some fungi use their fungal hyphae for trapping and adsorbing suspended solids to mitigate their energy and nutrient prerequisite. It has been reported that some filamentous fungi secrete some enzymes which help to degrade the substrates during WW treatment (Molla et al. 2004; Buragohain et al. 2017).

6 Conclusion

Preservation and sustainability of the environment is recognized at the highest levels of priority that require critical attention globally because it is vital for progressing into the future. To ensure sustainability, management of waste, preservation of NR and biodiversity and treatment of contaminant and pollutants are the key areas that really need a focus of priority. Nowadays safeguarding environment from deterioration is not only dismissal of the contaminants and pollutants but also recycling and reuse of hazardous substances by transforming different wastes to prosperity of useful things in an aesthetic and environment-friendly manners. Interest in the use of different microorganisms has intensified and got a priority in the recent scenario as humanity struggle to achieve sustainable manner to tidy up polluted environments and waste. With the advent of biotechnology, the potentiality of microorganisms for selected uses has received increased attention and speculation. Microorganisms are unique and often unpredictable in nature. Microorganisms can be used as an effective agent for solving many environment related problems. The scientific and trustable use of microbes is unavoidably illecebrous and figures out a spectacular evolution of research and innovative tools to provide an effective way to shield our planet and modern means of biological WM and environmental monitoring. At last it can be concluded that the use of microorganisms and microbiological techniques has opened up new vistas in the field of sustainable development particularly in the areas of environment and other important environment-related issues.

7 Future Prospective

WM is now becoming very important throughout the world as well as in India as it is an integral part towards sustainable environment and development. India has immense opportunity, and it is very true to say that the success is very few. So there are certain areas that should be answered to find out the meaningful future of WM. The questions are:

1. Growing importance of WM all over the world.
2. Identification of stakeholders involved in the WM process.
3. Recent trends and innovation in WM.
4. The challenges and best solution of WM.

Rapid urbanization and industrialization have put tremendous pressure on WM throughout the world. So the principle behind the WM should be based on precaution and sustainable development. The key for effective WM has to be identified to ensure waste separation from the source and also have to pass through different modes of recycling and recovery before depositing in the landfills. Biotechnology and microorganisms can be used effectively in WM, hence more research and knowledge would be developed related to the role and application of biotechnology and microorganisms in WM. Making energy from waste and waste to compost would minimize waste quantity. It is believed that if biodegradation part of waste is somehow separated, the challenges are reduced effectively. The future aim should be the development and redraw a long-term vision and strategy to cope up with the changing lifestyles. Community participation and development of knowledge towards sustainability have a direct effect on effective WM. Community has to develop the idea of recycling and reuse from very low scale to large scale.

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