Advances In Environmental Pollution Management

Wastewater Impacts and Treatment Technologies
Volume 1

Editors

Vinod Kumar | Nitin Kamboj | Temin Payum

Co-editors

Jogendra Singh | Pankaj Kumar

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Advances in Environmental Pollution Management

Wastewater Impacts and Treatment Technologies

Volume 1

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Preface

Dear Readers,

As we all know, environmental pollution has appeared as a hard to defeat demon which is affecting the life of the planet earth. Nowadays, a huge volume of wastewater produced from various anthropogenic activities is really hard to manage. This wastewater is often dumped into an open environment without adequate treatments. In this, middle and low-income countries are majorly affected by wastewater pollution due to a lack of resources and efficient treatment technologies. Wastewater pollution creates disturbances to air, water, and soil. In the case of air, it may release various harmful, smelly pollutants which may be deposited in the living cells. Apart from that, water and soils are the major receivers of the uncontrolled disposal of liquid and contaminated wastes. Various harmful pollutants like high nutrient, heavy metals, radioactive elements, organic and inorganic compounds, pesticides, sediments, fertilizers, etc. are the major constituents responsible for water pollution. These constituents when enters the living systems in high doses, create adverse effects leading to the misfunctioning of cells. Various plants and animals including human beings are majorly affected by such pollutants which creates various diseases.

The presented book entitled “Advances in Environmental Pollution Management: Wastewater Impacts and Treatment Technologies” has been designed to bind novel knowledge of wastewater pollution-induced impacts on various aspects of our environment. The book also contains novel methods and tools for the monitoring and treatment of produced wastewater. The book compilation included 14 selective chapters from nearly 33 authors. Each chapter contains detailed information on the proposed titles along with possible explanations using relevant tables and illustrations. The book chapters also present novel and eco-friendly approaches to wastewater treatment along with the generation of valuable resources like bioenergy, low-cost materials, etc.

Lastly, the editors are thankful to the contributors who submitted their precious findings and views related to the book theme and to make it succeeded. We hope that this book will help the readers in its best to provide them the relevant information.

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Chapter [1]

Deteriorating impacts of emerging water pollutants on biological diversity

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Abstract

Water pollutants are the substances that affect the physicochemical and biological properties of water that cause undesirable and great destruction of the ecosystem on earth. Industrialization, urbanization, and agriculture activities impact the quality of freshwater and also decrease the availability of freshwater. Water is the safeguard of biodiversity but the pollutants present in water accumulate in the body of the living organism and causes negative effect directly or indirectly on plants, animals, and human being. Excess plant food, herbicides, and pesticides once washed by rain into rivers cause danger to life. The control of water pollution increases the quality of water using various conventional treatments which reduces the pollutants that cause the reduction of water-borne diseases and increases physiological activities in the organism. Effective water quality prevention increases the economy and development of aquatic life as well as biodiversity. Biodiversity is the key to the earth ecosystem and nowadays the conservation of biological diversity is the biggest challenge. Thus, the present chapter enlightenment the impacts of various water pollutants on biodiversity and developing way of mitigation. The immediate actions need for making effective policies and implementation of acts reduce the pressure on the freshwater ecosystem.

Keywords Biodiversity, Conservation, Industrialization, Pollutants, Urbanization

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Introduction

Water is one of the most important sources of life and out of 75% only 3 % freshwater present on earth (Pathak, 2018). In India, water pollution is the most serious problem due to the contamination of various toxic, organic, biological, and inorganic pollutants (Murty and Kumar, 2011). In 21 century, water pollution is the universal challenge for developing and also for developed countries that causes various diseases in the human population and the polluted water also affects biodiversity (Bassem, 2020). Rivers, streams, lakes, ponds, and reservoirs are the resources of freshwater and due to the increase of the human population, urbanization and industrialization continuality affect the resources of freshwater and decrease the availability of freshwater (Pathak, 2018; Cherian and Shahare, 2011).

Chemical, physical, radioactive waste material, pathogens from industrial effluents, agricultural run-off, domestic sewage, construction activities, and mining activities causes contamination in freshwater and affect the freshwater biodiversity (Richardson *et al.*, 2007). However, 70% to 80% of municipal wastewater is discharged untreated into freshwater bodies and also many industrial activities are known for its responsibility for dumping millions of tons of heavily pollutants such as solvents, heavy metals, toxic sludge every year but the pollution of water does not only affect the water bodies, they also adversely affecting the land, agriculture, aquatic life and human health to a greater manner (Vishwanath *et al.*, 2017; Bassem, 2020; Kumar *et al*., 2020).

According to Odum (1971), pollution is undesirable changes within the physical, chemical, and biological characteristics of our air, land, and water which can harmfully affect human life, industrial progress, living conditions, and cultural assets. Biodiversity of aquatic organisms is greatly affected by the various types of pollutants differently and they are sensitive to any variation in the aquatic environment that causes drastic responses like effect in metabolic activity, reduction in reproductive capacity, migration to suitable habitat, and death. Moreover, pollution with heavy metals impacted the whole aquatic biodiversity. According to Bouraie (2010), in 1992, 50% of industrial waste which refers to the metallurgical industry effect the aquatic organism especially fishes.

The term biodiversity is an essential component of all water systems and the relation between water pollution and biodiversity will be covered through the following topics; Importance of biodiversity and its relation to ecosystems than their main threats. Assessment of biodiversity impacts on ecosystems and communities is required to be elucidated and eventually what are the conservation challenges facing biodiversity.

Key source responsible for water pollution

In 21 centuries, the quality of freshwater is the major challenge facing by a human being, freshwater and marine organisms, that causes negative impacts on human health in addition to other respective organisms (Fent, 2013). Moreover, the quality of water changes either directly or indirectly affects the immune system of fishes. (Poulin, 1992; Abdel, 2018).

Water pollution effect the activity of normal uses of water in daily life for agriculture, aquaculture, public water supply, industry, etc. There are many sources of aquatic pollutants viz; industrial effluents, municipal sewage, herbicides, and pesticides from agriculture wastewater that harms aquatic biodiversity and also terrestrial organisms. Moreover, according to Kumar (1997) and Pathak (2018) the source of water pollutions is:

***Domestic and municipal pollutants*:** The sewage is the largest source of water pollution that contains various components such as garbage, soaps, detergents, waste food, human, and livestock excreta.

***Industrial pollutants*:** Industries are liable for discharging their untreated effluents into rivers having heavy toxic metals like chromium, arsenic, lead, mercury, etc. along with hazardous inorganic waste material like acids, alkalies, cyanides, chlorides phosphate, nitrate, sulphate, and trace elements such as Hg, Cd, Pb, As, Se, etc and organic waste material like oil, petroleum compounds, pharmaceuticals, synthetic organic compounds. Petroleum products are widely used for fuel, lubrication, plastics manufacturing, etc.

***Agricultural waste*:** Agriculture wastes are enrichments of manure, fertilizers, insecticides, pesticides, etc, wastes or silt are drained as run-off from agricultural lands. The water body receiving large quantities of fertilizers (phosphates and nitrates or manures becomes rich in nutrients which results in eutrophication and consequent depletion of dissolved oxygen.

***Radioactive wastes*:** Water bodies are polluted by accidental leakage of waste material from uranium and thorium mines, nuclear power plants, and industries such as Ra^{226}, Sr^{90}, Cs^{137}, Ba^{140}, Kr^{85}, Co^{60}, Mn^{65}, Pu^{239} research laboratories and hospitals which use radioisotopes.

***Thermal sources*:** Various industries, nuclear power plants, and thermal plants utilize coal or nuclear fuel and require water for cooling, and the resultant hot water is often discharged into rivers or lakes.

***Sediments*:** Soil particles are carried to streams, lakes, or oceans from the sediments. A large number of sediment pollutants affect water quality.

Water parameters as an indicator of pollution

Water pollution is taken into account in normal conditions on the idea of bad odor, uncontrolled growth of weed, and a decrease in population of fishes and by the bad taste of the beverage. Water could also be called polluted when the subsequent parameters stated below reach beyond a specified concentration in water. The physicochemical properties of water are studied with standard methods which are given in APHA (1989; 2005; 2012).

- Physical parameters like color, odor, turbidity, taste, temperature, and electrical conductivity constitute the physical parameters and are good indicators of contamination. For instance, color and turbidity are visible pieces of evidence of polluted water while an offensive odor or a bitter and different than normal taste also makes water unfit for drinking. Color is necessarily harmful and is undesirable in potable water.

- Chemical parameters include the number of carbonates, sulfates, chlorides, fluorides, nitrates, and metal ions. These chemicals form the entire dissolved solids, present in water.
- Biological parameters include matter like algae, fungi, viruses, protozoa, and bacteria. The life forms present in water are affected to an honest extent by the presence of pollutants. The pollutants in water may cause a discount within the population of both lower and better plant and animal lives. Thus, the biological parameters give an indirect indication of the quantity of pollution in water.

Impacts of water pollution on biodiversity

Biological diversity or biodiversity term is referring to all aspects of variability evident within the living world, between individuals, populations, species, communities, and ecosystems. According to United Nations Convention on Biological Diversity, the definition of biological diversity is "living species variations from sources that include terrestrial, marine, different aquatic ecosystems and also ecological groups to which they belong: including diversity among species and also ecosystems (UNEP, 1992). There are up to about 100 million species on the earth, of which humans know only about 1.6 million species. Several of these species are known to be threatened, and an estimate puts the number of such threatened species at 41,415. It is also recognized that several species are already extinct and such extinctions are still happening (IUCN, 2019).

On earth, water is that the most vital supply of life most of the species pay their life in water. However, water bodies like ponds, stream, rivers, and oceans mistreatment many ways in which result from the negative impacts on diverseness. The Contamination of streams, lakes, seas, underground water, or oceans by substances, is harmful to live beings and result in H_2O diverseness (Richardson *et al.*, 2007). The expansion of the human population, industrial and agricultural practices is that the major causes of pollution. waste matter is that the biggest waste matter of H_2O that causes waterborne diseases and each year five million deaths per annum are often attributed to waterborne diseases (Viswanath *et al.*, 2017). Unhealthful (disease-causing), microorganisms (bacteria, fungi, protozoa, algae) enter the water system through waste matter creating it infected. Typhoid, cholera, stomach flu, dysentery, polio, hepatitis, and cancer area unit normally caused by drinking infected water. The watercourse of Ganges receives wastes from textile, sugar, paper and pulp mills, tanneries, rubber, and chemical industries. Most of those pollutants non-perishable thus harm the expansion of crops and therefore the impure water is unsafe for drinking functions (Pathak, 2018). Excess plant food, herbicides, and pesticides once washed by rain into rivers cause danger to life. Detergent is additionally terribly unhealthful to marine life once washed into the water. Some pesticides like pollutant area unit notably dangerous once allowed into bodies of water as a result of its concentration will increase the organic phenomenon (Pathak, 2018). The livestock sector is responsible for the majority of the most common pollutants called Nitrogen and phosphorus, in Europe 73% of water pollution from these sources can be attributed to livestock production (Leip *et al.*, 2015).

Pesticides and Insecticides**:** If not applied correctly, pesticides can end up in watercourses via similar pathways to the fertilizers mentioned above. Studies back in the mid-90s revealed that 90% of water and fish samples from waters in the USA contained one or more pesticides. Chlorpyrifos is a common contaminant in urban streams and is toxic to fish . Other pesticides such as trifluralin and glyphosate which are common in everyday garden weed killers might not directly kill fish but they can lessen the chance of survival which can impact the population as a whole (Liong *et al.*, 1988*).* The impacts of pesticides on biodiversity tend to be worse for non-flowing water bodies such as ponds and lakes where the substances aren't washed away and where wildlife can't re-populate areas as easily.

Heavy metals**:** Factories producing plastic, hydroxide and a few fungicides and pesticides unleash mercury (a serious metal) alongside different effluents in the close water body. Mercury enters the organic phenomenon through microorganisms, algae, and fish eventually into the organic structure. Consumption of water made in nitrates is dangerous for human health particularly for tiny youngsters (Pathak, 2018). Serious metal pollution of water will originate from several sources, from mining to cars, to cement production. Serious metals embody metals like mercury, arsenic, and metallic element that all have the characteristic of not breaking down simply once within the setting. These metals are found to own impacts on fish species impacting behavior and survival rates (Sehar *et al.*, 2014). When toxic substances enter into water reservoirs, they get dissolved or suspended in water or get deposited on the bottom. When freshwater is supplemented it results in an abnormal increase in water plants. The level of mercury in fish is most dangerous for humans, especially for pregnant women and infants. Mercury interferes in the development of the control nervous system, leading to long-term side effects. Industrial waste contains toxic compounds damaging the health of aquatic lives. They may cause minor effects or maybe fatal also. Heavy metals from industrial processes can accumulate in the water reservoirs. These are toxic to fish, shellfish, other aquatic lives, and humans eating them. Heavy metals like Cd may cause vomiting, abdominal pain, loss of consciousness, softening of bones, etc. Pb may cause retarded development, Brain damage, uncoordinated, body movements. Effects of heavy metals (Zn, Cu, Cd, Pb, and Hg) were examined in some commercial fish species collected from the Egyptian coastal region along the Mediterranean Sea (Shreadah *et al.*, 2015). Bangladesh has some of the most polluted groundwater in the world. In this case, the contaminant is arsenic, which occurs naturally in the sediments. Around 85% of the total area of the country has contaminated groundwater, with at least 1.2 million Bangladeshis exposed to arsenic poisoning and with millions more at risk. Each year, plastic waste in water and coastal areas kills up to 100,000 marine mammals, 1 million sea birds, and countless fish (Vishwanath *et al.*, 2017; Kumar *et al*., 2018).

***Oil and spill*:** Crude oil and the different connected product usually get into the water by accidental spillage from ships, tankers, pipelines, etc that causes. a significant water waste matter has been oil spilled in massive quantities from tankers of broken oil pipes from oil industries that kill ocean weeds, mollusks, marine birds, crustaceans, fishes, and different ocean organisms that function as food for humans. Oil enters the water from several sources however it's the most important impact on life throughout an oversized 'oil spill' event. This is often typically once oil is being transported during a ship across the ocean and somehow spills an oversized quantity of the load, inflicting mayhem on the compact system. While it's the birds and bigger animals that show the foremost visible effects of such an incident, scientists counsel the bigger impacts on diverseness area unit caused by the adverse effects on life within the deeper oceans.

***Radioactive elements*:** Radioactive materials enter living beings through water and food, and should be accumulated in blood and sure important organs. Higher temperature lowers the dissolved element level (which is incredibly essential for marine life) by decreasing the solubility of the element in water (Pathak, 2018). However, consistent with Kibria (2016), various classes of pollution result in the water quality of watercourse and diverseness of watercourse (Table 1). they're acid mine drain, bacteria, cold pollution, dirt, endocrine-disrupting chemicals, nutrients, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, pesticides, herbicides, fungicides, prescribed drugs, phthalates or plastic, trace or serious metals and transboundary pollution. In Asian countries, most impure rivers area units are found in Bharat, Bangladesh, China, Indonesia, Philippines. The water contaminated water by numerous pollutants affects human consumption, irrigation, agriculture, food process, eutherian mammal drinking, cultivation, and aquatic ecosystems protection. Loss of biodiversity due to the impact of water pollution harms the environment too. The direct and indirect way of effecting water pollutants disrupts biological diversity and also affect the ecosystem. The immediate actions need for making effective policies and implementation of acts reduce the pressure on the freshwater ecosystem. Awareness and education programs play an important role in the protection of rivers from pollution.

Conclusion

Nowadays, water pollution is the greatest environmental problem that affects biological diversity. Water pollution is enormous by the human contribution that affects the quality of water in various ways such as dumping of waste material, industrial wastes material, bathing and washing of clothes, etc. in rivers and lakes. Maintain the quality of water and practicing the habits of cleanliness, efforts for

Table 1. Different types of emerging water pollutants and their effects on biodiversity (Kibria, 2016)

Emerging pollutant	Sources	Effects
Acid Mine Drainage (AMD)	The outflow of acidic water from metal mines or coal mines. AMD waters can have very low pH (-3.6), with high sulfate, iron, and aluminum, and elevated copper, chromium, nickel, lead, and zinc, and elevated calcium, magnesium, sodium, and potassium.	AMD affects water quality AMD containing high metal and salt concentrations resulting in toxic effects on aquatic biodiversity (fish, invertebrates). AMD Kill freshwater organisms. AMD causes unfit for drinking, irrigation, and industrial use.
Bacteria (*Escherichia coli*)	Contaminated water	Contaminated water causes depletion of dissolved oxygen in water (foul dour) health effects. Contaminated water causes outbreaks of water-borne diseases.
Coldwater pollution	Coldwater being released into rivers from large dams.	Coldwater pollution may affect the richness of native freshwater fish species. Coldwater reduces the growth of native fish, their survival, and breeding.
Dirt	Floods, rain washes, removal of trees (erosion)	Dirt affects water quality and photosynthesis in aquatic plants. Dirt may clog the gills of fish. Dirt reduces the fish population.
Endocrine Disrupting Chemicals (EDCs)	Livestock farms wastewater effluent (run-off and wastewater discharge from intensive dairy, beef cattle, poultry pigs, and aquaculture farms). sewage treatment plants.	EDCs' low concentration causes an increased level of vitellogenesis in fish. EDCs affect reproduction in fish.
Nutrients	Nitrogen and phosphorus fertilizers used in agricultural farms and lawns, animal waste, sewage treatment plants, septic system, and animal manures;	Algal bloom and eutrophication, nitrates cause methemoglobinemia.
PAH (Polycyclic aromatic hydrocarbons)	Oil and oil spills, refinery effluents, aluminum smelting, domestic sewage effluents, stormwater runoff, and the wood preservative;	PAHs may cause the death of fish and birds. PAHs vary substantially in their toxicity to aquatic organisms. PAHs affect algae, mollusks, and other species. PAHs toxic causes genetic effects and cancer in aquatic animals and also kills fish, eutrophication, aesthetics.
PBDEs (Polybrominated diphenyl ethers)	PBDEs are synthetic compounds used as additives to retard fire (Flame retardants) used in a variety of commercial and household products (plastics, textiles, carpets, polyurethane foams, television sets, electronic devices, computers, and building materials).	PBDEs are hydrophobic, lipophilic, and bioaccumulate in the aquatic food chain and fish. PBDE affects fish thyroid hormone levels and Inhibited sperm production. PBDE reduced cumulative egg production and egg protein content, PBDE inhibited fish growth causes cancer and genetic defects

Table 1. *Continued*...

Emerging pollutant	Sources	Effects
PCBs (Polychlorinated biphenyls)	Aroclor, Clophen, or Kanechlor are used as dielectric fluids in electrical products such as transformers, and in hydraulic fluids, printing inks, adhesives, and paints.	PCBs are highly lipophilic and bioaccumulate in aquatic organisms through the aquatic food chain and affect the thyroid functions in fish. PCB toxic effects are harmful to aquatic life.

prevention of water pollution by primary, secondary, or biological treatment play an important role in providing clean and clear water for the future.

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Chapter
[2]

A review on impact of water pollution on freshwater fish species and their aquatic environment

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Abstract

Freshwater is a chief natural resource used for various types of activities in our daily life i.e. for drinking as well as different developmental purposes. An increase in pollution level leads to instability in our natural environment and harm both the physical systems and living organisms dwelling in the ecosystem. Various harmful substances present in polluted water bodies in the form of insecticide, pesticides, heavy metals, mills waste, and crude oil are frequently released into the aquatic ecosystem. When a large amount of these pollutants is released into any water body, causes an acute effect by rapid high-scale mortalities of aquatic organisms. Minor levels of pollutant discharge result in an accumulation of the contaminants in the body composition of fish species. Water pollution effects are classified into acute and chronic effects, which suppress immune-response, reduction of metabolism, harm to gills, and epithelial layer in the fish species. Some of the diseases caused by the pollutant include fin rot, tail rot, gill disease, damage hepatic tissues, and also causes ulceration. This chapter aims to reviews the various types of impacts caused by water pollution on the health of fish species and their ecosystem.

Keywords Aquatic environment, Fish species, Toxicity, Wastewater, Water pollution

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Introduction

Water pollution happens when some unwanted constituents enter into the water bodies and change the water quality (Alrumman *et al.*, 2016), and becomes harmful to human health and their environment (Briggs, 2003). Water plays an important role in nutrient recycling and is an imperative natural source used for drinking and other developmental purposes. Aquatic systems are usually used for disposal and reutilizing the sewage and contaminated wastes and drain off the excess to the sea. Due to the increase in the pollutant level and in turn overexploitation of the water resources for various developmental activities i.e. for agriculture, construction activities, industrial processes, and also in thermal power plants to encounter the necessities of the large-scale population, significantly lessens their assimilative volume. Thus, the double pressure wielded on the water bodies is eventually faced by the biological communities dwelling them.

Generally, the fish species are one of the most important aquatic communities concerning humans. The pollution generally denotes any unwanted alteration in the natural quality of any ecosystem brought around by the changes in their physical, chemical, as well as in biological factors (Subhendu, 2000). Aquatic ecosystems are delicate and at high risk mostly due to the majority of pollutants derived from domestic, urban and industrial sources i.e. various agricultural practices (Figure 1) result in the release of pollutants into the riverine system (Kaur and Dua, 2014; Pinto *et al.*, 2015; Byrne *et al.*, 2015). Mainly in aquatic ecosystem, the most frequent contaminants are in the forms of heavy metals and pesticides (Khoshnood, 2016). The heavy metals are one of the major pollutants, which quickly amass in the body and are leisurely digested in and excreted from aquatic animals. Mainly the pesticides used in agricultural activities are directly released into the open atmosphere by drift spray, volatilization and wind erosion of soil (Qiu *et al.*, 2004). These pesticides present in aquatic ecosystem can affect the life cycle of aquatic organisms (Ventura *et al.*, 2008).

Increases in the population rate resulted in an increase in the development and urbanization, water pollution by domestic activities, agronomic processes, the municipal and industrial processes have become a key concern for the wellbeing of humanity. Water-soluble pollutants released from different industries and municipal activities, leached in soils directly and in turn, the atmosphere has quickly transported to natural water bodies. Some of the toxins decay or volatilize to form insoluble salts and rest are precipitated and get combined into the substrate in bed surface. Fish species are the perfect model for sensing the occurrence of genotoxic toxins in aquatic ecosystems (Aich *et al.*, 2015; Walia *et al.*, 2015; Sharma *et al.*, 2018) because these aquatic organisms are very sensitive to little quantity of metals within the water body, are abundant, and also live in some different habitats (Ali *et al.*, 2008). Aquatic organisms like fish species directly uptake these toxic substances may be followed by the metabolism of these toxic substances which results in more toxic by-products. For example, mercury can be converted into very high toxic methyl-mercury by the microbial action which in turn taken up

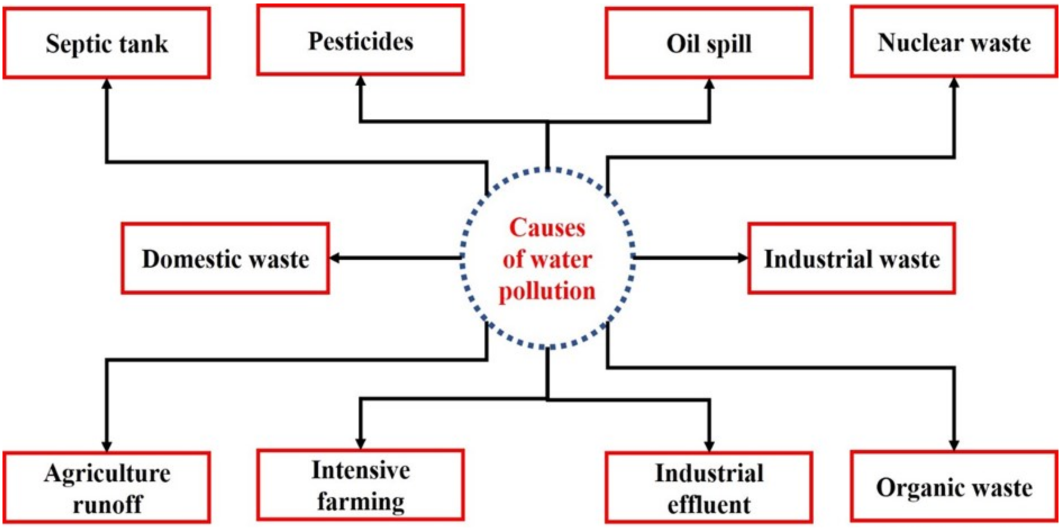

Figure 1. Different causes and sources of water pollution that affect aquatic life.

by fish species (Bukola *et al.*, 2015). Fish fry, larvae, yearlings and fingerlings are one of the most susceptible life stages which are harshly affected by pesticides and heavy metal pollution exposure as non-target aquatic organisms. Alterations of the vital organs i.e. gills, kidney, and liver might distress the physiology, rate of survival, osmoregulation, buoyancy, reproduction processes etc., and in turn lead to failures in stock conscription and populace changes (Khoshnood, 2017).

Some aquatic animals have been identified to concentrate the toxic solutes from their habitat without any apparent harm to themselves and thus acts as pollutant amplifiers, making the toxic substances offered to predators at dangerously high levels. Some cases have been reported explaining the adverse impacts of environmental pollutants on fish's health and also to fish consumers. Due to the increased anthropogenic activities, a high load on the aquatic ecosystem determines the necessity of researches fervent to check the adverse impacts of water pollution and its probable risk for the aquatic organism and their ecosystems. Different types of lethal impacts of water pollution have been perceived in aquatic communities inhabiting the water bodies over numerous scientific researches. The decreasing fish populaces and partial loss of commercial fishing predict huge changes in the aquatic ecosystem (Hinton and Lauren, 1990).

Fish communities are one of the most valued resources of high mark protein to humans. The modifications in the morphology, tissue and biochemical composition by the aquatic organism highlight the different types of stress and changes in habitat ecosystem e.g. if some fish species are exposed to chemical contaminants, acts rapidly and induces a series of modifications in different body parts and organs, mostly gills, kidneys and liver (Bukola *et al.*, 2015). Thus, a varied series of

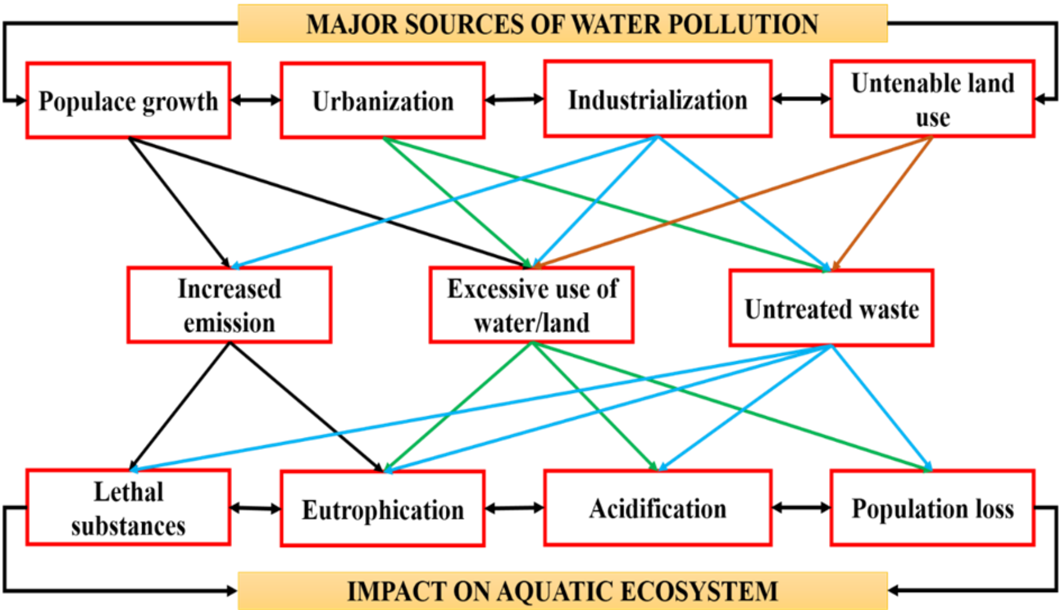

Figure 2. Impact of water pollution on aquatic ecosystem.

histo-cytological changes in fish species have been developed and endorsed as biomarkers for the purpose of monitoring the water pollution level. Several factors (Figure 2) like increasing population, industrialization, urbanization, forest loss, lack of environmental awareness among society, lack of policy implementation, rules and regulations, effluent discharge from different industries, etc leads to pollution in the aquatic ecosystem and ultimate loss of aquatic organisms.

The pollutants released from different types of industrial discharge and sewage not only pollute the surface water of rivers and reservoirs but also infiltrate into ground and also pollute the groundwater resources. Aquatic ecosystems are exposed to pollution loads is associated with the increase in urbanization and population growth (Edokpayi and Nkwoji, 2000; Nkwoji *et al.*, 2010). These pollutants cause major threats to aquatic ecosystems, alter hydrology, physicochemical and faunal characteristics (Nkwoji *et al.*, 2010). Nowadays, the most perilous difficulties of developing nations are unsuitable management of massive quantity of wastes material produced by numerous anthropogenic activities. Among them, the most challenging factor is the unsafe disposal of these effluents into the open ambient environment. From these activities the water bodies particularly, freshwater bodies like rivers and reservoirs are most affected and unfit these types of natural resources for both primary and secondary usage. Thus, the aim of this review paper mainly deals with the impact assessment of water pollution on fish health and their habitat.

Sources of water pollutants

Mainly water pollution derives from two extensive sources i.e. point sources and non-point sources (Figure 3). Point sources are the identified type of pollutants sources where all the pollutant materials enter into water bodies from a single recognizable source i.e. ultimate effluent discharge point of different industrial outfit wherein non– point source, the pollutant substances come in the contact water bodies in numerous and not easily recognizable sources. Almost all hominid actions have the potential to impact directly or indirectly the surface and groundwater quality of any water bodies e.g. fertilizers used by agriculturalists in the agricultural activities are steadily eroded by rain into the surface and groundwater nearby thus pollutes the water body.

Human and developmental activities e.g. effluents from industries, irrigation activities, waste managing problems, and also rise in urbanization possessed some serious threats to the freshwater ecosystem (Zhu *et al.*, 2018; Meijide *et al.*, 2018; Kamboj *et al.*, 2020). Climatic variation also possesses an impact on both biotic and abiotic characteristics i.e. water as well as air temperature and rainfall levels affect the regular function of any aquatic ecosystems including feeding and breeding of aquatic organisms (Figure 4).

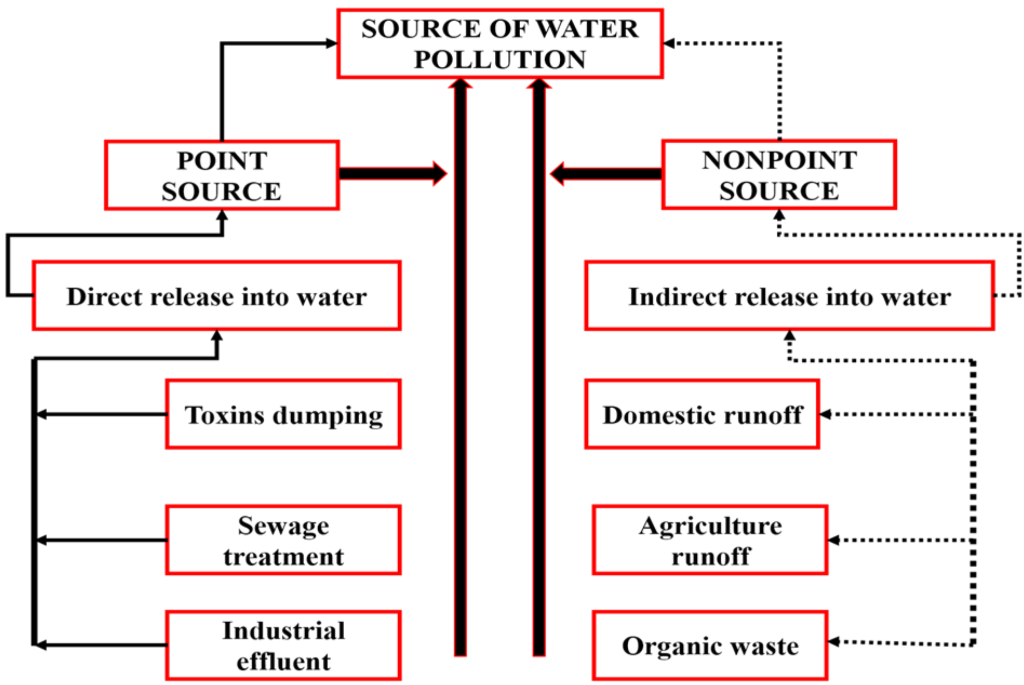

Figure 3. Point and non-point sources of water pollution.

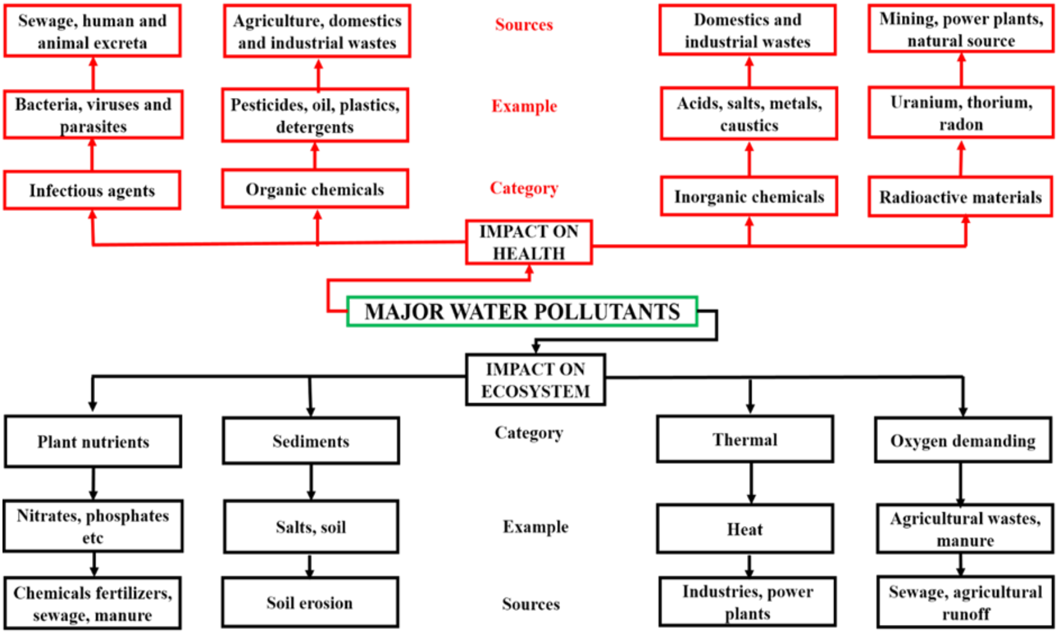

Figure 4. Major pollutants along with their source.

Table 1. Inorganic and organic pollutants from different industries.

Industry	Inorganic pollutants	Organic pollutants
Mining Industry	Chlorides, ferrous sulphate, hydrogen sulphide. ferric hydroxide, suspended solids and heavy metals.	-
Steel/Iron Industry	Suspended solids, iron cyanide, sulphides, oxides, of copper. chromium, cadmium, and mercury	Oil, phenol and naptha
Chemical Industry	Sulphates, nitrates, phosphorus, fluorine, silica, and suspended particles	Aromatic compound solvents, organic acids, nitro compound dyes, etc.
Pharma Industry	-	Proteins, carbohydrates, organic solvents, intermediate Products, drugs and antibiotics
Detergent Industry	Tertiary ammonia compounds, alkalies	Fats and fatty acids, glycerol, polyphosphates sulphonated hydrocarbons
Paper Industry	Sulphides, bleaching liquors	Cellulose fibres, bark, wood, sugars and organic acids

Source: Sonali Priyadarshi (nd)

Also, these contamination levels affect the habitats of aquatic flora and fauna (Schmeller *et al.*, 2018). Therefore, for conservation purposes, it is important to guard worldwide freshwater aquatic species and also safeguard the regular functions of ecosystems. Thus, it is very crucial to identify and classify the key pollution activities, sources, and fate in the aquatic ecosystem including their temporal and spatial distribution (Liu *et al*., 2018; Zhao *et al*., 2018). Considerate the influence of natural processes may support in developing conservation curricula and policies to avoid the disturbance of freshwater ecosystem (Schmeller *et al.*, 2018). The category of major water pollutants along with sources and example are given in flowchart (Figure 4).

Impact of pollutants on the water quality

Subhendu (2000) and Farkas *et al.* (2000) have reported several effects of pollution on physico-chemical properties of water.

***Light*:** High turbidity and colour variations of the water bodies reduced the penetration quantity of light.

***Fluctuations in temperature*:** The temperature of water increased during the thermal pollution where water is used for cooling power stations and also waste heat from industries.

***Depth and flow*:** Both flow and depth of the water body reduced due to heavy siltation of sediments coming from land erosion.

***pH*:** Acidic water due to acid rain or by burning of coal and oil fluctuates the pH of the water body. Large quantities of acids are originating from mines and many industrial processes like waste generated from DDT factory, from battery, tanneries and by vinegar etc. it is well reported that large scale of fish species habitually live between 6.0 and 9.0 pH levels, although they cannot bear a rapid variation within this range

***Dissolved oxygen*:** Due to the discharged of heavy sewage pollution and effluents containing high organic matter into any water body reduced greater amount of dissolve oxygen level. DO are also broken down by the physiological activity of microorganisms by using dissolved O_2.

***CO_2*:** Due to the eutrophication and organic pollutants dissolve oxygen depletes from water body with an increase in the CO_2 level, due to decomposition of undecomposed organic matter.

***Alkalinity*:** Wastes released from tanning, wool scouring, the mercerizing of cotton and the manufacture of certain chemicals industries (especially in chloro-alkali industries) contain caustic soda, sodium carbonate or lime. These alkaline effluents have pH range between 12-14, which becomes lethal to all types of aquatic life.

***Salinity*:** Salinity reduces dissolve oxygen level by increase in excessive amount of salts transported from sewage, effluents and chloro-alkali industries, which increase the level of chloride and thereby salinity of water, which is further responsible for increasing the osmotic pressure.

***Colour and turbidity*:** Colour of water also changed due to the fluctuation in dye, pigment and turbidity of water. Turbidity increased from soil erosion or heavy algal bloom due to high load of organic and inorganic nutrients from both industries or agricultural waste.

***Nitrates and phosphates*:** Water runoff by the agricultural wastes, soil erosion and organic pollutants i.e. from sewage and synthetic detergents) are rich in nitrates and phosphates quantity.

***Heavy metals*:** In natural water, various trace elements are present in very small and trace amount like Hg, Ni, Zn, Cd, Mn, Pb, Cu, Cr, Fe, As, Se etc. Increase in the quantity of the heavy metal can change the water quality e.g. exposure cadmium caused anaemia, discolouration of the teeth, damage to the olfactory nerve, ulceration of the nasal septum, rhinitis, and anosmia to the aquatic organism (Maurya *et al.*, 2019).

***Eutrophication*:** The eutrophication also effects directly or indirectly to the water quality. Water pollution from domestic sewage increases the organic load and also pollution from agricultural runoff containing huge amounts of nutrients such as potassium, nitrates; phosphates, etc. fertilize the water in and raise the rate of productivity of the aquatic ecosystem.

This process results in the complex growth of phytoplankton. Water becomes turbid due to the extreme growth of phytoplankton and suspended particles by soil erosion.

Impacts on aquatic biota

Instantly after organic pollution comes in contact with water bodies results in a decrease or even purging of algae due to de-oxygenation and little amount of light present. Further, this is followed by a gradual increase in algae abundance once situations improve. This gradual increase is stirred by the bulky concentrations of nutrients that are probable to be present (Mason, 1991). Planktons (phytoplankton and zooplankton), macrobenthos, fish species, and macrophytes are badly affected by biodegradable organic pollution (Hynes, 1960; Malik *et al.*, 2018; Kumar *et al.*, 2018). Generally, De-oxygenation decreases the light levels, increases TSS and settling material thus results in the reduction or loss of aquatic species which are most sensitive to the pollution (Hawkes, 1962; Haslam, 1987). Mainly in the downstream regions of rivers tends to be more of a problematic from biodegradable organic pollution (Mason, 1991).

This causes certain glitches for migratory fish species with high DO requirements i.e. in the case of *Salmo salar* and *Salmo trutta*. In a few cases, the levels of DO and organic pollutants can prompt avoidance behavior and acts as a barrier which averts them reaching highly oxygenated breeding and spawning grounds (Richardson *et al.*, 2001).

Impact of water pollution on algae and macrophytes

Macrophytes are types of aquatic plants that grow in water and are classified either as emergent, floating, or submerged. Macrophytes act as bioindicator because they quickly respond to the rate and variability of many environmental characteristics i.e. water flow, alkalinity, substrate, shading, and nutrient concentrations (Barendregt and Bio, 2003; Lacoul and Freedman, 2006). Total suspended sediment adversely impacts the algae and aquatic macrophytes over limiting the quantity of light penetrating over the water column, which afterward limits the frequency of photosynthesis. A high quantity of suspended solids is commonly transported by the fast-flowing rates also scrub algae and aquatic macrophytes away from bed substrates which result in damage to their photosynthetic structures (Steinman and McIntire, 1990).

The process of sedimentation can be smothering the submerged flora which extremely reduces the rate of photosynthesis. Certain plants grow especially in water having low dissolved nutrients and high DO whereas other plants grow fine in nutrient-enriched water. This made it probable to rank and score aquatic macrophytes according to their preference for various chemical and physical conditions (Haury *et al*., 2002). Apart from that, the macrophytes are reasonably tolerant of erratic pollution and sturdily inclined by geology and soil type (Mason, 1991). Also, the macrophyte community structure is frequently resolute by some interconnected aspects which can make assigning species absence/presence to specific pollutants difficult (Pentecost *et al.*, 2009). Macrophytes play an important role as bioindicator of chronic pollution problems in any water bodies.

Impacts on macrobenthos

Macrobenthos are aquatic animals that lack an internal skeleton, visible to the naked eye and inhabitant to bed substrate of water bodies. The bottom-dwelling organisms mostly comprise of larvae, pupae of insects, crustaceans, annelids, worms and molluscs. Macrobenthos are excellent indicators of water quality and pollution load due to some factors including (Malik *et al.*, 2020):

- Macrobenthos are widespread, abundant and can be found in all types of habitat but the most in polluted or disturbed habitats.
- Due to their short life cycles (usually about one year) mean fluctuations in water quality are reflected in the population.
- Mainly they are quite immobile and cannot escape pollution.
- Mostly spend their life in water.
- Easily to sample and also easy to identify.

Estimating the abundance and diversity of benthic macrobenthos in an aquatic ecosystem gives a clear indication of the biological conditions (Table 2). It is well known that unpolluted water bodies tend to support an extensive variability of macrobenthos taxa, including several pollution intolerant species, while any polluted water bodies sustenance only pollution–tolerant species and little species diversity. Total suspended solids can subject macrobenthos to abrasion as sediment and push them into the water

Table 2. Common groups of pollution tolerance freshwater macrobenthos.

Pollution tolerance	Group	Scientific name
Intolerant	Stoneflies	*Plecoptera*
	Caddisflies	*Trichoptera*
	Mayflies	*Ephemeroptera*
Somewhat tolerant	Dragonflies	*Odonata - Anisoptera*
	Damselflies	*Odonata - Zygoptera*
	Freshwater shrimp	*Amphipoda*
	Beetles (True bugs)	*Hemiptera*
	Black flies	*Nematocera*
	Flatworms	*Planaria*
	Alderflies	*Megaloptera*
Tolerant	Leeches	*Hirudinea*
	Midges	*Nematocera*
	Worms	*Oligochaeta*

column. This results in the damage to exposed respiratory organs or makes the organism more vulnerable to predation over dislodgement (Langer, 1980). A high quantity of suspended solids can choke the feeding structures and decline the feeding efficacy of filter-feeding macrobenthos which reduces the growth rates, amplified stress levels, and even mortality (Hynes, 1970). Several types of research showed that increased in suspended solid levels directly influences the downstream migration of macrobenthos. Sedimentation results in the infilling of the interstitial habitat of the macrobenthos which is crucial for crevice-occupying macrobenthos and also suffocates the benthic fauna by covering their respirational surfaces are probable to result in death.

Impacts of pollutants on survival of fish species

A high quantity of suspended water pollutants can interrupt the normal behaviour of fish populaces. Various fish species rely on sight to catch their prey quickly e.g. perch, brown trout, etc. are most susceptible to the high quantity of suspended solids and shows very strong avoidance behaviour. In some cases where the fish species survive in turbid water habitat, suspended solids can clog/harm gills aperture and reduced the resistance towards various disease and parasites (EPA, 2012). Fish species may also consume these suspended solids, results in illness by exposing to potential toxins or pathogens on the sediment. If the fish species do not die by consuming the suspended solids it can alter the blood profile and also damage its growth (EPA, 2012). Water pollutants can diminish the egg, embryo by reducing DO. Pollutants interfere various physiological processes without causing certain death. Lethal constituents and suspended dregs covers all the mucous membrane of fish gills which affect the respiration process. Mainly, mercury and lead hinder the activities of digestive enzymes.

Pollutants effects on a given fish population without being fatal to adult organisms in several ways i.e. (Subhendu, 2000).

- Nutrition and food chain
- Physiological progressions
- Life cycle
- Behaviour
- Incidence of diseases
- Migration.
- Genetic effects
- Breeding and spawning
- Alteration in morphology

Morphological deformities in fish body due to pollutants

Different types of morphological abnormalities formed on all portions of the fish was reported times to times by researchers (Abel, 2007; 2009; Adams, 2004; Kakulu, 1987; Kumar *et al.*, 2018: Kamboj *et al.*, 2020; Sharma *et al.*, 2018; 2019). These are:

- Scale disorientation
- Split fins
- Fin deformity
- Opercular deformity
- Hyperplasia of the surface of the mouth
- Protruding mouth or nose part depression
- Gill deformity
- Jaw deformity
- Eye deformity
- Muscle atrophy
- Skeleton deformity
- Outward protrusion of the lower lip
- Tumours and other swellings

Effects of pollutants on fish Behaviour

Pollutants effects directly and indirectly on the behaviour of aquatic organisms (Zala and Penn, 2004; Saaristo *et al.*, 2018), particularly in fish species (Robinson, 2009; Sloman and McNeil, 2012). Inorganic and organic pollutants also effect on various behavioural activities i.e. feeding, sexual and sociability aggressiveness behaviours (Table 3). Some pollutants can have caused alterations of the neurotransmitter, hormone levels and cholinesterase activity of fish species (Brodin *et al.*, 2014; Vindas *et al.*, 2017). Pollution-induced variations in behaviours of fishes could potentially increase further the level of exposure to pollutants and result in positive feedback loops which imply the negative impacts of pollution on fish health.

Several types of spatial behaviours i.e. activity, exploration, and avoidance are main behavioural characters that are habitually affected by water pollution. Those aquatic organisms which lead most of their life in metal-polluted regions (e.g. lead and cadmium) with high levels of metal in their blood profile showed slower exploration tendencies (Grunst *et al.*, 2019). Such reduced exploration tendencies have affected the fish ability to assess habitat quality because exploration is the main trait which enable individual to collect information and cues about their surrounding ecosystem (Reader, 2015), also, the interactions within the community are often altered by these contaminants (Ward *et al.*, 2008), which in turns decline the social learning and the gaining of information from their conspecifics (Brown and Laland, 2003). Spatial memory power and learning capacity are deeply impacted by pollutants as in the case of Atlantic salmon where aluminium contamination lessened the learning performance in a maze task and decreases their capability to process information and manage with novel environments (Grassie *et al.*, 2013). Pesticides also distressed certain activities and spatial memory in Danio rerio and Gobiocypris rarus (Hong and Zha, 2019).

Table 3. The linkage among the pollutants and behaviour in fish species.

Contaminant	Fish species	Behavioural traits	MS	S	V	Source
Fluoxetine	Several fish species	Antipredator behaviour, boldness, aggression, associative learning	Yes	Yes	No	Dzieweczynski *et al* (2016); Eisenreich *et al.* (2017); Martin *et al.* (2017); Saaristo *et al*. (2017)
Oxazepam	*Salmo salar*	Migration	Yes	No	No	Hellstrom *et al.* (2016); Klaminder *et al.* (2019)
Carbaryl, chlordane, 2,4 DMA, DEF, Methyl parathion, pentachlorophenol	*Oncorhynchus mykiss*	Activity, feeding	Yes	No	No	Little *et al.* (1990)
Mercury	*Danio rerio*	Activity, escape	Yes	No	No	Weber (2006)
Methylmercury MeHg	*Fundulus heteroclitus*	Sociality	No	No	Yes	Ososkov and Weis (1996)

MS: multi-stress; S: syndrome; V: variability.

Water pollution induced histopathological changes in fish organs/tissues

Histopathology deals with the structure of the body tissue. Any unusual alteration of cells can specify the effect of toxic substances and the presence of various diseases. Abdullah *et al.* (2008) reported various histological changes in the liver of *Tilapia nilotica* which was reared in polluted water with heavy metals showing cloudy swelling, vacuolar and hydropic variations of the hepatocytes and also prominent coagulative necrosis. Velcheva *et al.* (2010) studied the pathological fluctuations in both gills and liver of *Alburnus alburnus* and Perch from polluted Dame Lake showing deterioration of cytoplasm in hepatocytes, which finally become necrotic and infiltrated with inflammatory cells. Similar scratches were also recorded by (Abdullah *et al.*, 2008) in *Tilapia nilotica* fish. Recently Ebrahimi and Taherianfard (2011) reported the histopathological variations in liver, kidney and muscles of cyprinids fish species from polluted River Kor where hemosiderosis, melanophages hyperactivation, biliary canaliculi dilatation, and perivascular edema occurred in fish organ and tissue. Also, the skin of Tilapia species was adversely impacted by heavy metals pollution showing hyperactivation of goblet cells and dermal melanosis and dermal granuloma. Similarly, the polluted water kidneys of carp fish showed interstitial nephritis, renal necrosis, and mononuclear cell infiltration Also Brain shows dermal granuloma symptoms of meningitis and gliosis.

Impact of pollutants on fishe liver

El-Naggar *et al.* (2009) reported that the liver plays an important role in digestion activity during filtration and for the storage of glucose in all fish species. Tayel *et al.* (2008) reported that the bile is also produced by the liver which is then stored into the gall bladder. So, the liver of fish is a good indicator of aquatic pollution, because one of the chief functions of the liver is to clean any toxins or pollutants from the bloodstream (El-Naggar *et al.*, 2009). Because the liver is mostly associated with the detoxification and biotransformation progression, it is one of the most affected organs by contaminants in water (Mohamed, 2009). Different types of alterations included necrosis, fibrosis, pyknosis, fatty degeneration, and hemosiderin in hepatocytes are mainly caused by the heavy metal pollution. The liver of both Mugil cephalus and Mugil capito fish showed the same histopathological changes in kidney from lake Manzalah (Kadry *et al,* 2003). Mohamed, (2001) reported the cellular deterioration in the liver due to oxygen deficiency results the vascular dilation and intravascular hemolysis in the blood vessels with successive stasis of blood. Hepatocyte degeneration and necrosis may be due to the combine effect of nutrients and salts (Authman and Abbas, 2007). Also, the accumulation of hemosiderin in cells of the liver may be due to quick and constant destruction of erythrocytes (Ibrahim and Mahmoud, 2005).

Impact of pollutants on Kidney of fishes

The kidneys are the important organ of the fish body and play important functions like maintaining the homeostasis. The removal of wastes from the bloodstream, selective reabsorption activities, upholding volume, and maintaining the pH of blood and body fluid are done by the kidneys (Iqbal *et al.,* 2004). Thophon *et al.* (2003) reported in his research, that the kidney was one of the first organs to be affected by contaminants in the polluted water. The kidney of *Mugil cephalus* and *Mugil capito* from Manzalah lake showed the histopathological changes with diverse degrees of severity (Kadry *et al*, 2003). Mahmoud *et al.* (2008) reported that industrial, agricultural, and sewage wastes caused renal injury in the kidney of fish species dwelling in different regions of the Nile river. Similar results were observed in *C. carpio* species exposed to sewage waste (Kakutta and Murachi, 1997). Many necrotic scattered all over the hematopoietic tissue and renal tubules of the rainbow trout were observed by (Capkin *et al*., 2006) due to alteration in the quality of water like rising in pH level, temperature, hardness, etc. Kadry *et al.* (2003) reported some injuries in the kidney tissue of Liza Ramada fish obtained from polluted water in Manzalah lake. These injured kidneys showed degeneration of renal tubules and distortion of glomerular capillaries.

Effects on pollutants on fish eggs, spawn, fry and fingerlings

Generally, the eggs of fish species are much more resistant as compared to the adult fish species. Normally, Eggs are developed within between pH 6 to 9. The eggs displayed exosmosis and even collapsed in that water body where the acid is more than pH 4.0 Similarly in other conditions where water is more alkaline than pH 9.0 showed endosmosis along with the swelled eggs and also yolk became white. The critical value of the oxygen tensions for newly fertilized eggs is about 40 mm Hg and rises at the time of embryo development to about 100 mg Hg (60% saturation) at the time of hatching. Salmon and Trout fish species commonly lay their eggs in gravel-bed through which water must infiltrate while the eggs and the fry live the yolk of the eggs (Adams and Onorato, 2005).

Conclusion

Different types of impurities and toxins enter into the aquatic ecosystem and impact the water quality and disturb the life cycle of aquatic organisms. Some pollutants are very active to damage the aquatic organisms both morphologically and metabolically. Nevertheless, there is only inadequate evidence that water impurities and pollutants are truly accountable for the expansion of disease in aquatic animals. The revelation of aquatic animals to pollutants for the long term caused the ceaseless risk of health. So, directly and indirectly, aquatic animals are at higher risk due to various anthropogenic activities. For these problems, it is very clear that everyone should take the essential pre-emptive measure to guard the aquatic communities. Diverse effect of pollutants on the population of various fish species has been reported by a number of researcher's time to time and predict a chronic level which causes different effects on the aquatic life i.e. changes in histopathological, physiological damages, migration, embryonic and developmental changes especially in fish species. Several pollutants in the atmosphere constituted of various toxicant compound i.e. organophosphate compounds bring lethal effects in fish species. Thus, to overcome these problems it is important to develop some approaches using molecular biology techniques that will modernize toxicological bids that are low-priced and do not demand the aquatic animals to detect ecological stressors. More research struggles must be done to establish the concentration level and exposure time of all the pollutants and also it is very important to persuade significant lethal and sub-lethal effects on the aquatic organism.

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Chapter [3]

Impacts of agricultural pollutants on water resources and their management

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Abstract Water pollution is a rising global challenge that has expanded in both developed and developing nations, discouraging the growth of the economy as well as the physical and environmental health of billions of individuals. Recognizing the significance of water, the 2030 Agenda for Sustainable Development has incorporated certain water quality mark that is needed to be attained in Sustainable Development Goal (SDGs) 6. Human settlements, industries, and agriculture are the main causes of water pollution. Water pollution in agriculture is complex and multidimensional, and its effective management requires a comprehensive package of responses. Such responses need to act on key drivers of agricultural expansion and intensification, such as unsustainable dietary shifts and food waste and loss; limit the export of pollutants from farms; protect water bodies from agricultural pollution loads, and help restore already-affected water bodies. Responses for influencing both farm and landscape-scale practices may include regulation; the use of economic instruments; education and awareness-raising; cooperative agreements; and research and innovation. Policies to change farmer behavior and incentivize the adoption of good practices are the key to prevent pollution at the source. Demonstrating the economic benefits to the farmers for adopting good practices has also been shown to be effective.

Keywords Agricultural pollution, Sustainable development goal, Water pollution

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Introduction

Worldwide, the municipal wastewater that accounts for almost 80% in its raw and unprocessed form is ejected out into the aquatic bodies, the production houses and industries are solely responsible for discarding millions of tonnes of volatile organic compounds, poisonous solvents, toxic sludge, and other wastes into water bodies every year (WWAP, 2017). According to World Health Organization statistics, half of India's morbidity is water-related (WHO, 2012). Not only 70% of India's surface water resources but also an expanding percentage of the groundwater reserves are polluted by toxic, biological, organic, and inorganic pollutants due to indiscriminate dumping of commercial sewage, wastes arising from domestic household and agricultural pollutants.

These effluent sources pose a life-threatening danger for human utilization and also for other undertakings such as agriculture and commercial needs. Water pollution takes place when injurious substances are released into the water bodies in bulk volume causing harm to people and the environment. Besides human activities, natural events like volcanoes, earthquakes, and storms also bring about considerable changes in the quality of water and its ecological status. Agriculture alone makes up for 70% of water extraction globally, plays a vital role in degrading the water quality (UNEP, 2016). Greater quantities of agrochemicals, sediments, and saline drainage are poured out by the farms into aquatic bodies. The resultant pollutants pose an illustrated threat to aquatic ecosystems, the health of the people, and production activities. Pesticides, pathogens, nutrients, and sediments being the main agricultural donors to pollution of the water bodies are the primary challenges for controlling the same.

Agriculture utilizes the largest percentage of fresh water on a global basis. The linked up agro food-processing units are also a notable cause of organic pollution in various countries. Aquaculture is now realized as the main issue in freshwater and marine environments, leading to eutrophication and destruction of the aquatic ecosystem. The vital public and environmental health aspects of global water quality trouble are highlighted below:

- Five million people die annually from water-borne diseases.
- Ecosystem dysfunction and loss of biodiversity.
- Contamination of marine ecosystems from land-based activities.
- Contamination of groundwater resources.

Impacts of agricultural pollutants on water quality

The pesticides, nutrients, salts, organic carbon, and drug residues mainly contribute to water pollution. Table 1 shows the relative contributions of these pollutants to water-quality degradation. The importance of different forms of agricultural pollution varies with individual situations, and negative impacts such as eutrophication (which may include sediments, nutrients, and organic matter) arise from combinations of stressors. Table 2 described various activities contributing to water pollution.

Table 1. Relative contributions of these pollutants to water-quality degradation.

Pollutant category	Indicators/examples	Relative contribution by		
		Crops	Livestock	Aquaculture
Nutrients	Primarily nitrogen and phosphorus present in chemical and organic fertilizers as well as animal excreta and normally found in water as nitrate, ammonia or phosphate	***	***	*
Pesticides	Herbicides, insecticides, fungicides and bactericides, including organophosphates, carbamates, pyrethroids, organochlorine pesticides and others (many, such as DDT, are banned in most countries but are still being used illegally and persistently)	***	-	-
Salts	E.g. ions of sodium, chloride, potassium, magnesium, sulphate, calcium and bicarbonate. Measured in water, either directly as total dissolved solids or indirectly as electric conductivity	***	*	*
Sediment	Measured in water as total suspended solids or nephelometric turbidity units – especially from pond drainage during harvesting	***	***	*
Organic matter	Chemical or biochemical oxygen- demanding substances (e.g. organic materials such as plant matter and livestock excreta), which use up dissolved oxygen in water when they degrade	*	***	**
Pathogens	Bacteria and pathogen indicators. E.g. *Escherichia coli*, total coliforms, faecal coliforms and enterococci	*	***	*
Metals	E.g. selenium, lead, copper, mercury, arsenic and manganese	*	*	*
Emerging pollutants	E.g. drug residues, hormones and feed additives	-	***	**

***Nutrients*:** In crop production, water pollution from nutrients occurs when fertilizers are applied at a greater rate than they are fixed by soil particles or exported from the soil profile (e.g. by plant uptake or when they are washed off from the soil surface before plants can take them up). Excess nitrogen and phosphates can leach into groundwater or move via surface runoff into waterways. Phosphate is not as soluble as nitrate and ammonia and tends to get adsorbed onto soil particles and enter water bodies through soil erosion. In livestock production, feedlots are often located on the banks of watercourses so

Table 2. Impacts of various agricultural activities on surface and groundwater.

Agricultural activity	Impacts	
	Surface water	**Groundwater**
Tillage/ploughing	Sediment/turbidity: phosphorus and pesticides carried by sediments get adsorbed to the surface of sediment particles; siltation of river beds and habitat loss, spawning ground, etc.	
Fertilizing	Excess runoff of nutrients like phosphorus and nitrates resulting in eutrophication, leading to excess growth of algae which then leads to a condition of hypoxia of water bodies and fish kills.	High levels of nitrate leaching into groundwater; pose a threat to public health.
Manure spreading	Carried out as a fertilizer activity; spreading on frozen ground results in high levels of contamination of receiving waters by pathogens, metals, phosphorus and nitrogen leading to eutrophication and potential contamination.	Contamination of groundwater, especially by nitrogen
Pesticides	Runoff of pesticides leads to contamination of surface water and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish. Pesticides are carried as dust by wind over very long distances and contaminate aquatic systems 1000s of miles away (e.g. tropical/subtropical pesticides found in Arctic mammals).	Some pesticides may each into groundwater causing human health problems from contaminated wells.
Feedlots/animal corrals	Contamination of surface water with many pathogens (bacteria, viruses, etc.) leading to chronic public health problems. Also, contamination by metals contained in urine and faeces.	Potential leaching of nitrogen, metals, etc. to groundwater.
Irrigation	Runoff of salts leading to salinization of surface waters; runoff of fertilizers and pesticides to surface waters with ecological damage, bioaccumulation in edible fish species, etc. High levels of trace elements such as selenium can occur with serious ecological damage and potential human health impacts.	Enrichment of groundwater with salts, nutrients (especially nitrate).
Clear cutting	Erosion of land, leading to high levels of turbidity in rivers, siltation of bottom habitat, etc. Disruption and change of hydrologic regime, often with loss of perennial streams; causes public health problems due to loss of potable water.	Disruption of hydrologic regime, often with increased surface runoff and decreased groundwater recharge; affects surface water by decreasing flow in dry periods and concentrating nutrients and contaminants in surface water.
Silviculture	Broad range of effects: pesticide runoff and contamination of surface water and fish; erosion and sedimentation problems.	
Aquaculture	Release of pesticides (e.g. Tributyltin) and high levels of nutrients to surface water and groundwater through feed and faeces, leading to serious eutrophication.	

that (nutrient-rich) animal waste (e.g. urine) can be released directly into those watercourses. Manure is usually collected for use as organic fertilizer, which, if applied in excess, will lead to diffuse water pollution. In many cases, manure is not stored in contained areas and during significant rainfall events, it can be washed into watercourses via surface runoff. In fed aquaculture, the primary function of feed conversion and feed composition (faecal wastes) are the nourishing nutrient piles that are fed to the aquatic bodies. Residual feed in intensive fed aquaculture can be a noticeable donor to nutrient heaps in the water ecosystem. High-level nutrient loads along with other pollutants lead to the eutrophication of lakes, ponds and coastal waters that further leads to algae blooms that dominates and suppresses surrounding aquatic plants and animals. Nearly 415 coastal areas have been recognized worldwide to be undergoing eutrophication in some or the other form, 169 of which are hypoxic (WRI, 2008). The excess nutrients that get accumulated may also trigger adverse health effects, like blue-baby syndrome, due to excessive nitrate levels in drinking water.

Pesticides**:** In most countries, intensive application of pesticides and Insecticides are done (Schreinemachers and Tipraqsa, 2012). When not administered and managed properly, they can prove to be hazardous to water resources carrying carcinogenic and other toxic substances that can have a deleterious effect on human health. Pesticides may also affect biodiversity by killing weeds and insects, with negative impacts on the food chain. In developed countries, although considerable use of older broad-spectrum pesticides persists, the trend is towards the use of newer pesticides that are more selective and less toxic to humans and the environment and which require lower quantities per unit area to be effective. Nevertheless, millions of tonnes of active pesticide ingredients are used in agriculture (FAO, 2016). Acute pesticide poisoning causes significant human morbidity and mortality worldwide – especially in developing countries like India, where poor farmers often use highly hazardous pesticide formulations.

Salts**:** The production of brackish drainage and leaching water in agriculture has grown proportionally with the increase in irrigation in recent decades. Irrigation can mobilize salts accumulated in soils (leaching fractions), which are then transported by drainage water to receiving water bodies and cause salinization. Excessive irrigation can also raise water tables from saline aquifers and increase the seepage of saline groundwater into watercourses. Another major contribution to the salinization of coastal waters is by the entry of the salty seawater into aquifers – this result from unrestrained extracting of groundwater for agriculture (Mateo-Sagasta and Burke, 2010).

Major water-salinity problems have been reported in Argentina, Australia, China, India, Sudan, The United States of America, and many countries in Central Asia (Earthscan, 2011). In 2009, approximately 1.1 billion people lived in regions that had saline groundwater at shallow or intermediate depths (Van Weert *et al*., 2009). The geochemical cycles of major elements – such as carbon, nitrogen, phosphorus, and sulphur are altered due to high salt concentration that impacts the ecosystem (Herbert *et al*., 2015). Salinization can affect freshwater biota by causing changes within species and in community composition and can ultimately lead to biodiversity loss and migration. In general, when salinity increases, the biodiversity of microorganisms, algae, plants, and animals decline (Lorenz, 2014).

***Sediments*:** Unsustainable land use and improper tillage and soil management in agriculture are increasing erosion and sediment runoff into rivers, lakes, and reservoirs, with massive quantities of soil lost and transported to water bodies every year. The global rate of erosion in croplands is estimated at 10.5 megagrams (Mg) per ha per year, which equals 193 kilograms of soil organic carbon per ha per year. Approximations for pastureland are lesser, at 1.7 Mg per ha per year, which corresponds to 40.4 kilograms of soil organic carbon per ha per year. As per estimation, 43 % of the agricultural sediment flux is in Asia (Doetterl *et al*., 2012). Higher rates of erosion occur in areas where precipitation is high, slopes are steep and vegetation cover is poor. Erosion is aggravated by overgrazing in pasturelands, by inappropriate ploughing on steep slopes, and more broadly, by deforestation, land clearing, and the degradation of riverine vegetation.

Sediment in river systems is a complex mixture of minerals and organic matter, potentially including physical and chemical pollutants. Sediments can cover and destroy fish spawning beds, clog fish gills, and reduce useful storage volume in reservoirs. Sedimentation can damage watercourses, choke streams, and make filtration necessary for municipal and irrigation water supplies. It can also affect delta formation and dynamics and limit the navigability of water bodies. Particles of clay and silt in sediment can adsorb many types of chemicals on their surfaces, including nutrients, heavy metals, and persistent organic pollutants. Sediment, therefore, is a key means by which such pollutants are transported to water bodies.

***Organic matter*:** The organic matter obtained from the residual animal fodder and their excreta, animal-processing units and crop residues acquired from poor agricultural practices is the prominent pollutants of water bodies. The wastes acquired from livestock have one of the highest biological oxygen demand (BOD). For example, pig slurry has a BOD in the range of 30,000–80,000 milligrams per litre, as compared to the typical BOD of domestic sewage that is in the range of 200–500 milligrams per litre (Steinfeld *et al*, 2006). Aquaculture can be considered as the main donor to organic effluent in water. The dissolved oxygen of the water bodies is then utilized by the microorganisms for the degradation of organic matter which results in the hypoxic condition of the aquatic body. The chances of eutrophication and algal blooms in lakes and coastal areas are further enhanced by the release of organic loads in them.

***Pathogens*:** Several multicellular parasites and zoonotic microorganisms that can be injurious to human health are contained in livestock excreta. When food is irrigated using polluted water, pathogenic microorganisms can be food-borne or waterborne. Various pathogens have long lives and can live up to days or weeks in the excreta discharged onto land and thus polluting water bodies via runoff (Steinfeld *et al*, 2006; Dufour and Bartram, 2012). Bacteria like *Escherichia coli*, *Clostridium botulinum*, *Salmonella spp*. and parasitic protozoa like *Microsporidia spp*., *Giardia lamblia*, *Cryptosporidium parvum* are injurious to human health, all of these are reported every year to cause hundreds of thousands of infections (Christou, 2011).

***Emerging pollutants*:** New agricultural pollutants such as antibiotics, vaccines, growth promoters, and hormones have emerged in the last two decades. These can reach water via leaching and runoff from livestock and aquaculture farms, as well as through the application of manure and slurries to agricultural land (OECD, 2012). Residues of heavy metals in agricultural inputs such as pesticides and animal feed are also emerging threats. Agriculture is not only a source of emerging pollutants, but it also contributes to the spread and reintroduction of such pollutants into aquatic environments through wastewater, (re)use for irrigation, and the application of municipal biosolids to land as fertilizers. An estimated 35.9 Mha of agricultural lands is subject to the indirect use of wastewater (Thebo *et al*., 2017). The potential risks to human health posed by exposure to emerging pollutants via contaminated agricultural products need attention.

Mitigation of groundwater pollution caused by agricultural pollutants

Water pollution in agriculture is complex and multidimensional, and its effective management requires a comprehensive package of responses. There arises the need for such responses to act upon the main drivers of intensification and expansion of agriculture, such as waste derived from food and unsustainable dietary shifts, restricting the emission of farm-level pollutants; safeguarding of water bodies from agricultural pollutant piles, and help restore already-affected water bodies. Responses for influencing both farms and landscape-scale practices may include regulation; the use of economic instruments; education and awareness-raising; cooperative agreements; and research and innovation.

***Sustainable diets and reduced food waste*:** Different environmental footprints are dependent on the various diets consumed. There is an ever-increasing demand for food with high environmental footprints due to the rising population, such as meat from industrial farms, contributes to the depletion of water quality and unsustainable agricultural intensification. This can be changed, however. The more healthy and sustainable diets can be encouraged by accurate policies and incentives thereby neutralizing increases in food demand. For instance, a positive influence on dietary behaviour has been noticed by giving financial incentives such as taxes and subsidies on food and coupons to the consumers (Purnell *et al*., 2014).

Food losses and waste should be reduced as much as possible to bring food-production closer to actual food demand and to minimize the waste of resources and associated environmental impacts. About 25% of produced food is lost along the food supply chain. The production of this lost and wasted food accounts for 24% of the freshwater resources employed in crop production, 23% of total worldwide cropland zone, and 23% of total global fertilizer use (Kummu *et al*., 2012). Nitrogen pollution is very important for water quality, nitrogen released in the environment linked with global food waste is about 6.3 teragrams per year (Grizzetti *et al*., 2013), they also estimated that 12% of the water nitrogen diffuse pollution in agriculture is linked to food waste in the European Union. FAO has rigorously reviewed options for reducing food loss and waste (FAO, 2013, 2015).

***Policy interventions*:** Well-known principles like "polluter pays" for reducing pollution are not easy to apply in a practical sense to the non-point agricultural pollution because recognizing the actual polluters is neither easy nor cheap. Typical regulatory instruments include prohibitions on the direct discharge of pollutants; limits on the marketing and sale of dangerous products; and restrictions on agricultural practices or the location of farms. Regulatory approaches require inspection or self-reporting to ensure compliance, with violations subject to penalties such as fines and compensation payments; however, enforcement remains a challenge. A combination of approaches like regulations, economic incentives, and information work well than regulations alone according to a study (OECD, 2008). Policies addressing water pollution in agriculture should be part of an overarching water policy framework at the national or river-basin scale, with all pollutants and polluters considered together. Policies to change farmer behaviour and incentivize the adoption of good practices are key to prevent pollution at the source. Such policies need to include (free) advisory services and training to farmers. Demonstrating the economic benefits to farmers of adopting good practices has also been shown to be effective. Benchmarking can promote behavioural change among farmers by showing them how they perform compared with their peers (without identifying the best and worst individuals). Benchmarking can be applied to the application of fertilizers, manure and slurries, and pesticides. A more subtle form of persuasion is the incorporation of environment modules into school curricula and involving students in raising environmental issues in their communities. Regulations to protect water quality need to be enforceable. Water-quality targets also need to be realistic and time-bound, and they need to balance the costs of adopting a solution and the benefits brought about by higher water quality. Typically, pollution prevention will be cheaper than the restoration of affected aquatic ecosystems. When formulating and implementing policies, priority should be given to major polluters and to water bodies where pollution is highest. The smart identification of pollution hotspots, for example in areas of major livestock concentrations, can help in prioritizing interventions. Finally, policies need to be coherent. Interventions aimed at increasing food production and farm income on the one hand and at mitigating pollution on the other should be mutually supportive – or at least not conflicting, although this may be hard (politically) to achieve in practice. For example, the subsidies frequently in place for agrochemicals do not act as an incentive for efficient use, and they encourage farming on more fragile lands. Effective interministerial cooperation mechanisms are required to increase policy coherence (Adelodun and Choi, 2020).

***On-farm responses*:** In crop production, management practices for reducing the hazard of water pollution due to organic and inorganic fertilizers and pesticides involves limiting and optimizing the type, amount, and timing of applications to crops. Setting up protection zones along surface waterways, within farms, and in buffer zones around farms have been demonstrated to be viable in decreasing contamination of water bodies. The storage and discarding of pesticide waste and empty containers need to follow government safety guidelines. Also, efficient irrigation systems will decrease water return flows and therefore can significantly reduce the migration of fertilizers and pesticides to water bodies (Mateo-Sagasta and Burke, 2010). Contour ploughing and restrictions on the cultivation of steeply sloping soils are measures for reducing soil erosion (USEPA, 2003). Conservation agriculture has also proved very effective in erosion control. Manure management is one of the main concerns in livestock production and it needs to be stored, treated, handled, and disposed off or preferably reused safely. Manure treatments include composting and anaerobic fermentation, which can produce valuable organic fertilizers and soil conditioners. Intensive livestock operations such as feedlots that concentrate livestock need to be managed as point sources of pollution and should follow specific national regulations. The use of feed additives, hormones, and medicines should also adhere to national standards and international guidelines. In extensive livestock systems, overgrazing should be avoided to reduce land degradation and erosion. Aquaculture farms should adopt the right management practices to protect the surrounding aquatic environment, such as creating suitable production biomass based on the carrying capacity of the aquatic system; normalizing feed inputs to avoid excess feed; using fish drugs appropriately and abstaining from prohibited drugs; removing, treating and disposing of excessive nutrients in fishponds; and encouraging integrated multitrophic aquatic systems in which the waste of one species serves as a food source for another.

***Off-farm responses*:** It is clear that the most effective way of mitigating pressures on aquatic ecosystems and rural ecosystems more generally is to avoid or limit the export of pollutants from where they are applied: the costs of mitigation increase greatly once pollutants are in an ecosystem. Simple off-farm techniques, such as the construction of riparian buffer strips or constructed wetlands, can cost-effectively reduce loads entering surface water bodies. The remediation of contaminated waters such as lakes and aquifers is a long-term and expensive undertaking and, in some cases, may not even be feasible. Buffer strips are a well-established technology. Vegetated filter strips at the margins of farms and along rivers are effective in decreasing concentrations of pollutants entering waterways. In agriculture and forestry, buffer zones usually comprise strips of vegetation that act as filters for sediment and their attached pollutants. Buffer strips can also perform other functions, such as stream shading, carbon sequestration, biomass production, channel stabilization, water purification and the provision of terrestrial and stream habitats, and provide cultural and recreational services. Constructed wetlands have been employed mainly to treat point-source wastewater, including urban and agricultural stormwater runoff. Such wetlands can also be used to treat agricultural drainage and remove sediments, nutrients, and other pollutants. The risks associated with brackish and saline agricultural drainage (return flows) need to be managed. Water management options include minimizing drainage by conserving water, treating drainage water (e.g. via evaporation ponds), and reuse (brackish and saline drainage water can be reused downstream directly or blended with freshwater). Such approaches require planning at the watershed scale to adapt agricultural practices and crops to increasing salt content at different cycles of reuse, which may include the production of prawns and fish using brackish or saline waters. Crops, vegetables, livestock, trees, and fish are managed collectively in the aquaculture–agriculture–forestry system that can elevate production sustainability, resource utilization efficiency, and environmental stability. To optimize the use of resources and reduce pollution, waste from one enterprise can be used as an input to another by utilizing integrated farming.

Future research and recommendations

There are many knowledge gaps concerning water pollution in agriculture, and more data and research are required. The contributions of crops, livestock, and aquaculture to water pollution are not well known, particularly in developing countries like India. Quantifying these contributions is essential if national governments are to understand the full extent of the problem and to develop meaningful and cost-effective responses. The polluter-pays principle cannot be applied if the source of pollution is unclear. Sustained research and modelling effort, supported by water quality monitoring, is needed to better understand pollutant pathways and the links between pollution causes and effects. The pathways of, and the health and environmental risks posed by, emerging agricultural pollutants such as animal hormones, antibiotics, and other pharmaceuticals are growing areas of research that require more attention. For example, greater understanding is needed of the contributions of animal medicines to the increasing problem of antimicrobial resistance among pathogens. Research cannot be conducted without data. Better data are needed for understanding process and detail in specific cases and also at a broader scale to understand the pressures on and state of aquatic systems and trends in their condition. Because many indicators are subject to temporal and spatial variability, adequate monitoring programs with appropriate sampling rates and density are key (but expensive) priorities for improvement. Research results need to be applied if they are to be effective in reducing pollution in agriculture.

Conclusion

Immediate action is required to avoid water resource pollution as well as the nature-friendly reuse of the enormous wastewater assimilated by the agriculture sector. It is possible to reduce agricultural water pollution with the help of enhanced nutrients, pesticides, crop, soil, and water management practices. There is a need to strengthen the database on the quantity of sediment, nutrient, and pesticides in runoff resulting from a basin or watershed. Increasing the number of monitoring stations for effective monitoring of agricultural/industrial water pollution is the hard-pressing need of the present times. India has well-defined wastewater discharge standards for the domestic and industrial sectors but there are no discharge standards for the pollution originating from the agriculture sector which needs to standardize. The policy for water pollution needs to deliver essential guidelines for monitoring and control of pollution resulting from industrial, agricultural, and other activities.

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Chapter

[4]

An overview on environmental pollution caused by heavy metals released from e-waste and their bioleaching

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Abstract

The consistently expanding quantum of e-waste is booming at an extremely high pace which is around 20-25 Mt for every year. The metal recovery from e-waste is a developing zone of scientific enthusiasm because of quality of wide scope of valuable metals present in it. Bioleaching can improve and recover the heterogenic metals present in electronic waste in a proficient way, thereby helps in its effective management. The microbial strains involved in metals bioleaching mobilize the metals under the influence of cyanide and acidic medium. *Acidithiobacillus thiooxidans*, *Thiobacillus ferrooxidans*, *Thermoplasma acidophilum*, *Chromobacterium violaceum*, *Acidithiobacillus* and *Aspergillus niger* are the major microbial strains engaged with metals bioleaching. This chapter emphasized on the types of microorganisms and their performance in metal bioleaching and inspects the bioleaching of gold, iron and copper from e-waste scrap. Additionally, the key environmental and health concerns associated with e-waste exposure are also discussed. Therefore, this chapter provides comprehensive information on eco-friendly and efficient bioleaching of heavy metals from environment.

Keywords Bioleaching, Electronic waste, Heavy metal recovery, Waste management

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Abbreviations: MoEFCC: Ministry of Environment, Forest and Climate change, EEE: Electrical and electronic equipment's, e-waste: Electronic waste, HF: Hydrofluoric acid, GEWM: Global e-waste monitor, Mt: metric tons, PCBs: Poly Chlorinated Biphenyls, BFR: Brominated flame retardants, PDA: Potato dextrose agar, SF_6: Sulphur hexafluoride, ICP-OES: Inductively coupled plasma-optical emission spectrometry, CRTs: Cathode ray tubes.

E-waste definition: According to e-waste (management) rules, 2016 *"e-waste' means electrical and electronic equipment, whole or in part discarded as waste by the consumer or bulk consumer as well as rejects from manufacturing, refurbishment, and repair processes"*.

Introduction

Electrical and electronic equipment (EEE) constitute a major proportion of e-waste (Ghosh *et al*., 2020). These appliances have become an integral part of human life as a symbol of extravagance and a higher standard of living. Most recent turns of events and innovative upgradations in the technology decrease the expense of electric and electronic equipment prompt their higher utilization, and in this manner extending the electronic market at a higher rate (Pavithra *et al*., 2020). Notwithstanding, the assortment and recycling of electronic waste happen at a moderate pace when contrasted with its production which thus causes natural concerns (Awasthi *et al*., 2016). e-waste is a worldwide ecological issue that especially influences the natural ecosystem through its harmful synthetic substances that leached out in the distinctive natural environmental spheres in small fractions and hence initiate toxic impacts in the earth's ecosystems (Vaish *et al*., 2020). Scientific management of e-waste is kept on being a test in the present situation. In this manner to handle the persevering issue, different physical and chemical modes have been adopted (Kaya, 2016). Since these advancements are profoundly proficient for e-waste management and source recuperation, they are known for their higher energy utilization and operational expense. Despite these, bioleaching offers a characteristic, natural, and cost-benefit organic methodology for e-waste management and recuperation of valuable metals present in it using a variety of bacterial and fungal species. The bioleaching productively oversees electronic waste and recoup valuable metals present in e-waste scrap with minimal ecological harms.

This chapter emphasized the types of microorganisms and their performance in metal bioleaching and inspects the bioleaching of gold, iron, and copper from e-waste scrap. Additionally, health and environmental impacts are also discussed.

Statics on e-waste generation

The consistently expanding quantum of e-waste is booming at an extremely high pace which is around 20-25 Mt for every year (Mihai, 2016). As indicated by the GEWM report (2020), the absolute e-waste generated in 2019 is assessed to be 53.6 million metric tons over the globe which was configured to 7.3 kg per capita generation. The scientists anticipated that the absolute e-waste will ascend to 74 Mt in 2030. Aside from generation, the documented collection and recycling of e-waste was found to be 9.3 Mt which was merely a total fraction of 17.4% when compared to the total waste generated (Forti *et al*., 2020). The amount of e-waste in the year 2019 involved various Categories as appeared in Table 1. In the case of Asia, this report gauges 24.9 Mt (5.6 kg per capita) generation of e-waste while just 11.7% of it is appropriately collected and recycled (Forti *et al*., 2020).

Bioleaching pathways

Bioleaching includes biochemical systems of bacterial and fungal strains for proficient metal recuperation from e-waste. The procedure utilizes their metabolic byproducts and enzymatic activities. There are two fundamental modes of bioleaching pathways as described below:

Direct

This pathway includes the process of metal oxidation with the assistance of enzymatic responses started by explicit microorganisms (Bal *et al*., 2019; Zhao and Wang, 2019). In this procedure, the electronic waste is presented at the inoculation stage by the addition of metabolic acids in a single stage and two-way stages (Arya and Kumar, 2020; Baniasadi *et al*., 2020). For instance, certain microbes like *Thiobacillus ferrooxidans*, which are profoundly acidophilic and gram-negative aides in the oxidation of Fe^{2+} to Fe^{3+} and in this way acquired vitality for their metabolic capacities (Miao *et al*., 2017). Reactions are delineated below:

$$4\,FeSO_4 + 2\,H_2SO_4 + O_2 \longrightarrow 2\,Fe(SO_4)_3 + 2\,H_2O$$

$$2\,S^0 + 3\,O_2 + 2\,H_2O \longrightarrow 2\,H_2SO_4$$

$$2\,FeS_2 + 7O_2 + 2\,H_2O + 2\,H_2SO_4 \longrightarrow 2\,FeSO_4 + 2\,H_2SO_4$$

Table 1. Different categories of equipment's that produces e-waste (Forti *et al*., 2020).

Categories of equipment's	Quantity (Mt)
Smaller equipment's	17.4
Large electronic equipment	13.1
Electronic temperature exchange equipment	10.8
Monitors and Screens	6.7
IT and telecommunication equipment's	4.7
Lamps, bulbs	0.9

Indirect

This pathway is a two-way process where microorganisms don't legitimately include in the mineralization of metals yet they generate solid oxidizing agents. For example, ferric ions and sulfuric acid that cooperate with metals and balance out them in a profoundly acidic medium. The oxidation of Fe, S, and distinctive metal sulfides assumes their significant role in keeping up acidic conditions fundamental for mental disintegration (Sajjad *et al*., 2019; Sand, Gehrke *et al*., 2001). The mechanism of copper bioleaching is represented in Figure 1. Bioleaching includes the use of biological agents for e-waste metal recovery. They transform the metals present in the electronic waste scrap (Pant *et al*., 2018). The biochemistry involved in bioleaching is presented in Table 2.

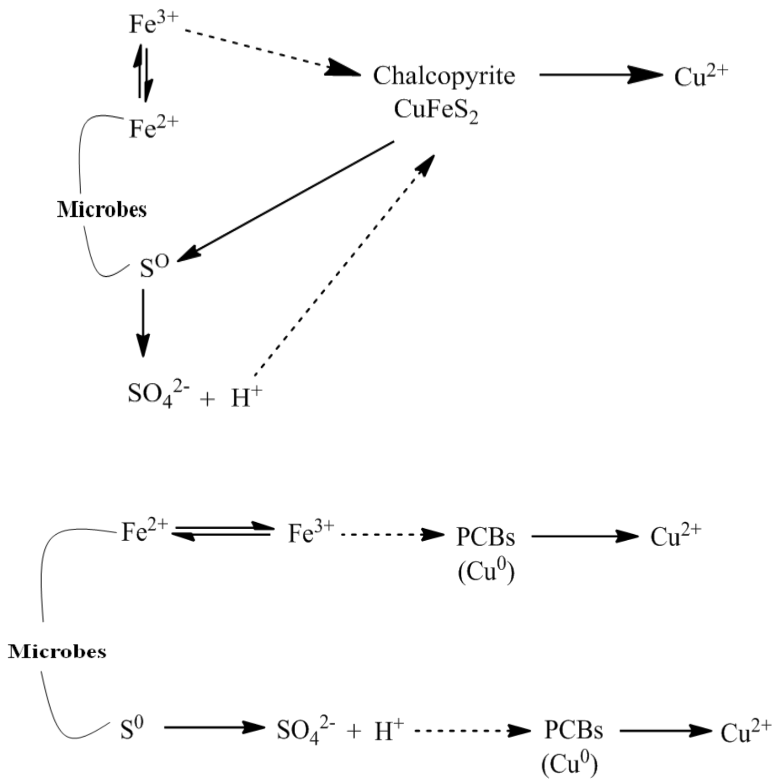

Figure 1. Indirect bioleaching pathway of copper bioleaching from chalcopyrite and PCBs (Source: Zhao and Wang, 2019).

Table 2. Biochemistry involved in biological leaching of various metal ions.

Reagents	Leached metals	Microbes involved	Biochemistry	References
HCl, HNO_3, H_2SO_4, Aqua regia	Co, Li	*Aspergillus niger, Acidithiobacillus thiooxidans*	$Co^{2+}+Na_2S \rightarrow CoS_{(S)}+2Na^+_{(aq)}$ $Co^{2+}_{(aq)}+2NaOH \rightarrow Co(OH)_{2(s)}+2Na^+$ $Co^{2+}_{(aq)}+Na_2C_2O_4+2H_2O \rightarrow CoC_2O_4.2H_2O_{(s)}$ $+2Na^+_{(aq)}$ $2Li^+_{(aq)}+ Na_2Co_3 \rightarrow Li_2Co_{3(s)}+2Na^+_{(aq)}$	Biswal *et al.* (2018)
Aqua regia, Concen-trated HF	Mn, Al, Zn, Cu, Ti	*Thiobacillus ferrooxidans*	$ZnS + 2Fe^{3+} \rightarrow Zn^{2+} + 2Fe^{2+} + S^0$ $ZnS + 2O_2 \rightarrow Zn^{2+} + SO_4^{2-}$ $4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$	Arshadi *et al.* (2020)
KCl, K_2HPO_4, $(NH_4)_2SO_4$	Fe	Thermophilic culture	$Fe_7S_8+7FeSo_4 \rightarrow 7FeSo_4+7H_2S+S$ $Fe_7S_8+H_2O+15.5O_2(g) \rightarrow 7FeSo_4+H_2SO_4$ $Fe_7S_8+O_2(g) \rightarrow 7FeSo_4+ S$ $Fe_7S_8+31Fe_2(SO_4)_3+32H_2O \rightarrow 69\ Fe(So_4)$ $+32H_2SO_4$ $Fe_7S_8+7Fe_2(SO_4)_3 \rightarrow 21FeSO_4+8S^0$	Altinkaya *et al.* (2018)
Inorganic Sulfuric acid	Cu	*Acidithiobacillus thiooxidans*	$S^0+1.5\ O_2+H_2O \rightarrow 2H^++SO_4^{2-}$ $Cu \rightarrow Cu^++e^-$ $Cu^+ \rightarrow Cu^{2+}+e^-$ $O_2+4H^++4\ e^- \rightarrow 2H_2O$ $2Cu^++O2+4H^+ \rightarrow 4Cu^{2+}+2H_2O$ $Cu^{2+}+SO_4^{2-} \rightarrow CuSO_4$	Hong and Vali (2014)
Sulfuric acid	Cu, Al, Zn, Ni	*Thermoplasma acidophilum*	$Cu^0+Fe_2(SO_4)_3 \rightarrow CuSO_4+2FeSO_4$ $Zn^0+ Fe_2(SO_4)_3 \rightarrow ZnSO_4+2FeSO_4$ $Ni^0+ Fe_2(SO_4)_3 \rightarrow NiSO_4+2FeSO_4$ $2Al^0+3Fe_2(SO_4)_3 \rightarrow Al2(SO_4)_3+6FeSO_4$	Ilyas *et al.* (2007)
Cyanide	Au	*Chromobacterium violaceum*	$FeS_2+6Fe^{3+}+3H_2O \rightarrow S_2O_3^{2-}+7Fe^{2+}+6H^+$ $S_2O_3^{2-}+2O_2+H_2O \rightarrow 2SO_4^{2-}+2H^+$ $S_2O_3^{2-}+4Fe^{3+}+5H_2O \rightarrow 2SO_4^{2-}+4Fe^{2+}+10H^+$ $2Fe^{2+}+2H^++0.5O_2 \rightarrow 2Fe^{3+}+H_2O$ $UO_2+2Fe^{3+} \rightarrow UO_2^{2+}+2Fe^{2+}$ $4Au+8CN^-+O_2+2H_2O \rightarrow 4Au(CN)_2^-+4OH^-$	Nancharai-ah *et al.* (2016)
Sulfur	Fe	*Acidithiobacillus*	$6Fe^{3+}+S^o+4H_2O \rightarrow 6Fe^{2+}+SO4^{2-}+8H^+$ $6FeO.OH+S^o+10H^+ \rightarrow 6Fe^{2+}+SO4^{2-}+8H_2O$	

Mechanisms of metals bioleaching

Gold bioleaching

Gold bioleaching gives a significant and alluring exploration research area including innovative progression in gold recovery from electronic waste. The mesophilic, facultative, and gram-negative microbe *Chromobacterium violaceum* (Pant and Sharma, 2015) gives a chance to recoup the gold from printed circuit boards of the waste gadgets (Li *et al.*, Ma, 2015). This specific microorganism generates CN^- that may help in gold solubilization in the acidic medium in this way helps in gold bioleaching in an effective manner (Chi *et al.*, 2011). The mechanism of gold bioleaching (Liu *et al.*, 2016) is summarized in the following chemical reactions:

$$4Au + 8CN^- \longrightarrow 4Au(CN)^-_2 + 4e^-$$

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

$$4Au + 8CN^- + O_2 + 2H_2O \xrightarrow{\textit{Chromobacterium violaceum}} 4Au(CN)^-_2 + 4OH^-$$

Various investigations have been done on in a similar field to get upgraded recuperation rates of gold (Willner and Fornalczyk, 2013). Aside from *Chromobacterium violaceum*, researchers also utilize *Pseudomonas balearica* SAEI strain for gold bioleaching and a recuperation rate of 68.5% has been observed (Kumar *et al.*, 2018). Also, another specialist utilizes the organism *Aspergillus niger* of the family *Trichocomaceae* for gold bioleaching and 56% of the recuperation rate has been accomplished (Argumedo-Delira *et al.*, 2019; Becci *et al.*, 2020). The flow chart of gold bioleaching (Figure 2) using *Aspergillus niger* from printed circuit boards is given below:

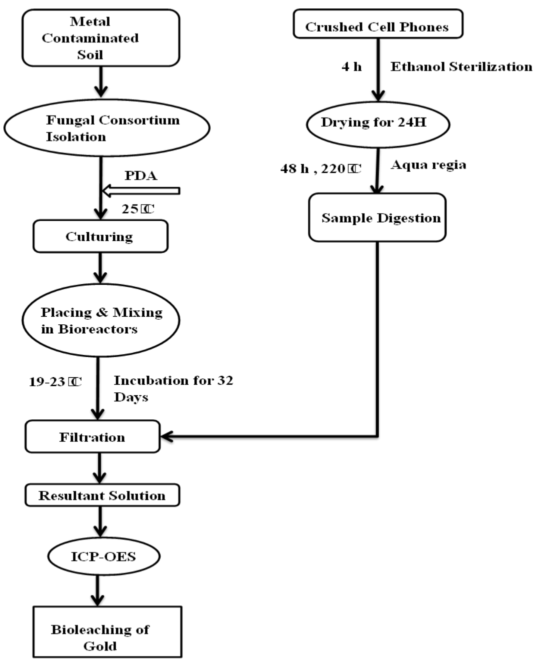

Figure 2. Gold (Au) bioleaching from printed circuit boards of mobile phones using *Aspergillus niger* (Argumedo-Delira *et al*., 2019).

Iron bioleaching

Iron is bleached by acidophilic microbial species including the cooperation of ferric ions with H_2SO_4 either by thiosulfate or polysulfide pathways (Figure 3) and in this way metal solubilization occurs. These bacteria can contact with iron and oxidize the Fe^{2+} ions to Fe^{3+} and reduces sulfur to $S_2O_3^{2-}$. For example, *Acidithiobacillus ferrooxidans* bacteria attacks iron and initiate extracellular enzymatic actions (Maluckov, 2017; Saavedra *et al*., 2020). Oxidation of Fe^{3+} to Fe^{2+} ions happened due to electron transfer (Drits and Manceau, 2000). At the outer membrane of bacteria, Fe^{2+} ions are reoxidized to Fe^{3+} ions (Geerlings *et al*., 2019). The thiosulfate oxidation mechanism (Masau, 1999) is represented in the following generalized equations:

$$FeS_2 + 3.5O_2 + H_2O \longrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

$$MeS + 2Fe^{3+} + 1.5O_2 + H_2O \longrightarrow Me^{2+} + 2Fe^{2+} + SO_4^{2-} + 2H^-$$

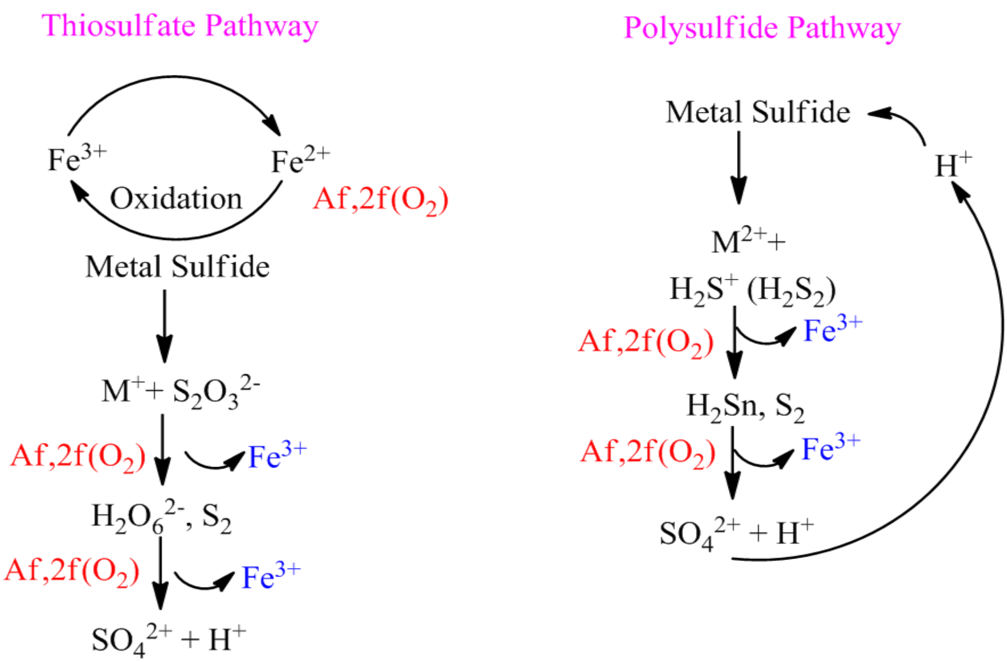

Figure 3. Mechanism of iron bioleaching involving thiosulfate or polysulfide pathways (Pant *et al*., 2018; Srichandan *et al*., 2020).

Copper bioleaching

The copper dissolution from e-waste generally occurs in two main phases. The first phase involves the oxidation of the ferrous ion to ferric ions with the help of bacteria and the second phase involves the copper mobilization from the e-waste scrap which is induced by the ferric ion's reduction to ferrous ions. In this way, the continuous cycle between ferric and ferrous ions is going on and the copper metal is bleached from the electronic waste (Wu *et al*., 2018). The copper bioleaching chemical reactions are given ahead:

$$Fe^{2+} + O_2 + 4H^+ \xrightarrow[\textit{Acidithiobacillus thiooxidans}]{\text{Microbes}} Fe^{3+} + 2H_2O$$

$$2Fe^{3+} + Cu \longrightarrow 2Fe^{2+} + Cu^{2+}$$

Environmental consequences and health impacts

A few investigations attempt to audit the toxic impacts of e-waste on people just as on various ecological environmental spheres. Investigations are referencing its natural concerns and related effects. The use of unscientific e-waste management practices like melting, roasting, open-air burning and so forth generate toxic dioxins and other air born hazardous chemicals that may have direct ecological concerns and health-related issues. Table 3 shows different environmental and health impacts that are associated with e-waste.

Table 3. List of environmental and health impacts of hazardous constituents present in e-waste.

E-Waste Sources	Constituents	Consequences	Health impacts	References
Mercury vapor lamp PCBs Relay, Board switches	Mercury vapors Mercury Mercury	-Bioaccumulation causes higher level of toxicity in aquatic animals. e.g. fish, seabirds, etc. -Dry deposition in air causes air pollution. -Ground level interactions with ozone.	-Neuronal dysfunction. -Insomnia -Distorted vision. -Muscle weakness. -Blood poisoning. -Disturbed sensations. -memory loss.	Ha *et al*. (2017); Lindqvist (1995); Sarikaya *et al*. (2010); Wang *et al*. (2020); Wang *et al*. (2019)
Housing wiring	BFR	-Affect air quality of e-waste dismantling facility. -Contaminate the soil through their sedimentations with soil particles. -Bioaccumulation within the food chain.	-Cancer. -Diabetes. -Neurological concerns. -Reproductive and developmental abnormalities.	Kim *et al*. (2014); Segev *et al*. (2009); Yu *et al*. (2016)

Table 3. *Continued...*

E-Waste Sources	Constituents	Consequences	Health impacts	References
Circuit Breakers	SF_6	-High level of global warming potential as compared to carbon dioxide and methane. -Highly persistent in nature. -On its decomposition, it generates highly toxic Di-sulfur decafluoride. -Highly persistent in nature.	-Damaged hepatic and renal organ systems. -Suffocation. -Nasal and bronchitis congestion. -Extensive lung damage. -Respiratory problems. -Dizziness and fainting.	Blackburn and Solutions (2017); Dervos and Vassiliou (2000); Tsai (2007)
CRTs	Barium, Lead	-Contaminate underground water sources on mixing when leaked from shale gas wells. -Ba is long term stable in the environment. -Lead from anthropogenic sources enters in the soil and water therefore, causes soil, water pollution.	-High blood pressure. -Respiratory problems. -Cardiovascular and kidney disease. -Behavioral changes. -Altered metabolism. -Neurological and mental illness. -Anemia. -Nervous system disorders in babies, -Abnormal enzymatic system of the body.	Kravchenko *et al*. (2014); Lecler *et al*., (2015); Wani (2015); Xu *et al*. (2013)
Plastic of Key-boards, Monitors etc.	Brominated dioxins and Hydrocarbons	-Brominated dioxins are highly persistent environmental pollutants. -Increases total toxicity of environment. -Hydrocarbons contribute in global warming and green house effect.	-Affect neuronal development. -Irregular heart beat. -Coma. -Prostate cancer.	Birnbaum *et al*. (2003); Ince and Ince (2019); Tue *et al*. (2013)
Mobile battery	Lithium and Nickel	-Lithium leaching affects soil and water systems. -Toxic effects of lithium causes river water pollution and wildlife destruction. -Nickel adversely affects the environment. -Nickel promotes GHG emissions, habitat loss and air, water, soil pollution.	-Burning sensation. -Cough. -Skin rashes and redness. -Vomiting. -Abnormal lung activity. -Chronic bronchitis. -Lung cancer. -Dermatitis.	Gaines and Dunn (2014); Genchi *et al*. (2020); Hedya *et al*. (2019); Nakajima *et al*. (2017)

Table 3. *Continued*...

E-waste Sources	Constituents	Consequences	Health Impacts	References
Semiconductors and Chip resistor	Cadmium	-Highly persistent toxicant. -Industrial activities like smelting and reclamation raise cadmium concentration in the air.	-Deformed brain development. -Cancer. -Emphysema. -Chronic obstructive pulmonary disease. -Renal and Cardiovascular ailments.	Dhiman (2020); Dökmeci *et al*. (2009); Fleischer *et al*. (1974); Hayat *et al*. (2019)

Conclusion

Bioleaching is a simple and exceptionally successful innovative technology for metal extraction from e-waste scrap and its scientific management. Aside from metal recovery, this technique likewise gives remedial measures to the detoxification of wastewater, mechanical waste, heavy metals, and sewage sludge. Organisms assume their significant role in the biogeochemical cycling and productive extraction of metals from electronic waste. The inclusion of organisms modifies the procedure of metal extraction when compared with the ordinary metal extraction procedures of pyro and hydro-metallurgy. Nonetheless, a few confinements like inconsistent and low recovery yield, slow procedure, risk of contamination have been distinguished as the genuine problems with this process. Therefore, additional research is needed to modify the existing bioleaching process for higher metal recovery rates from electronic waste scrap.

Conflict of interest: The authors declare no conflict of interest.

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Chapter [5]

Leachate disposal induced groundwater pollution: A threat to drinking water scarcity and its management

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Abstract

The increasing population over a period of sometime increased the generation of solid waste as well. The process of waste dumping in prehistoric times was very crude as it was disposed of on roads or on the exposed pits in the periphery of the cities. Solid wastes play a lead role in affecting the biotic as well as abiotic components of the surrounding poorly. Until recently, wastes were dumped in the landfill outside the urban area or village boundary where they are burnt or compacted. Dumping and burning of the waste is are not considered an appropriate practice from environmental and human health's point of view. Landfill is the most common mode to remove wastes. The problem linked with landfill is the formation of leachates. The leachates are formed when the waste mixes with the water and penetrates into the ground. The solid waste effect quality of soil, water as well as environment. It is the need of an hour to find the techniques for resource recovery from waste and leachate. This Book chapter discusses in detail about the types of solid waste and leachate their characteristics, techniques of resource recovery from the solid waste and leachate treatment and mitigation methods.

Keywords Hazardous substances, Leachate waste, Solid waste, Waste management

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Introduction

Wastes can be produced during the extraction and processing of resources into intermediate and end products, its consumption etc, and other human activities. Every day to day human activity leaves behind some kind of waste. It is significant to note that solid waste is not substantially constrained to wastes that is physically solid. The production of waste has increased to such an extent that it generates hurdle in the daily lives of today's as well as the future generations (Sharholy *et al*., 2008). In prehistoric times, garbage was tossed onto the unpaved streets and roadways, where they were left to pile up. It was not till 320 BCE in Athens that the initially known law forbidding this practice was recognized. Shortly this type of system progressed in Greece and the Greek-controlled cities of the eastern Mediterranean. Later during the fall of Rome, waste collection facility declined that persisted throughout the Middle Ages. In the 14th century, scavengers were assumed to perform the duty of dragging waste to landfills outside city walls, but this was not the situation in smaller townships. This went on till the 18th century until when America began the public collection of garbage in Boston, New York, and Philadelphia (Hickman, 2003).

Traditionally, the waste collection was accomplished by sweepers, mostly women. The women used to sweep the streets with the broom and collect the waste in trays (Colon and Fawcett, 2006; Nema, 2004; Malviya *et al*., 2002; Kansal *et al*., 1998; Bhide and Shekdar, 1998). The collected waste was then dumped to the nearest storage sites. (Hoornweg and Bhada, 2012). The males generally drive the bullock carts to transfer garbage to the disposal site. In 1994 India faced a nationwide plague epidemic in south-central and western parts of the country. There were flooding in large areas after the sewer were clogged due to heavy rain (Raza, 1997). In 1995 the government of India established a High-Power Committee known as the Bajaj Committee whose crucial characters were the evaluation of the prevailing technologies for municipal solid waste collection, transportation, and dumping. Also, it had to recommend suitable, eco-friendly, and cost-effective technologies options (Joardar, 2000). It was the time when the waste management system was very poor. Technical developments continued throughout the first half of the 20th century. There were two reasonable choices for dumping of the waste and they were either on the land or in the ocean. As now the environmental damage done to oceans by the disposal of waste is well known, the countries decided to ban the dumping of waste in the ocean (Jambeck, 2015). The development of garbage grinders, compaction trucks, and pneumatic collection systems took place during this time. Then later during the mid-century, though, it had become apparent that inappropriate incineration and exposed dumping of solid waste were instigating difficulties of contamination and threatening human health. Therefore, landfills were developed to substitute the exercise of open dumping and to lower the dependence on the burning of the waste (Munawar *et al*., 2018). The disposal of waste in the landfill is extensively used due to its monetary benefits in relations to the capital costs. In addition to the monetary benefits, landfills allow meticulous disintegration of waste to stable end product (Renou *et al.*, 2008). Though, there are certain apprehensions linked to the production of leachate from landfills. The leachates migrate from landfill site to the ground and contaminate the ground water.

Leachate is said to be liquid material that leaches from a waste landfill. They usually comprise of numerous toxins. The composition and content differ with respect to location, composition of waste, pH, moisture, and other characteristics of site (Bove *et al.*, 2015). It consists of suspended and dissolved material. The term leachate is commonly used as landfill leachate. Landfill leachate are the variegated waste with substantial distinction in composition and volume. The amount of production of leachate depends on the climate, age and design of the landfill, degree of compaction and the composition of the waste. In the middle of nineteenth century it was proposed to develop a landfill site with porous underground layer to avoid formation of leachate (Renou *et al.*, 2008). In certain parts of Europe, it was decided to choose sites with engineered lining as landfill. Later United States started developing leachate retentive and gathering systems. This led to the development of multiple lining in all landfills.

The waste dumped in the landfill take many years for complete degradation, undergoing physical, chemical, and biological transformation, and then being converting into liquids and gases by the biodegradation process. The leachate produced easily moves into the food chain through the infiltration of soil and surface waters. The presence of leachate into food chain threaten health and environment safety severely. The main type of leachate is landfill leachate, transmission station leachate, leachate due to incineration plants and leachate produced in the waste collection and in the transport process. (Fatta *et.al.*, 1999). The chief sources of leachate from the landfill include precipitation infiltration, surface leachate infiltration, infiltration of ground water, free water in waste, leachate from covering materials and leachate produced from the decomposition of organic matters (He *et al.*, 2015).

The properties of leachate are relied on the components of waste and moisture. For landfill leachate, rainfall is the leading parameter, amongst the features that influence the characteristics of leachate (Aziz *et al.*, 2016). The water of rain enters landfill and transports the pollutants into the liquid from the solid. At the same time, the biological matters in garbage are decayed into soluble organic matters, which then mixes with the leachate under the influence of microorganisms. The leachate in the landfill gets collected at the bottom and penetrates through the soil and later reaches the groundwater (Mor *et al.*, 2006). The groundwater contamination is prevalent in the areas near landfill since the potential leachate originate from neighbouring dumping site. Due to the increase in population and the effect of landfill leachate on groundwater and soil has led to number of studies recently (Saarela, 2003).

Different types of leachate

Wastewater is generated in many landfills from various sources both on and off site, including landfill leachate, landfill gas condensate (LFG), wastewater from washing vehicles, drained free liquids, stormwater, contaminated groundwater, wastewater from laboratories, washing floors etc. These different types of leachates are discussed in this section.

***Landfill leachate*:** Leachate from a dumping site differs extensively in composition. It generally comprises of suspended solids. They are produced chiefly by rainfall saturating the waste collected in the landfill. Once the water comes in interaction with decomposing solid waste, the water becomes polluted, and after getting contaminated flows out of the waste known as leachate (Washington State Department of Ecology). Further the volume of leachate is twisted through the breakdown of carbonaceous material manufacturing a variety of other resources like methane, carbon dioxide, aldehydes, alcohols and simple sugars (Nika *et al.*, 2020). The risks of leachate production can be eased by accurately engineered landfill spot, like those that are built on geologically impervious materials that use resistant linings made of engineered clay. Use of Such liners are compulsory in United States, Australia, and European Union apart from the places where waste is believed to be inactive (Mishra *et al.*, 2018). Moreover, utmost poisonous and difficult materials are now specially excluded from land-filling. Nevertheless, in spite of much stringent legal control, leachates from the dumping sites are frequently found to comprise a variety of contaminants coming from unlawful activity and domestic products (Renou, 2008). Landfill leachate comprises of wastewater that is seeped from the compact waste stacked up on the landfill. This liquid may be rainfall that has sieved through the pile of waste or it may be any kind of liquid or moisture that has originated from the waste itself (Raghab, 2013). Generally, it is a mixture of both and contains suspended contaminants that were detached from the garbage as it passed through the solid waste material. This waste water can possibly travel into the wider environment over a period of time. As liquid travels through a landfill, it can seep elements of concern that are found in the waste pile, transporting them deeper into the substrate. This poses a probable ecological and public health risk as both soils and groundwater can become contaminated (Klinck and Stuart, 1999).

***Landfill gas condensate*:** Landfill gas condensate is formed when a liquid condenses in the landfill gas collection system as gas is extracted from the landfill (Zhao, 2012).). Hazardous gases such as methane and carbon dioxide are produced by microorganisms as they breakdown the garbage on the landfill. These gases produced in the landfill need to be removed to avoid the build-up of gases that can result in explosion on and off site (Fjelsted, 2020).

***Industrial leachate*:** Leachate is produced in a landfill or a land that is polluted by the chemicals or toxic waste of the industrial activities like godowns, storage locations, factories, mines, manufacturing plants etc. Composting sites having high precipitation also produce leachate (Gotvajn *et al.*, 2009; Turan *et al.*, 2011).

***Mining leachate*:** Leachate which is associated with various mining activities comes under leachate mining. The stockpiled coal, waste materials of metal ore, waste from rock mining procedures (Botelho, 2018).

***Leachate from concrete*:** In terms of civil engineering (more specifically reinforced concrete design), leachate is formed by washing off of the concrete material or infuses through the cement, thus catalysing its oxidation and disintegration. This type of leachates cause defect in genes also known as genotoxicity due to physical and chemical agents (Singh, 2007).

General characteristics of leachates

The characteristics of leachate is dependent profoundly on numerous factors such as composition and the age of waste, degree of decomposition, procedure of waste-filling, waste moisture content and temperature (Armstrong and Rowe, 1999). The amount and nature of leachate is extremely inconstant (Purwanta, 2007). The chief pollutants in the leachate is ammonia and organic matter, but if the age of landfill increases, the concentration of organic matter in leachate also decreases (Kulikowska and Kilimiuk, 2008).Toxicity and health hazards due to wastewater are firmly administered by their composition in comparison to the set permissive levels for the environment (Bhalla *et al.*, 2013). Leachate can also be characterized as a type of wastewater due to its relative variability of composition (Ehrig and Robinson, 2011). This variability is a result of many site-specific parameters like climate, geography, design of the landfill, and composition of the waste, but also the regulatory measures and management practices applied. For the Evaluation of risks associated with leachate, it is mandatory to understand attenuation of leachate in aquifers entering the groundwater, for interpretation of groundwater samples from monitoring of the wells, and for determining suitable curative action, together with monitoring natural attenuations (Christensen *et al.*, 2001). The initial stage is aerobic degradation of organic matter which is usually short. When the oxygen is depleted, degradation continues anaerobically. The process of anaerobic degradation comprises of two main fermentation stages i.e. the acidogenic phase which produce a young biodegradable leachate, and the methanogenic phase which generate stabilized old leachates (Welander, 1998). Leachate composition becomes complex when industrial waste is mixed with municipal solid waste in the landfill, because of the suspension of contaminants in the industrial wastes (Lee *et el*., 2010). The leachate found in incineration plants and transfer stations is relatively different to that found in landfill. The following are the few characteristics of leachate.

Colour and odour: Leachate display brown, black or dark brown as it has high contrast, with a pungent smell.

pH: The landfill shows weak acidity of pH value between 6 and 7 at the primary stage. Later when the landfill stabilizes the pH between 7 and 8.

Organic compounds: Numerous organic compounds, organic acids, aromatic hydrocarbons, alkanes and alkenes, phenols, ketones, lipids, alcohols, aldehydes and amides are found in leachate. These organic substances may be carcinogenic or may contain blacklist priority pollutants.

Xenobiotic organic compounds (XOCs): The concentration of xenobiotic organic compounds varies because of the differences amid the landfill as well as the composition of waste and also the time of landfill. The common XOCs are tetrachloroethylene, trichloroethylene, toluene, benzene, ethylbenzene, and xylene. In the leachate sometimes phenoxy acid herbicide has also been detected.

Ammoniacal nitrogen: The half mature leachate contains high concentration of ammonia-nitrogen. The hydrolysis and fermentation of nitrogenous organic substances increases the difficulty of ammonia nitrogen elimination process. In the landfill site during methanation stage the concentration of pollutant increases as most of the landfill sites uses anaerobic technology. The concentration of ammoniacal nitrogen (NH_3-N) is higher in the stable stage.

Phosphorus: The concentration of phosphorus is low in leachate, especially of dissolved phosphate, irrespective of its source.

Heavy metals: Amongst the numerous contaminants in leachate, the metallic ions, specifically, heavy metal, should be paid more attention as they are harmful to the environment and the effect on the biological treatment. There are various types of heavy metal ions in the leachate. The insoluble metals are converted into soluble metal and later mix in the leachate through various physical and chemical reactions.

Total dissolved solids: There is high concentration of total dissolved solids found in the leachate. Normally, the maximum range is reached within 15 months. Also, it comprises a high concentration of Na, K, Cl, SO_4, and other inorganic salts, which will steadily deteriorate until the ultimate stability of landfill. Because of the consumption habits of Asians, the potassium, sodium and chlorine content are fairly higher in the Asia landfills; so, it is better to have a pre-treatment prior to the biological treatment. Commonly, a 10-year matured leachate comprises of 100-400 mg/L of sodium, 50-400 mg/ of potassium and 100-400 mg/L of chlorine, but in Asia the concentrations are 1500-5640 mg/L, 400-1940 mg/L, and 875-2900 mg/L, respectively.

Microorganisms: Microorganisms like nitrite bacteria, nitrifying bacteria, denitrifying bacteria, desulphobacter, thiobacillus denitrificans, iron bacteria, sulphate reducing bacteria, methanogenic bacteria, pathogenic bacteria, and pathogenic microorganisms are found in large number in leachate. They play a vital role in the degradation of leachate. Moreover, the high concentrations of ammonia nitrogen and heavy metal creates an unevenness of microbial nutrients, which hinders the growth and regeneration of microbes. The common bacteria in the leachate are *Corynebacterium*, *streptococcus*, Achromobacter, granular bacteria, aerobic bacteria, *Clostridium* etc.

Solid waste disposal and leachate formation

Landfill of solid waste may cause serious ecological effects if the emission of gases and leachate are not administered. A clear-cut understanding of the amounts and physical characteristics of the waste being produced is a crucial element in the growth of tough and cost-efficient solid waste management approaches. Even Though complete or reliable evidence is absent, at the country level, a few broad trends and widespread features are noticeable. In general, the developed countries produce much greater amounts of garbage per capita related to the developing countries (Hwang, 2007). However, in some situations, the management of even minor amounts of waste is a considerable task. Many countries have categorized waste into two categories, i.e. hazardous and non-hazardous. But generally, the solid waste is divided into municipal solid waste, industrial waste, agricultural waste, and hazardous waste (Figure 1). The types of waste are given below:

***Municipal solid waste (MSW)*:** The terminology municipal solid waste (MSW) is usually used to define most of the non-hazardous solid waste from an urban area or village that needs routine gathering and transportation to a processing and dumping site (Kumar *et al.*, 2016). The MSW is collected from households, business-related organizations, and institutions, as well as industries. Though, MSW does not comprise waste from industrial practices, sewage sludge building, and demolition debris, mining, or agronomic wastes. It is also described as trash or garbage.

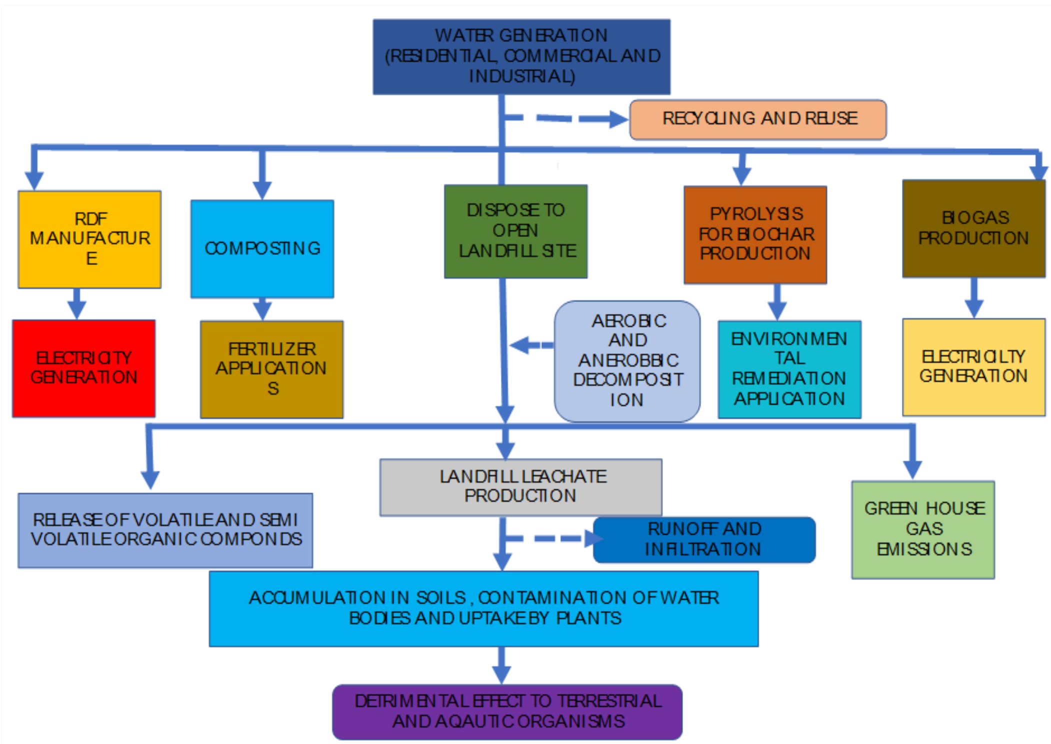

Figure 1. Flow-diagram showing the formation of leachate from different wastes.

Commonly domestic waste and MSW are treated as substitutes (Cheng and Hu, 2010). Municipal solid waste comprises a large variety of items. It may include food waste like vegetable and meat leftover, unused food, eggshells, etc, which is categorized as wet waste as well as paper, newspaper, glass bottles, plastic bags, plastic canisters, packaging boxes, aluminium foil, wood pieces, etc., are classified as dry garbage (Joardar, 2000; Singh *et al.*, 2011). The population of the urban area in India is expected to increase from the existing 350 million to about 600 million by 2030. The challenge of controlling municipal solid waste (MSW) in an ecologically and efficiently viable approach is destined to accept gigantic proportions. State-wise and union territory generation, collection, and treatment data by CPCB of 2016 are given in Table.

As the towns and cities are growing in size with an increase in the population, the quantity of waste generated is also becoming uncontrollable. The local corporations have adapted diverse approaches for the waste disposal like open dumps, sanitary landfills, landfills, incineration plants and composting.

***Agricultural wastes*:** The waste produced by farming comprises waste from crops and cattle. In developing countries, this type of waste does not create severe trouble as most of it can be utilized e.g., dung is used for compost, hay is used as feed. Agrarian wastes are rice husk, degasses, nutshells, straw of cereals, maize cobs, etc. (Agamuthu, 2009). Agriculture waste can be categorized into field waste and process waste. Field wastes are remains that are left in the field after the crop harvesting. These residues are seed pods, stalks, leaves, and stems. The process wastes are leftover found in the field even after the crop is transformed into a valuable product. Example molasses, bagasse, husks, seeds, stem, straw, stalk, leaves, shell, pulp, peel, stubble, roots, etc. and used for animal feed, fertilizers, soil improvement, manufacturing, and various other processes (Jecu, 2000). India produces about 350 million tonnes of agrarian waste each year. In 2015 the ministry of renewable energy estimated the 18,000 MW of power can be generated from this waste apart from the organic manure for the field. Composting is also one of the best choices for disposal of agriculture waste as it become nutrient rich fertilizer. Other waste disposal methods are land filling, piling, burning, dumping etc. Some of these methods help in recycling and recovery of the nutrients but some process cause pollution of environment and resources (Kumar *et al*., 2020a).

***Bio-medical wastes*:** Bio-medical waste implies any waste, produced through the diagnosis, medication, or vaccination of individuals or animals. It also includes the animals involved in research events concerning there to or in the manufacture or testing of medications (Ezirim *et al.*, 2018). According to study Associated Chambers of Commerce and Industry of India (ASSOCHAM) and Velocity, India is expected to produce nearly 775.5 tonnes per day of medical waste by 2022 from the existing amount of 550.9 tonnes daily. But the COVID 19 pandemic has increased this burden to an unexpected level. Earlier 500 grams of medical waste was produced per bed but during COVID this went up to 2.5 to 4 kg daily. Also, a COVID hospital produces approx. 1800- 2200kg medical waste each day which includes gloves, PPE kit, masks, shields etc. According to the government instructions, PPEs like masks and gloves generated are mandatory to stock separately for a minimum 72 hours for discarding along with waste after shredding. Also, the shredded masks and gloves from residential area can be collected as dry waste by Local Bodies Various common methods for treatment and disposal of medical waste are incineration, autoclaves, chemical disinfection, microwave, irradiation and vitrification. The sufficiently sterile waste which is treated can be disposed with other waste in a landfill, or in few cases discharged into the sewer system. Earlier, the waste was treated on the hospital site itself but now new regulations have developed which allow workers to gather, treat, and dispose the waste.

***Industrial wastes*:** Industrial waste is the toxic waste released by food processing businesses, metallurgical chemical and pharmaceutical companies, sugar mills, paper, and pulp industries, fertilizer, and pesticide industries (Skrinde and Bhagat, 1982). These toxins require special handling (Gyawali *et al.,* 2012). India generates about 7.46 million metric tonnes of hazardous waste generated from more than 40,000 industries (ASSOCHAM, 2017). While disposing this type of waste, it must be classified into three categories on the basis of method of waste disposal. Three methods are incineration, land disposal and underground injection.

***Hazardous wastes*:** Hazardous wastes are those which harm the human and the natural environment (Orloff *et al.,* 2003). Wastes are categorized as harmful if they display four primaries characterises like toxicity, reactivity ignitability, and corrosively based on physical or chemical properties (Malviya *et al*., 2006). Hazardous waste is also of five types:

- **Toxic wastes**: Toxic wastes are those that are toxic in minor or trace quantities. A Few may have acute other may have a negligible effect on humans and the environment (Hamilton, 1985). Prolonged exposure in some amount sometimes leads to carcinogenic or mutagenic effects. Examples of pesticides, heavy metals.
- **Reactive wastes**: Reactive wastes tend to alter actively with air or water. They are volatile generally when encounter the heat (Lussiez, 1993). Examples: Gun powder, nitroglycerine.
- **Ignitable wastes**: Ignitable waste is those that burn up at reasonably low temperatures (< 60 °C) and are capable of spontaneous ignition during storage, transportation, or dumping. Examples: Gasoline, paint thinners, and alcohol (Schoenberger *et al*., 1984).
- **Corrosive wastes:** Corrosive wastes are those that damage objects by chemical reactions. Examples: acids and base (Lee *et al*., 2007).
- **Infectious wastes**: Infectious wastes are the human tissue from a surgical procedure, utilized bandages, needles, and other hospital wastes (Sawhill *et al*., 1995). Generation of leachate is a chief concern for municipal solid waste (MSW) landfills and causes substantial risk to surface and groundwater. The leachate produced in the landfill consists of large quantities of organic and in organic pollutants (Kettunen and Rintala, 1998). Even though this type of waste was thrown in

landfills in olden times, which caused the adjacent atmosphere to be polluted with hazardous substances. Presently, only few hazardous wastes can be dumped into landfills, but only if they are first solidified and stabilized. Numerous harmful wastes can be recycled, batteries, circuit boards, fluorescent tubes, mobile phones, etc. Other approaches of hazardous waste disposal include incineration also known as waste-to-energy, second is pyrolysis, and third is isolated landfills used explicitly for harmful waste (Table 1).

Table 1. Statistics of solid waste generation and collection in India (CPCB, 2016).

State/Union Territory*	Generated (tons per day)	Collected (tons per day)
Andaman and Nicobar*	70	70
Andhra Pradesh	4760	4287
Arunachal Pradesh	116	70.5
Assam	650	650
Bihar	1670	-
Chandigarh*	370	360
Chhattisgarh	1896	1704
Daman Diu and Dadra*	85	85
Delhi*	8370	8300
Goa	450	400
Gujarat	9988	9882
Haryana	3103	3103
Himachal Pradesh	276	207
Jammu and Kashmir*	1792	1322
Jharkhand	3570	3570
Karnataka	8697	7288
Kerala	1339	655
Lakshadweep*	21	-
Madhya Pradesh	6678	4351
Maharashtra	22,570	22,570
Manipur	176	125
Meghalaya	208	175
Mizoram	552	276
Nagaland	344	193
Orissa	2374	2167
Puducherry*	495	485
Punjab	4105	3853
Rajasthan	5037	2491
Sikkim	49	49
Tamil Nadu	14500	14234
Tripura	415	368
Telangana	6740	6369
Uttar Pradesh	19180	19180
Uttarakhand	918	918
West Bengal	9500	8075
Total	**1.41,064**	**1,27,832.5**

Leachate is an outcome of precipitation or the moisture present in the landfill with the waste. It also has a high concentration of metals and few harmful organic substances. The elimination of these organic solids on the basis of COD, BOD and ammonium from leachate is the common requirement before discharging the leachates into waters (Kettunen *et al.*, 2009). The configuration of leachate from the dumping ground may differ depending on numerous features in the waste such as degree of compaction, like composition, climate and moisture content. When water penetrates through the litter, it helps and supports the procedure of disintegration of waste by bacteria and fungi. These procedures in turn release by-products and quickly utilize available oxygen, forming oxygen free atmosphere. In actively decaying waste, the temperature increases and the pH reduces quickly with the outcome that several metallic ions that are fairly insoluble at neutral pH become dissolved in the formation of leachate. The processes of decomposition discharge more water, which enhances the volume of leachate. Leachate also responds to the materials that are not susceptible to decay themselves, such as building supplies, gypsum-based materials and ash which change the chemical composition. In places where we can find huge amount of construction waste, specifically those gypsum, the reaction of leachate can produce huge volumes of hydrogen sulphide. This hydrogen sulphide may be released in the leachate and also become a big part of the landfill gas. The appearance of leachate is black, yellow or orange coloured gloomy liquid with strong odour when emerge from a typical landfill site. Due to the hydrogen, nitrogen and sulphur-rich organic species the smell is acidic and offensive (Mor *et al*., 2006).

In a landfill that collects a variety of commercial, municipal, and industrial waste but eliminates substantial volumes of concentrated chemical waste, landfill leachate may be considered as a water-based solution of four groups of contaminants: dissolved organic matter such as alcohols, acids, aldehydes, short chain sugars etc.; inorganic macro components like common cations and anions including sulphate, chloride, iron, aluminium, zinc and ammonia; heavy metals example Pb, Ni, Cu, Hg; and xenobiotic organic compounds such as PCBs, dioxins etc. (Kjeldsen, 2002). A large amount of multifaceted organic pollutants have also been found in landfill leachates.

Impacts of leachate and solid wastes on the environment

Municipal solid wastes pile up on the streets due to inadequate disposal system. People clean their own homes and litter their environments which alters the vicinity including themselves. This type of dumping permits biodegradable items to decay under unrestrained and unsanitary circumstances (El-Fadel *et al.*, 1997). This produces obscene odour and breeds a variety of insects and infectious creatures besides ruining the aesthetics of the place. Industrialized solid wastes are sources of toxic metals and hazardous wastes, which may spread on land and can initiate variations in physicochemical and biological traits thus altering the efficiency of soils. Toxic materials may percolate to pollute the ground water (Havlicek *et al*., 1971). In refuse mixing, the hazardous wastes are combined with trash and other inflammable wastes. This makes separation and discarding complicated and dangerous.

Environmental standards are met by few landfills in the world. The decomposing garbage release methane gas which is a chief environmental concern these days. Methane is the by-product of the anaerobic respiration of bacteria, and these microbes flourish in landfills with high quantities of moisture. At high anaerobic decomposition, the methane concentration can reach up to 50% of landfill gas. Additional problem linked with these gases is their contribution to the greenhouse gas effect and climate change. There is a difference in the leachate management in the landfills of the developing countries, a thick sand deposit is used at the bottommost of waste pits, fixed with plastic sheet liners to circumvent penetration of liquid into the adjacent soil. Therefore, instead of infiltration evaporation is encouraged. The group of people at risk because of the unscientific dumping of the solid waste are the pre-school kids; labours working in dumping location; and employees in services manufacturing poisonous and infectious material. Other risky zone includes inhabitants living nearby a dumping site and those who consume the water which gets contaminated due to dumping of waste from landfill sites. The uncollected solid waste also increases the risk of diseases, and infections.

Organic waste specifically poses a serious threat, producing circumstances favourable to the existence and development of microbial pathogens. The handling of solid waste directly can result in numerous chronic diseases and types of infectious in which rag pickers and waste workers are most vulnerable. Serious danger on well-being is caused by waste from agriculture and industries. Discarding of harmful waste of industries with community waste can expose public to chemical and radioactive hazards. The solid waste which is not collected sometimes hinder runoff water, resultant in the establishing of still water bodies that become the breeding ground of disease. Waste discarded near a river also contaminate the water source. Dumping of untreated waste directly into the seas, rivers, and lakes results in the gathering of toxic matters in the food web through the plants and animals. Dumping of hospital waste requires special care since this can produce major health hazards. This waste generated from the hospitals, and other health centres like syringe needles, bandages, cotton, plaster, and other types of infectious waste are often disposed with the regular non-infectious waste (Alam and Ahmade, 2013). The sites where wastes are disposed and treated cause health risks for the surroundings. The incineration plants are not properly run also cause air pollution and inappropriately managed and planned landfills attract all kinds of bugs and rodents that spread disease (Hester and Harrison, 2002). Preferably these sites should be situated at a harmless distance from all anthropological settlement. They should be lined so that it should not seep underground. There is a health risk in recycling as well if suitable safeguards are not followed. Employees may face toxic exposure working with waste comprising chemical and metals (Reinhart and Basel, 1996). Removal of health-care wastes need special care since it can create major health hazards, such as Hepatitis B and C, through discarded needles. Rag pickers and others who are involved in searching recyclable material from waste, may get wounds and come into direct contact with these infectious items.

Techniques of resource recovery from the solid waste and leachate treatment

The world is facing the rising rates of petroleum and its products, scarcity of electrical energy supply, degradation of the environment, and accessibility of millions of tons of biomass. The Research and Development events in the field of bioenergy including bioethanol, bio methanation, biodiesel, biomass gasification, biomass cookstove, etc. is receiving a lot of attention and consideration throughout the world (Fassell, 1977). The Government of India has started the combination of 5% ethanol in the gasoline, thinking about the increasing fuel demand. It is also expected by the Jatropha Mission at least 10% of the liquid fuel that can be used in the transportation sector can be replaced. Likewise, the Ministry of New and Renewable Energy (MNRE) has introduced the distribution of advanced biomass cookstoves in the 12th five-year plan out of carbon expenditure. The evolution of renewable energy usually promotes energy divergence, in terms of the technology portfolio and geographic sources. It can also diminish fuel imports and shield our economy to from fossil fuel price fluctuation (Figure 2).

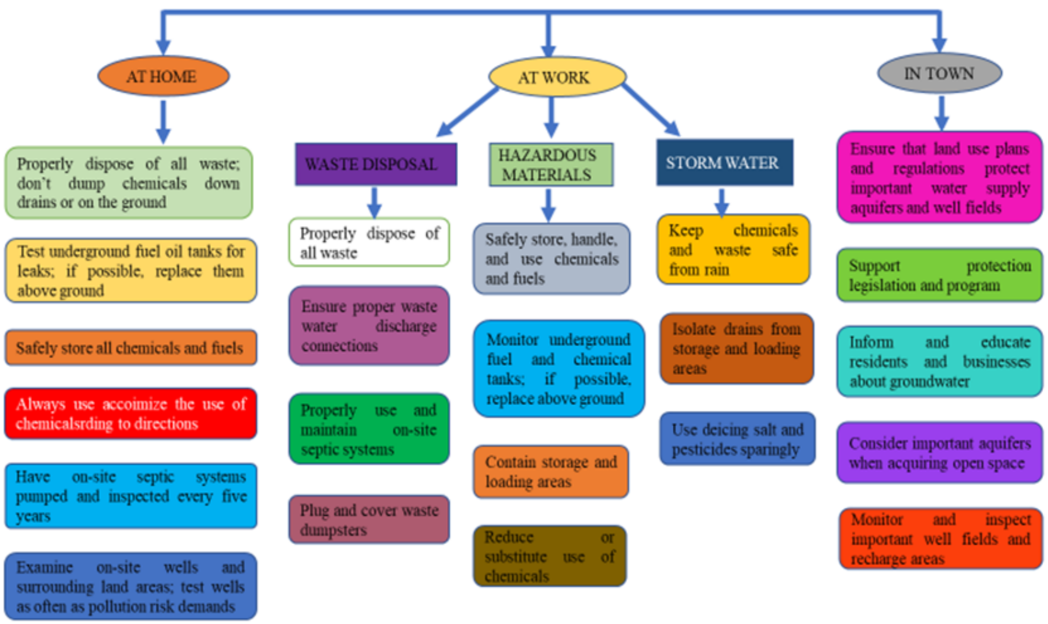

Figure 2. Mitigation measures of ground water pollution caused by leachate disposal.

The processes of transforming garbage into energy is an evolving and inventive development of technologies designed to generate a safer and sustainable environment. The emerging technique to form energy from waste is a safer technique to protect our Environment. It is believed to resolve the energy crisis of the globe. Although the level of energy production using waste to energy approach is still insignificant right now, it can be a great solution for the energy needs in the future (Lens *et al.*, 2004). In this chapter, we will deal with the common techniques used for energy generation. The process is commonly divided into two categories i.e. Thermal Technologies and Non-Thermal Technologies .

Thermal technologies

Gasification**:** Single most prevalent thermal technologies, gasification can simply transform low-value feedstocks into high-value commodities. In this method, carbonaceous materials are transformed into carbon dioxide, carbon mono oxide, and a little quantity of hydrogen at an elevated temperature in the presence of oxygen. Synthesis gas is produced in the process which is a great type of alternative energy. This gas is utilized to generate electricity and heat (Figure 2). The green energy source is given for fertilizers, fuels, baseload electricity, and chemicals through this technology. This will lower the country's reliance on natural gas and oil. The fuel produced by this process can be carried and collected effortlessly. Gasification technology is even now being employed by the energy, refining, chemicals, and fertilizers industries. Some industries like Royal Dutch Shell, Siemens Energy, etc have made an enormous investment in this technology.

Depolymerization**:** One of the best ways to deal with plastic waste is depolymerization technology. In this technique, the waste is converted into liquid energy like fuel oil. One key benefit of depolymerization is that it converts all heavy metals found in the garbage into stable oxides. The depolymerization technology employs thermal decomposition in the presence of water. Here, the organic complexes present in the waste are heated at a high degree temperature to generate thermal energy. We can make fossil fuels from the waste using this technique (Adams *et al.*, 2010). The method of thermal decomposition is also termed as Hydrous Pyrolysis**.**

Pyrolysis**:** Pyrolysis is a thermal process that decomposes organic matter with no use of oxygen. Products like coal, cardboard, paper, plastic, rubber, human waste, and are used in this procedure. Like gasification, pyrolysis facilitates in lowering the amount number of carbon emissions. This processed product like char that carry to the carbon of biomass which therefore makes it appropriate for enhancing soil efficiency (Chen, 2014). Most Recently this technique has also been utilized to produce bio-oil from biomass. This is also very useful in treating drained sludges. The heat produced in this process is divided into three kinds, based on its utilization. First is the heat which can be used for moisture vaporization, second denotes the calorific necessity of pyrolysis, whereas third is the energy loss throughout the process (Weng *et al.*, 2013, Boukis *et al.*, 2007). The greatest benefit of pyrolysis over incineration very less impact on the environment in terms of air pollution. Even Though, preliminary expense and procedure price is high which is making this method challenging to appear commercially.

Non-thermal technologies

Fermentation and anaerobic digestion are the two non-thermal technologies which that are widely used to reduce the greenhouse effect. These are regarded as the finest substitutes for fossil fuels. Developing countries are using non-thermal technologies to make low energy solutions (Figure 3-5).

Fermentation**:** The procedure that uses yeast and natural microorganisms to manufacture ethanol, involving a series of chemical reactions like hydrolysis, distillation, etc. is known as fermentation. With the ever-increasing population and consumerism, managing waste has come to be an essential part of sustainable development. Thus, transforming garbage into energy is a blessing that can not only improve the standard of living but also help maintain the environmental balance that is very critical. The product which we get at the end of the process is ethanol, it can be combined with gasoline and utilized in motor vehicles (Hay *et al*., 2013).

Anaerobic digestion**:** The process of anaerobic digestion can either one take place in nature or in a digester. The digester is heated airtight and airless vessel, which encourages microbes (bacteria) to ferment litter consisting of organic waste like animal waste and slurries to generate biogas (Kumar *et al*., 2020b). It is the method that produces biogas when the garbage is left untouched (Figure 3).

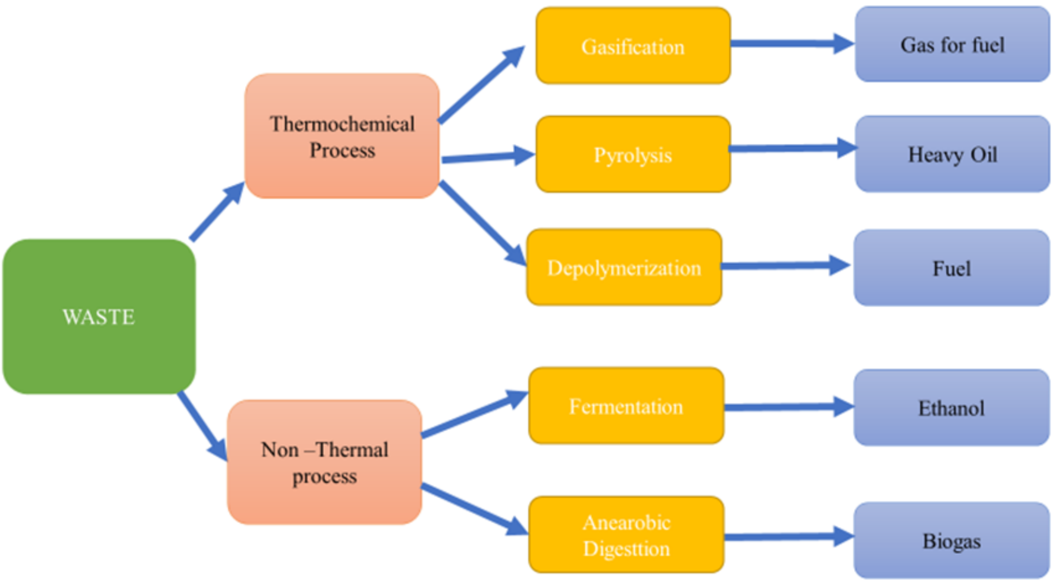

Figure 3. Various processes of energy generation from solid waste and leachate.

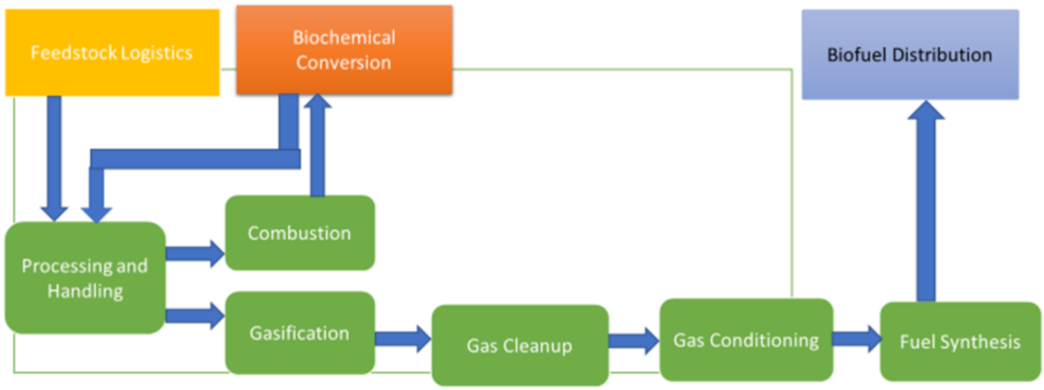

Figure 4. Processes of gasification of solid waste.

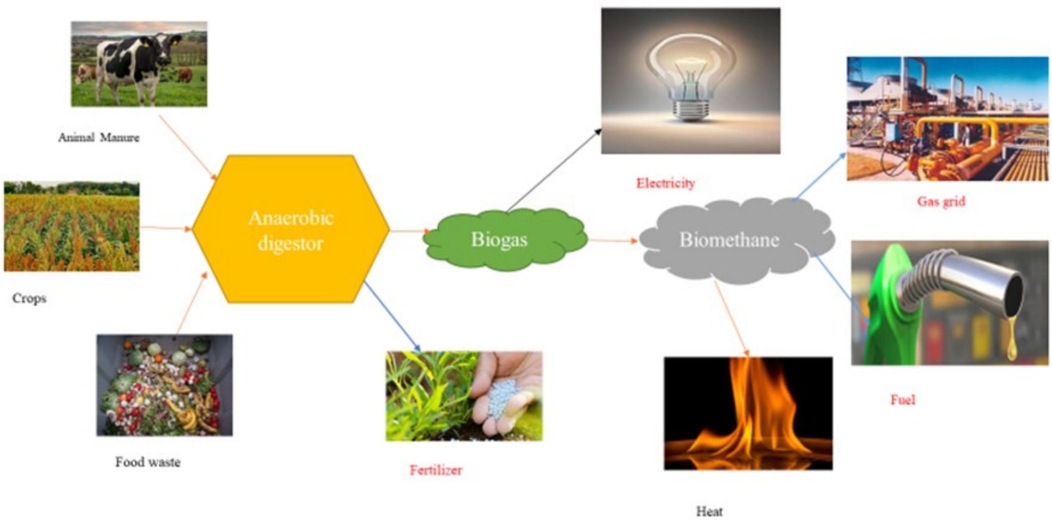

Figure 5. Processes of bioenergy generation from solid waste.

The major problem with this method is that it utilizes liquid trash as well, which does not apply to all the above techniques. It is generally used in small-scale chores as the production depends on the size of the digester or landfill. The biogas provides a clean fuel in the kitchen, and automobile. 50-85% volume of the waste can be reduced by this process. In many cosmopolitan towns, automatic units have been installed, whereas physically controlled units are established in fairly minor urban places (Bhide and Shekdar, 1998; Kumar *et al*., 2009). In Bangalore, Baroda, Mumbai, Calcutta, Delhi, Jaipur, Kanpur and Indore, large scale unit were established having the capacity of 150 to 300 tonne/day in 1975- 1980. Later they were closed because of low and minimal use. Subsequently that a large-scale unit was established in Mumbai in 1992 having has a capacity of 500 t/day followed by Vijaywada, Bhopal, Delhi, Hyderabad, Bangalore, Ahmedabad, Lucknow, and Gwalior of India (Sharholy *et al*., 2008; Rao and Shantaram, 1993; Kansal *et al*., 1998; Reddy and Galab, 1998; Gupta *et al*., 1998; Srivastava *et al*., 2005).

Other methods

***Plasma arc gasification*:** The process uses a plasma torch. Initially in this process, waste is compressed then the plasma torch is utilized to ionize the gas. The product gives Syngas or Synthesis gas which is used to produce electricity (Ojha *et al*., 2012)

***Incineration*:** It is the most popular process. It is performed by combusting organic garbage. The heat is generated in the process which is used to convert water into steam which is tapped to power turbine to produce electricity (Lee and Huffman, 1989). This plant produces lots of emission of gases like nitrogen oxide, sulphur sulfur dioxide, dioxins, and heavy metals which is a great disadvantage to it. this is one of the reasons for making this technique unpopular these days. Some left-over product from this process is also harmful and need to be handled with care. The drawback of this method is that some harmful compounds like sulphur, nitrogen, and halogens deteriorating air quality are released. Generally scrubbing and filtering are performed to dilute the concentrations to an acceptable level before releasing into the environment (Misra and Pandey, 2005).

***Bio-electrochemical systems*:** Leachate of the landfill also known as landfill leachate has lately been examined as a substratum for bio electrochemical systems (BES) for power generation. The biological complexes in leachate can be directly transformed to electric energy through microbial interface. The recovery of nutrient like ammonia can be done through electricity generation which is driven by ammonium migration and the conversion of ammonium to ammonia in a high-pH which is a result of cathode reduction reaction. Metals in leachate may also be retrieved, but the retrieval is affected by their concentrations and values (Iskander *et al*., 2016).

Landfill leachate treatment by microalgae

Solid waste has been expected to grow globally. Right now, the common method is to dump off waste is landfill (Lin *et al*., 2007). Though, over a significant time leachate is produced which pose serious issue. With growing emphasis on sustainability, there has been a demand for emerging eco-friendly, green treatment schemes for leachates with resource recovery. Microalgae-based methods can be a possible method for such a treatment. The application of algae to eliminate impurities from waste water or leachate is named as phytoremediation (Bordoloi *et al*., 2020). The study is conducted by many scientists. A relative study was done at three scales i.e. small scale of 0.25 L, medium of 100 L, and large of 1000 L. The bacterial-algal was taken from the pond of fish. The small-scale test was directed in flasks as lot experiments, the medium as well as large-scale experiments were carried out as semi-batch procedures inside a greenhouse in an unrestrained setting with working capacity 60% of their total volume. Kolmogorov–Smirnov statistical tests were functional to the experimental data to regulate if the ammonia elimination, total nitrogen exclusion, and biomass development rate at each scale were diverse (Hernández, 2019). The study demonstrated that there is a substantial change between all rate determined at the large-scale reactors in comparison to that of small-scale reactors. The treatment of leachate with algae require a huge land with appropriate light infiltration and CO_2 absorption into the pond. The leachates are often dark brown to grey in colour. The colour affects light penetration undesirably and thus challenges progress of algae. So, it is suggested to use a shallow pond with microalgae. Algae have remained as a 3rd generation biofuel for sometimes now.

Treatment of landfill leachate using reverse osmosis

The treatment of landfill leachate using reverse osmosis has gained attention in the recent years and many plants have been installed in countries like Germany, the Netherlands and Switzerland. In this system, the landfill leachate can be divided into old and new. They both are further divided into different categories. The new one is toppled in the cell of waste having separate system of collection. A linear correlation is seen among flux and conductivity from the old landfill and from the decomposable waste cell for leachate, where flux varies depending on the conductivity of the leachate. The decrease of contaminants, COD, salt concentration, osmotic pressure comes high. NH_4-N is also seen in over 98 % for leachate from both old landfill and the biodegradable waste (Chianese *et al.*, 1999; Hasar *et al.*, 2009).

***Advantages of resource recovery*:** Resource recovery helps to preserve the non-renewable reserve which are is reducing at a reckless pace. It is not only a left-over disposing technique, but also supports to handle the garbage. It purposes as substitute to the valuable natural resource and uses the ability that remains in refuse. Two-thirds of carbon dioxide neutral fuel can be used from the left-over. Transformation of waste is a method that is a choice to use oil and other types of energy. A major part of the household waste can be used to generate energy for daily use. It is tactic that can back us to decrease our role in global warming. By harnessing this clean energy, we will reduce our dependence on diminishing fossil fuels.

***Disadvantage of resource recovery*:** The process is proposed for conversion but is constrained to merely specific sorts of waste. Thus, with more upgrading in technologies, transformation methods can be prolonged to use all kinds of waste leaving the toxic ones.

Strategic measures for mitigating the groundwater pollution

Contamination of groundwater can last for ages but is difficult and expensive to clean. The key is the prevention of pollution. The mitigation measures should be divided into three parts i.e. to be followed at home, at work and in town. At home, basic measures like using less chemicals in forms of detergent, shampoo, car cleaner and disposing them properly, also safe storage is important, septic tanks cleaning etc. At work the mitigation measures are carried in three steps. First for hazardous material, second storm water and third is method of waste disposal (discussed in flowchart in detail). And in town it is the duty of all the people living to ensure proper water supplies, also support legislations for protection etc. The common measures which can be followed by everyone are discussed in flowchart.

Conclusion

Leachate generation is a chief problem of municipal solid waste (MSW) is generation of leachate in landfills. It causes substantial danger to surface water and groundwater. Leachate are formed when water passes through the landfill. Solid waste, biomass residues and leachate are transformed into fuels and bioelectricity, using Thermal Technologies, Non-Thermal Technologies for waste and reverse osmosis, phytoremediation and BES for leachate. The preference of method depends on the product required and the feedstocks. Conventionally, thermochemical technology which utilizes thermal heat may possibly not be susceptible to the biomass waste composition when linked to the biochemical approaches for the manufacture of biofuels. However, the manufacture of biofuels from biomass litter is even believed to be more robust in raw material processing, transport, and transformation skill, when compared to traditional food crops-based biofuels. The process of treatment of leachate are chosen to reduce the contaminants around the landfill and nearby water bodies. A proper understanding of the features of the leachate is expected to be used to select suitable management and economical technique. The effect of leachate on groundwater quality as well as on living being is adverse. The solid waste and leachate both pose threat to environment especially water bodies. As the population is increasing solid waste is also increasing but the water is decreasing. If the landfill site is near the water body, it will affect the water resources. Therefore, it is very important to find an eco-friendly treatment for the waste and leachate treatment which do not affect the environment and the end product can be used as well.

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Chapter [6]

Recent advances in novel remediation processes towards heavy metals removal from wastewaters

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Abstract

Increasing demand and overexploitation of natural resources leads to their quality degradation. Water is such a natural resource whose mismanagement causes loss of its natural integrity and therefore, it faces serious pollution concerns. Apart from hydrosphere, different environmental compartments severely facing the challenge of environmental degradation. Heavy metals are natural but anthropic factors release them in the environment including water system which is highly prone to their toxic effects. Due to the direct toxic impact of heavy metals on water sources, special focus is required to check their presence. The methods developed in the past for their remediation purpose were not so efficient and have concerns about toxic byproducts generation. Therefore, to fight with the persisting challenge, cost-effective, highly efficient, and eco-friendly remedial processes and technological advancements have been developed in the recent past and present scenarios. This chapter summarizes the recent advances in novel remediation processes toward heavy metal removal from wastewater. A case study of Rāmgangā aquifer was also discussed.

Keywords Environment, Heavy metals, Metal ions, Remediation, Wastewater

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Heavy metals definition: *"Heavy metals are natural elements characterized by their high atomic mass and relatively high density compared to water".*

Introduction

Water is a unique gift by Mother Nature to all living beings for their survival (Kumar and Joshiba, 2019). It is used as an imperative resource by human beings for drinking, agriculture, industries, hydro-energy, and various other important life-sustaining and recreational activities (Sanghavi and Balaji, 2013). Unfortunately, humans harness the water resources in an unsustainable way and degraded its natural quality by its human-induced activities such as unsustainable industrial growth, unplanned infrastructure development, deforestation, discharge of contaminated effluent in water bodies and agricultural runoff containing synthetic pesticides and fertilizers (Dhiman, 2020a; Iyer and Giri, 2020; Meybeck and Chapman, 2006; Pinto and Oliveira, 2020). Previously, USEPA (2012) report confirms the higher release of pollutants in the water bodies in recent decades which certainly going to affect the under-developed nations in the coming years (Adejumoke *et al*., 2018; Sikder *et al*., 2013). This unsustainable approach of rapid growth and industrialization has resulted in the release of heavy metals in the different environmental spheres of the ecosystem, thus disturbs their normal functioning. The water contamination by heavy metals is one of the major environmental concern nowadays. Naturally, heavy metals are introduced in the water sources through the soil-rock weathering, volcanic eruptions (Bradl, 2005; Buccolieri and Turnone, 2006) while local rock-mineral mining, processing and synthetic agricultural pesticides, etc. are some of the anthropogenic routes of heavy metals transport in the water sources (Quansah and Luginaah, 2014; Kumar *et al*., 2019; Hernández *et al*., 2020).

Huge population burden, technological advancement, agricultural-domestic runoff, and excessive natural resource exploitation are some of the major contributors to environmental pollutants. Also, Industrial effluent discharge and dumping sites along the river banks introduced these water pollutants, therefore, causes serious concern for water pollution. Among the variety of pollutants released, heavy metals constitute a highly toxic and environmentally persistent group (Masindi and Muedi, 2018; Wuana and Okieimen, 2011). These metal pollutants are known for their higher-level molecular density, toxicity, non-biodegradability, and bioaccumulation potential (Khan and Ilahi, 2019). They usually existed in parts per million (ppm) or parts per billion (ppb) concentration ranges in water bodies, still pose a higher level of toxic threat to the resident population (Pugazhenthiran *et al*., 2016). USEPA listed chromium, arsenic, zinc, cadmium, copper, mercury, and nickel as the class B metals which are usually widely spread, non-essential, and highly toxic (Moo-Young, 2019). The description of the broad classification of heavy metals is represented in Figure 1.

According to the World Health Organization (WHO) standards, permissible limits of heavy metals in drinking water is as follows, Mercury- 0.010 mgL^{-1}, Arsenic- 0.010 mgL^{-1}, Lead- 0.010 mgL^{-1}, Zinc- 3.000

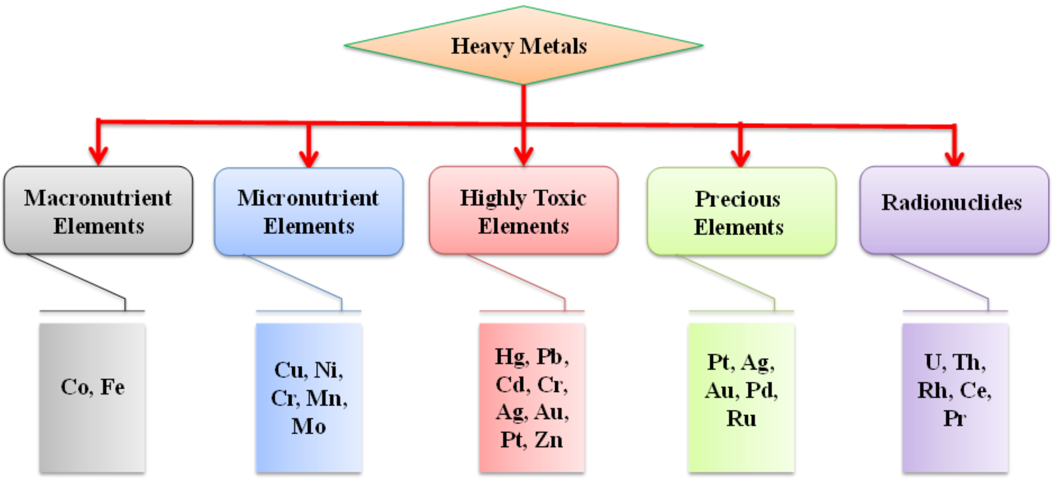

Figure 1. Schematic representation of the broad classification of heavy metals (Koller and Saleh, 2018; Selvi *et al*., 2019).

mgL^{-1}, Cadmium- 0.003 mgL^{-1}, respectively (Duwiejuah *et al*., 2015). Similarly, Comprehensive Environmental Response Compensation and Liability Act of United States of America set its standards for maximum permissible limits of heavy metals in an aqueous medium for chromium, arsenic, cadmium, mercury, lead and, silver to 0.01, 0.01, 0.05, 0.002, 0.015 and, 0.05 mgL^{-1}, respectively (Selvi *et al*., 2019). It is evident from the fact that, on exceeding these permissible limits, heavy metals raises a serious environmental threat in the form of environmental toxicity, development of life-threatening ailments in human beings (e.g. neural disorders, kidney failure, hypertension, low immunity, physical disability, cancers, reproductive disorders, etc.) and other living biotas (Verma, 2020). Some heavy metals are important for various biological functions in humans and animals within a defined concentration range (Fisher and Gupta, 2020). Despite their biological functioning in humans and animal metabolism, their chemical co-ordination and redox reaction chemistry enable them to induce stress by free radical generation in the organism's body which is highly toxic to them (Dhiman, 2020b; Ferdinand *et al*., 2019). Besides, their bioaccumulation potential is also a triggering factor in inducing toxicity. Studies reveal that freshwater animals such as fish, phytoplankton's and, zooplankton's are very prone to heavy metals as they bio-accumulate them in their body tissues (Achary *et al*., 2020). Recently, a study on Ganga water and its fishes explores the realistic situation of heavy metals bioaccumulation. It was found that heavy metal concentration trend in Ganga river water was Zn > Cu > Pb > Cd > Cr in almost all targeted fish species.

Zinc was found to be 0.29 ± 6.45µg/g, Copper- 11.05 ± 2.65µg/g in liver cells, lead- 4.77 ± 0.34µg/g, Cadmium- 2.54 ± 0.33 and chromium- 1.74 ± 0.31 (Maurya *et al.*, 2019). Due to their potential toxicity and environmental hazards, heavy metals must be remediated from the environment and to bring these highly toxic pollutants within the permissible limits set by the international organizations. During the advancement processes of heavy metal remediation from water sources, many physical, chemical, and biological methods were developed. Despite their effective role in heavy metals bioremediation, some loopholes like a large amount of reagent requirement, toxic sludge generation, higher cost, lower efficiency, unpredictable metal ion removal, etc. were observed. Research is continuously going in the direction to develop more effective and novel remedial processes toward heavy metal removal from contaminated water. Therefore, we, here in this chapter have focused to explore and discuss recent advances in the processes implied for heavy metals remediation from contaminated water. To the best of our knowledge, this is the first of its kind of chapter that summarizes recent and latest advancements in the field of heavy metals remediation.

Heavy metals inception

Different studies have documented different sources of heavy metal inception. However, there are two broad categories existed: i) Natural sources and, ii) Anthropogenic sources. Through the Natural and anthropogenic activities, heavy metals released in different environmental compartments such as soil, water, and air where they make negative interactions within the living biota and interfere with their normal behavior. Different sources have been represented in Figure 2.

Figure 2. Diagram showing various heavy metal sources (Alloway, 2013).

Natural inception

Volcanic eruption: The volcanic eruption is known to contain elevated concentrations of titanium, manganese, copper, and zinc. The eruption is also having a substantial amount of metal halides that became soluble and dissolved when entered in the hydrosphere. These metal halides release heavy metals in the water systems and contaminate them, therefore, induce a serious level of metal toxicity (Ma *et al*., 2019; Ragnarsdottir, 1994).

Rock-Sediments weathering: Studies confirm the rocks and sediments as one of the important natural sources and sink of heavy metals. In due course, rock-sediments weathering takes place under the influence of several physicochemical factors (e.g. hydrodynamics, temperature variations, amount of organic matter present, microbial interactions, reduction-oxidation chemistry, ionic behavior, salinity, particle size and, pH of medium) and promotes heavy metals leaching in the water system (Ali *et al*., 2019; Bradl, 2005; Masindi and Muedi, 2018).

Sea-salt spray: Sea-salt spray contains a significant amount of heavy metals concentration in the sea surf zone. This natural phenomenon involves the fundamental role of air which effectively transfers radionuclides and different air pollutants to the seawater from the land ecosystem. Mackay and Walker in their study observed this inland transfer of different pollutants along the Cumbrian coastline and various other sites of the Irish Sea. It has been found that the heavy metals such as Al, Fe, ^{239}Pu, ^{241}Pu, and Am constitute the major proportion of Sea-salt spray (McKay *et al*., 1994)

Wildfire: The remained ash after a wildfire is known to contain a fraction of heavy metals along with oxides and hydroxides of calcium, magnesium, potassium, silica, and phosphorous which are highly alkaline. Wildfires result in mineralization of organic matter which in-turn induces heavy metals transport to the water and soil, therefore, contribute to environmental contamination. Studies established the fact that the heavy metals concentration varies with the type of species and the part burned (Pereira and Úbeda, 2010).

Anthropogenic inception

Acid-mine drainage: Waste rock material when exposed to acidic water, metal leaching occurs. Acid-mine drainage poses a serious environmental concern as it promotes percolation of acidic water along with nickel, cobalt, zinc, and copper like metals to the groundwater sources and hence degrades its quality (Lei *et al*., 2010).

Raw wastewater and sludge disposal: Different studies conducted across the globe confirm the presence of a residual concentration of organochlorine pesticides and heavy metals like zinc, lead, copper and, nickel, etc. in wastewater and sludge. Household laundry wastewater and untreated effluent from local industries are the main contributors to water pollution that release highly toxic contaminants in the hydrological system and causes water contamination (Jiries *et al*., 2002).

Rock-minerals mining: Studies establish the role of Rock-Minerals Mining at a local and commercial level in causing water bodies pollution by releasing As, Cd, Cr, Cu, Ni, Pb and, Zn like heavy metals in the surrounding water bodies and underground water sources. Therefore, it plays a significant role in the destruction of the fragile water ecosystem (Wei *et al*., 2018).

Metallurgical waste: The metallurgical industry produces diverse kinds of hazardous waste where heavy metals constitute the major proportion. The water extracts of metallurgical slags of copper and zinc itself contain Cd, Cr, Cu, Ni, Pb and, Zn metals in different concentrations ranges from 5.19 to <0.050 mg/dm^3. These metals are well known for their higher leaching potential and therefore pose a significant environmental risk (Mizerna, 2016).

Atmosphere-Soil-Water distribution cycle

The rapid industrial growth and expansion of urban areas increase the rate of heavy metal pollution in the water sources. For example, the river ecosystem is found to be more prone to metal pollution (Sharma *et al*., 2020). These toxic metals undergo different interactions with environmental compartments of soil, air, water, etc. within a distribution cycle and therefore moved and transport from one environmental sphere to another (Kennish, 1996; Masindi and Muedi, 2018). In the case of different heavy metals, mercury, arsenic, and chromium are one of the toxic and known heavy metals which have several industrial and household uses (Jaishankar *et al*., 2014).

Therefore, to explore the interaction and distribution of heavy metals with different environmental spheres, these metals are a suitable example to represent the atmosphere-soil-water distribution cycle.

Mercury

Mercury shares the same periodic group with other metals like zinc and cadmium (Jensen, 2003). It existed as elemental mercury, mercury (I) chloride and, mercury (II) chloride in nature (Park and Zheng, 2012). As for their water solubility, mercury (I) chloride showing low solubility; mercury (II) chloride is readily water-soluble while its elemental form is non-soluble (Park and Zheng, 2012). It undergoes methylation when entered in fresh or seawater. Some bacterial strains of *Pseudomonas* spp. and sulfate triggers the mercury methylation under aerobic conditions (Ma and Wang, 2019). Mercury enters the atmosphere in the form of vapors and volatile toxic form from industrial emissions, fossil fuel burning and, gold mining activities. Upon entering, it starts its dry deposition in the air where it undergoes methylation and demethylation processes.

When rain occurs, it comes to the terrestrial ecosystem with its water droplets and surface runoff during rain paves the entry of mercury in the natural water sources (Figure 3). In waters, it bioaccumulates in fishes and other freshwater species thereby entered in the food chain of the living system (Berlin *et al*., 2015; Siddiqi, 2018).

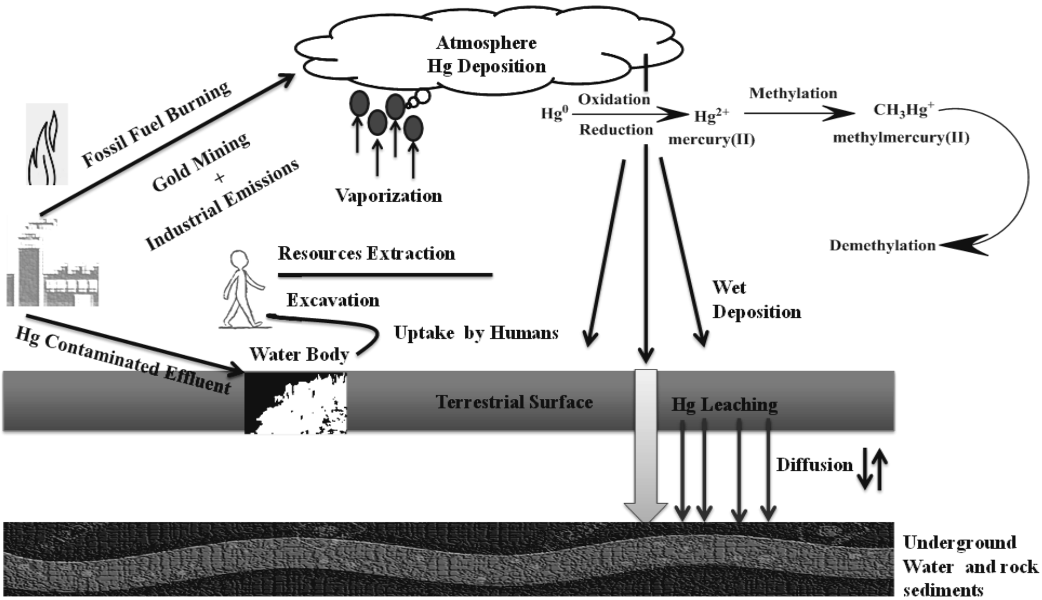

Figure 3. Schematic representation of the Atmosphere-Soil-Water Distribution cycle of mercury (Modified after: Berlin *et al*., 2015; Selin, 2009; Siddiqi, 2018).

Arsenic

Arsenic is one of the most toxic heavy metals that existed in the environment (Jaishankar *et al*., 2014). It is exposed to humans through underground water systems, used for drinking purpose (Shankar *et al*., 2014). Bangladesh and India's state of West Bengal are the two most arsenic affected regions across the world (Chakraborty *et al*., 2015). Arsenic finds its diverse applications in paint industries, pesticides, herbicides, cotton industries as a desiccant, and as wood preservatives (Lim *et al*., 2014). As far as their oxidation states are concerned, it exists as a trivalent and pentavalent form. The trivalent form of arsenic is sixty times more toxic than its pentavalent form (Flora, 2014; Gomez-Caminero *et al*., 2001; Ratnaike, 2003).

Anthropogenic activities like extraction and excavation of minerals release arsenic in the environment where they mix with surface runoff during wet deposition and thereby enter into water systems. It also concentrates on the animal's tissues and causes extreme toxic effects in the exposed animals through transfer and movement across the food chain system (Mandal, 2017). A schematic representation of the Atmosphere-Soil-Water Distribution cycle of arsenic is represented in Figure 4. If we studied the redox chemistry of arsenic, it is a proven fact that these redox reactions decide the chemical speciation of arsenic and its derivatives in a particular environment. The pH level of any environmental medium in particular influences its chemical interactions with environmental components. Also, the bioavailability

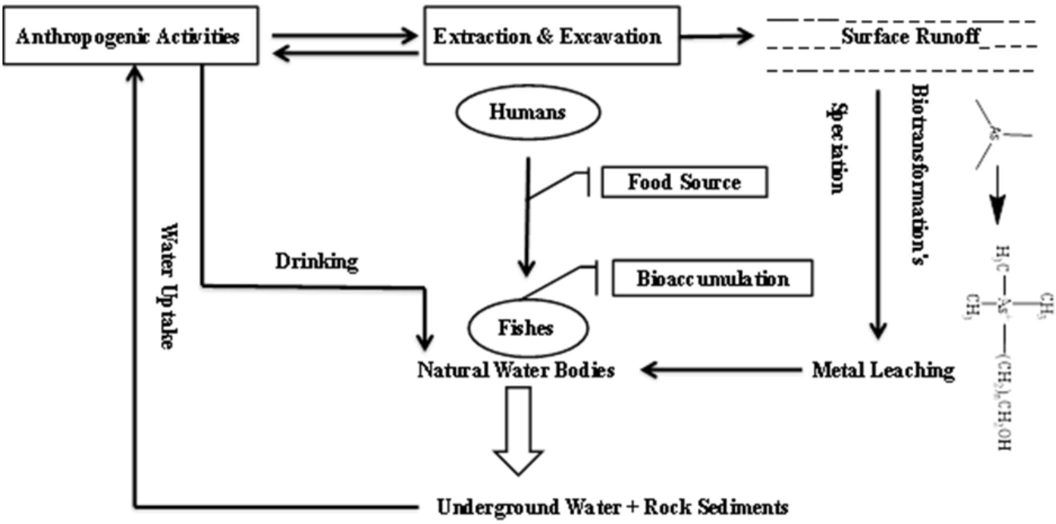

Figure 4. Schematic representation of the Atmosphere-Soil-Water Distribution cycle of arsenic (Modified after: Chatterjee *et al*., 2017; Masuda, 2018).

of arsenic in different environmental spheres depends upon the transformation reactions of pentavalent and trivalent forms of arsenic. Methylation reactions of arsenic are represented in Figure 5. Here, trimethylarsine is transformed into dimethylarsinous acid and trimethylarsino fatty alcohol. The trivalent arsenic bio-transforms with the catalytic actions of arsenic (III) methyltransferase into MNA (Zhu *et al*., 2017).

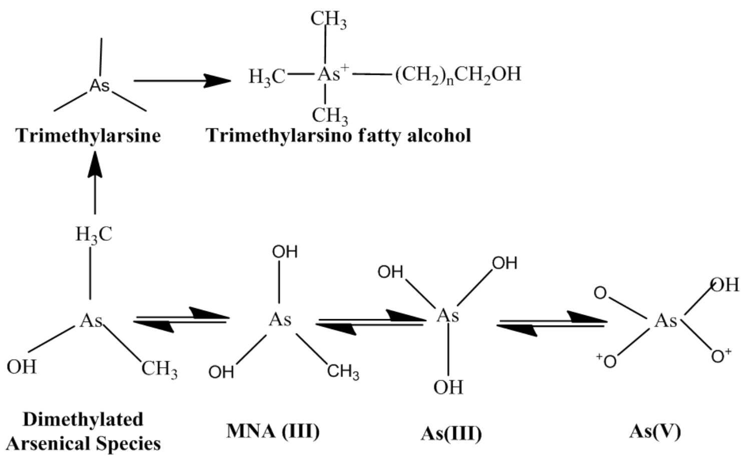

Figure 5. Schematic representation of Redox reactions of arsenic and synthesis of organoarsenicals (Source: Zhu *et al*., 2017).

Chromium

Chromium is considered as one of the most toxic and pervasive environmental pollutant (Oliveira, 2012). Its hexavalent form is categorized as group 1 carcinogen because it has a high capacity to initiate complex stress-inducing reactions in the animal's body and thereby causes cancer in the body (Pohanish, 2017). Chromium also exists in its trivalent form which finds its place in nutritional supplementation (Cefalu and Hu, 2004). Chromium vaporizes from industrial emissions and enters into an atmospheric component of the environment. Also, industrial effluents containing chromium slag are discharged into natural water bodies, thereby, polluting them to a serious extent (Owlad *et al*., 2009). The trivalent and hexavalent form of chromium also mixes in the groundwater resources through leaching and contaminate them (Figure 6) (Das and Mishra, 2008). The trivalent form of chromium is oxidized at higher temperatures. It requires an alkaline medium for its oxidation (Peng *et al*., 2019). The schematic representation of oxidation reactions of chromium (III) ion is given in Figure 7.

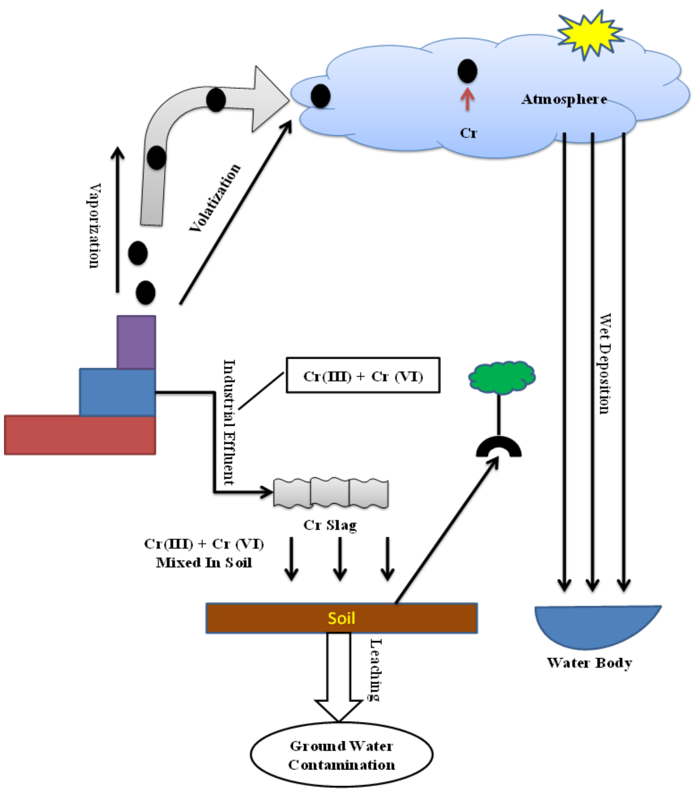

Figure 6. Schematic representation of the Atmosphere-Soil-Water Distribution cycle of Chromium (Sources: Avudainayagam *et al*., 2003; Bartlett, 1991).

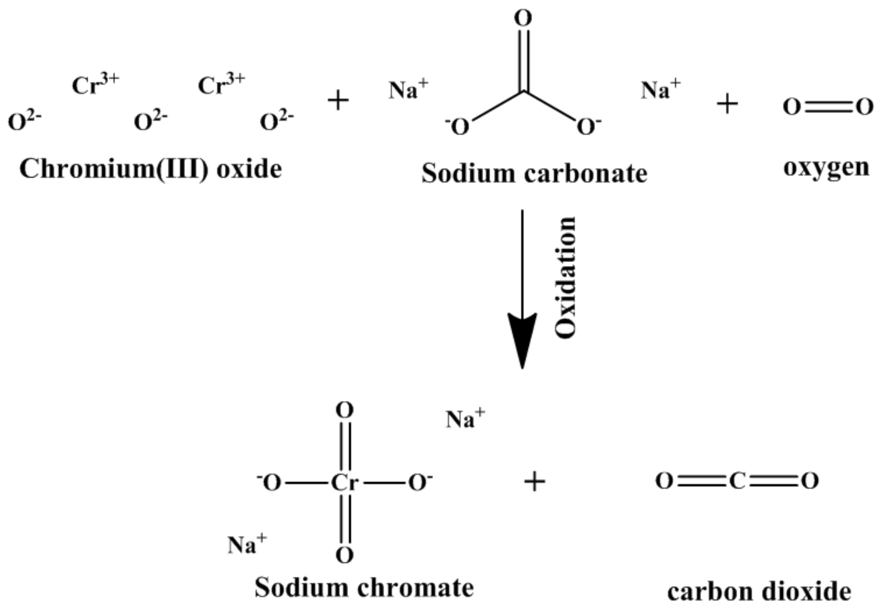

Figure 7. Schematic representation of oxidation of Cr(III) ion (Modified after: Panichev *et al*., 2008).

Heavy metals chelation

Chelation of heavy metals in the environmental spheres depends upon the basics of coordination chemistry. Chelating agents are organic or inorganic in their chemical nature. They attracted to specific heavy metal ions and binds with them to form a complex ring-like structure, termed as "chelate" (Tandon and Khandelwal, 1982). Chelators used for target heavy metals such as palladium, cadmium, copper, mercury, zinc, nickel, etc. (Hong *et al*., 2002). They are known for their high specificity and complexing power with the target heavy metal. These chelators play their important role in heavy metals extraction from water and soil and therefore, help in heavy metals removal (Al-Qahtani, 2017). For example, a well-known metal chelator, EDTA, is widely used as a metal chelator because of its higher level of complexing power (Oviedo and Rodríguez, 2003). But in due course, several metal chelators have been developed (Figure 8) which are strong enough and desirable for specific metal targeting by adding additional cations like Ca^{2+} and Fe^{3+}. They develop metal precipitates with the target heavy metals and therefore, heavy metals can be easily removed.

However, effective heavy metal removal is still a challenge and various new processes and techniques have been developed and some are under the process of development. All these processes and techniques are discussed in detail in the further sections of the chapter.

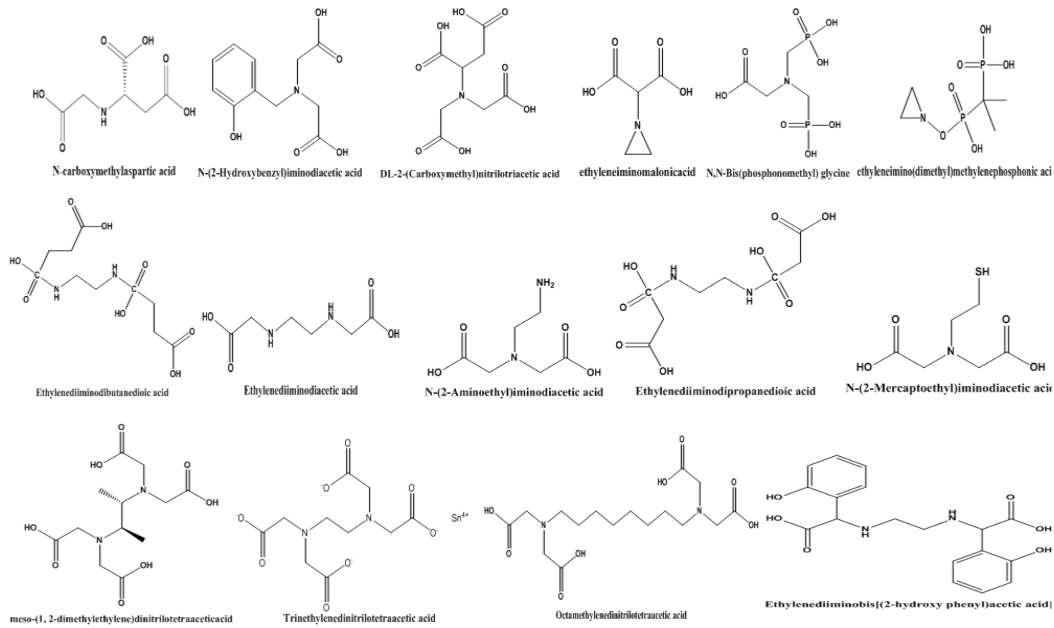

Figure 8. Chemical structures of synthesized metal-chelators (Source: Hong *et al*., 2002).

Case study of Rāmgangā aquifer heavy metal pollution

Groundwater sources are the purest form of water beneath the earth's surface (Abdullahi and Garba, 2015). But heavy metal pollution raises serious environmental concerns toward the purity of groundwater. A recent study has been conducted on Rāmgangā aquifer which shows the drastic condition of water pollution due to heavy metal contamination. The area of Rāmgangā basin is ~4120 square km and is situated in the Indian state of Utter Pradesh, district Bareilly (Tripathi, 2017). The studied area is highly significant concerning industrial developments *viz.* small-scale industries and expanding urban developments. This will raise the demand for water to a higher level which in turn causes water quality degradation due to its overexploitation. The industrial discharge from small scale industries was found to be the major contributor of water pollutants. This will eventually lead to a higher concentration of a variety of heavy metals in the aquifer water and rendered the water source unfit for human use. The study concluded that the rising concentration of zinc and nickel in aquifer water is a prime matter of concern. Also, the trace amount of Ca^{2+}, Mg^{2+}, and HCO_3^{2-} were also found there. With zinc and nickel, equal proportions of other heavy metals were determined in the water samples but the heavy metals concentration varies with the seasonal monsoon changes. The following concentration ranges of Cu- 0.001 to 0.183 (premonsoon) and 0.001 to 0.305 (postmonsoon), Mn- 0.11

(premonsoon) and 0.0166 to 1.308 (postmonsoon), Zn- 0.075 to 0.146 (premonsoon) and 0.156 to 2.245 (postmonsoon), Ni- 0.247 to 0.976 (premonsoon) and 0.294 to 1.246 (postmonsoon), Co- 0.143 to 0.624 (premonsoon) and 0.011 to 0.261 (postmonsoon), Cd- 0.06 to 0.299 (premonsoon) and 0.091 to 0.303 mgL^{-1} (postmonsoon), determined by the researchers. However, the higher Zn and Ni concentrations in aquifer water were related to their use in pesticides and higher solubility in water, and on mixing with agricultural runoff, it enters in the Rāmgangā aquifer water (Mazhar and Ahmad, 2020). This case study indicates the level of water pollution due to heavy metals discharge. Therefore, it the need of the hour to develop relevant and effective remedial processes of heavy metals from contaminated water sources.

Novel remedial advancements in heavy metals removal

Remedial mechanisms for heavy metals removal and their efficient extraction from the contaminated water source or any other environmental sphere is not an easy task. This is because; a huge variety of heavy metals, their metalloids, and related anionic components existed in free as well as in the form of different metal complexes in the environment. There are well known remedial methods such as precipitation (Chen *et al*., 2009), adsorption (Arora, 2019), ion exchange, bio-sorption (Bashir *et al*., 2019), solvent extraction (Černá, 1995), chemical precipitation (AbiD *et al*., 2011), and some membrane technologies (Khulbe and Matsuura, 2018), already existed for handling issues of heavy metals contamination but recent researches focused on the further development of advanced materials and technologies that are proved be highly effective and more efficient than the existing methods. So, to tackle the persisting challenge of heavy metals pollution with special reference to water, scientifically efficient materials, processes, and mechanisms are tested and are developed in recent times. From the latest developments, some of them are discussed below:

Activated graphene nanomaterial

Chemically, graphene is carbon originated nanomaterial with a two-dimensional atomic arrangement. It shows *an* sp^2 hybridization form with a 6-membered ring structure. Recently, researchers synthesized G-ASP2 nanomaterial, a graphene-based adsorbent for heavy metal removal from water sources. This newly synthesized nanomaterial was found to be highly effective in the removal of lead and iron ions from contaminated water. It has been observed that it removes iron ions from the water with 100% efficiency (Atkovska *et al*., 2020).

Ionic liquid clay

Recently, the latest development has been made by researchers in the field of heavy metal bioremediation. A newly modified ionic liquid clay material was developed by using triazole and

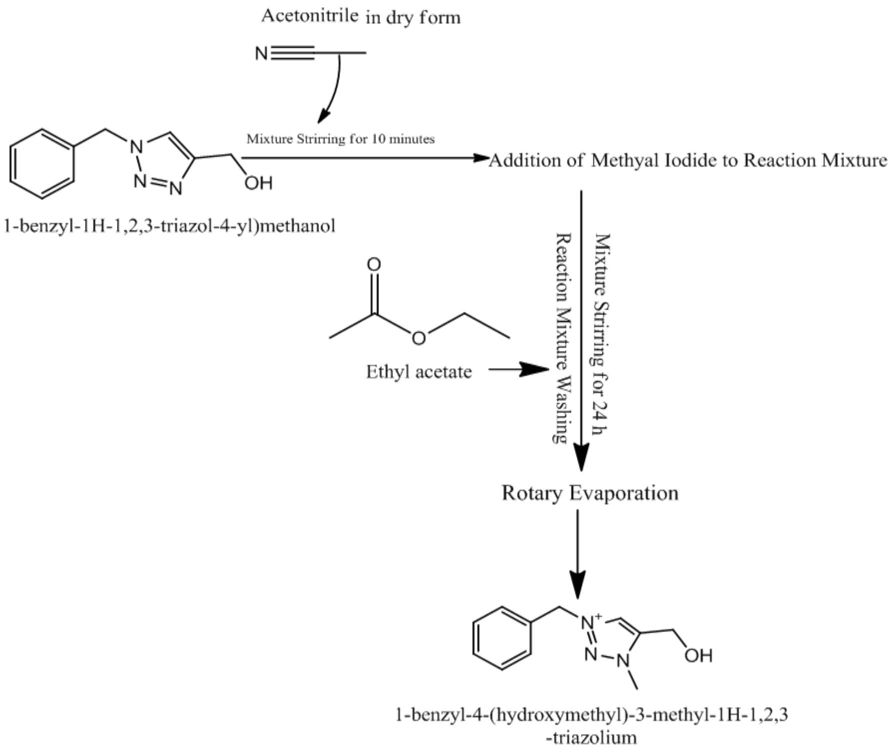

Figure 9. Schematic representation of the synthesis process of ionic liquid clay (Adopted from: Kakaei *et al*., 2019).

triazolium ligands. The newly synthesized material is of high grade and alleviates heavy metals from industrial wastewater in a very efficient way by performing their adsorption. The synthesis process is represented in Figure 9.

Lemon peel-based biomaterials

Developments have been made recently in using green, ecofriendly, non-eatable agricultural parts for heavy metals adsorption from contaminated water. One such low agricultural waste i.e. lemon peel was harnessed from juice producing industries. The basic idea behind using lemon peel was the presence of pectic acid and cellulose in it. It was found that the carboxylic and cellulose functional groups provide significant binding sites for the different heavy metal ions. These functional groups act as binding receptors and therefore bind heavy metal ions of Cu, Cr, Cd, Mn, Pb, and Ni at a specific site. Thereby, providing an alternative and eco-friendly process of heavy metal removal from such contaminated environments (Figure 10) where heavy metal removal is not possible.

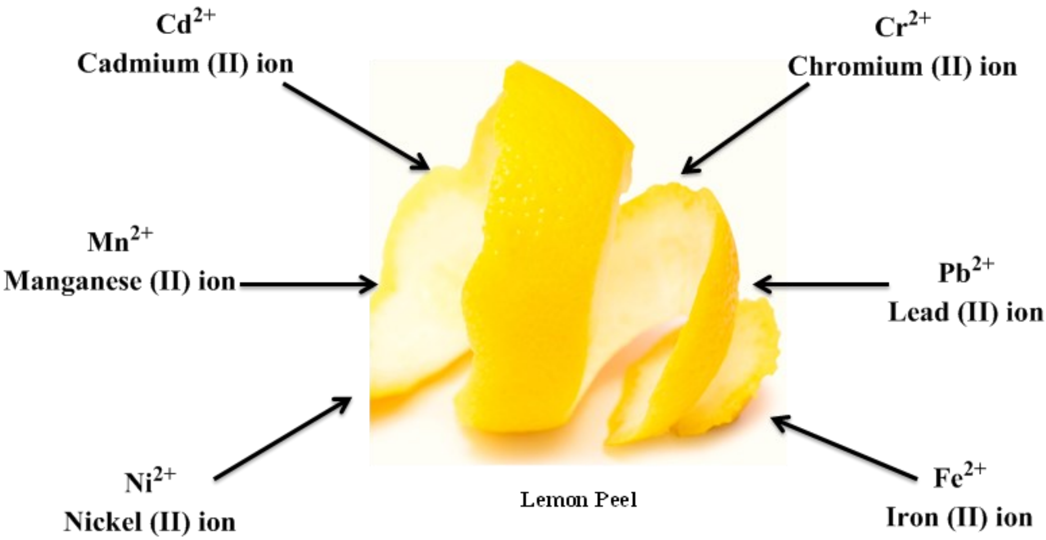

Figure 10. Lemon peels as novel bio-sorbent material for heavy metals sorption (Adopted from: Šabanović *et al*., 2020).

Magnetic graphene oxide

Graphene is a highly conductive, electric, and thermal form of carbon having a wide surface area of 2630 m^2g^{-1}. Due to its large surface area, it is an effective material for the development of high-grade adsorbents. Therefore, researchers focus on the development of graphene-based nanoparticles with a fraction of magnetic properties. Moreover, the magnetic property of synthesized graphene oxide composites establishes their role in effective magnetic separation of heavy metal ions thereby helps in water purification processes (Farooq and Jalees, 2020).

Synthetic thin film nanocomposite osmosis active layer membrane

Synthesis of novel active thin layer osmosis membrane is the latest addition in the ongoing technological advancement in the heavy metal remediation process. The synthesis involves the preparation of a mixture of polythene glycol, polysulfone and, 1-methyl, 2-pyrrolidone in different fractions using phase inversion process, in which further addition of 1,3-phenylenediamine, graphene oxide and, 1,3,5-benzene trichloride takes place by performing interfacial polymerization process (Figure 11) along with the polyamide layer which ultimately leads to the formation of active layer membrane. This newly synthesized active layer osmotic membrane removes cadmium, chromium and, lead like heavy metals from the industrial water effluent.

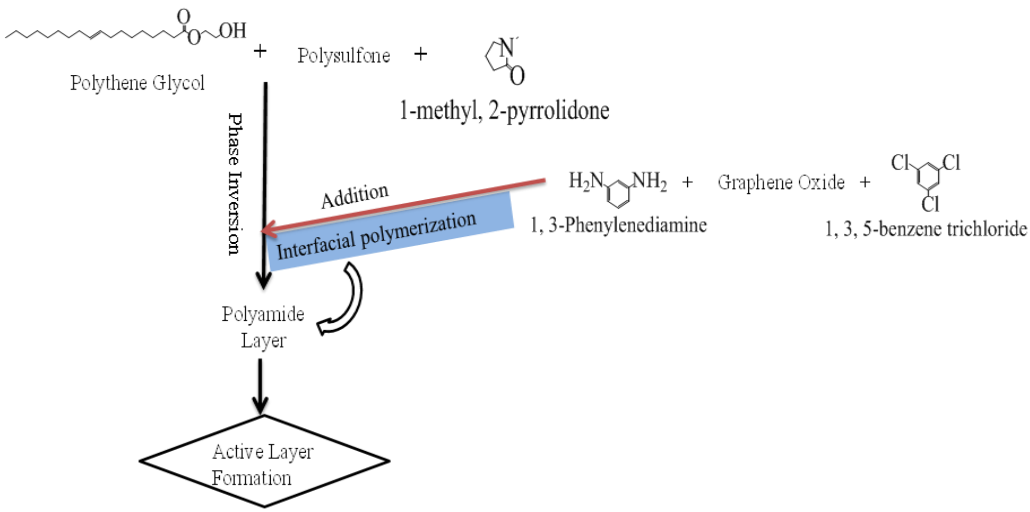

Figure 11. Schematic representation of the synthesis process of thin-film nanocomposite osmosis active layer membrane (Saeedi-Jurkuye *et al*., 2020).

Polyaniline based materials

In recent years, the polyaniline-based materials and products have proved their efficiency in catalysis and adsorption processes. They have a wide number of applications. Polyaniline is highly conductive and stable and can be easily prepared. Owing to its biocompatibilities and adsorption potential, it is itself used as sorbent material and is mixed with other formulations to prepared polyaniline based sorbents that are highly effective in eliminating heavy metal ions from contaminated water sources (Eskandari *et al*., 2020).

Carbon nanotubes

The current situation of risk posed by heavy metals in water sources demands more technological developments. One of the latest in the list is the development of multiwalled carbon nanotubes which significantly show their effectiveness in heavy metal removal. Metal ions of copper, manganese, and zinc are effectively removed from the polluted water samples. Recent studies observed their high level of heavy metal remediation potential as copper and manganese ions were observed to be removed by 79% and 78% respectively (Bassyouni *et al*., 2020; Nayak *et al*., 2020).

Two-dimensional nano-sheets

Researchers recently synthesized water-stable 2-D zinc-based metal-organic framework nano-sheets. These sheets are found to be highly efficient for capturing heavy metals from the aquatic system with a high adsorption capacity of 253.8 mg/g for lead (II) ions and 335.57 mg/g for copper (II) ions. This much of adsorption capability of these 2-D nano-sheets is directly related to the strong affection of amino and hydroxyl groups of nano-sheets towards lead and copper metal ions (Xu *et al*., 2020).

Biochar based sorbents

High-temperature pyrolysis of agricultural biomass results in the formation of biochar. It is highly porous, activated, eco-friendly, and carbon-rich material which is known for its well-established role of carbon sequestration. It also produces bioenergy and acts as an agricultural fertilizer agent. Hence, it increases soil fertility. Due to its porous nature, it provides a large surface area for attachment of a variety of pollutants in the form of their complexes. The functional groups such as hydroxyl, phenolic, amino, and alkyl groups play their important role in it. Therefore, biochar is used in the development of biochar based sorbents (Shakoor *et al*., 2020).

Magnetic iron-oxide (FeO) nanoparticles

Recently, studies have been conducted to test the effectiveness of magnetic iron-oxide nanoparticles in heavy metals removal from the wastewater. This nano-particle is synthesized in the laboratory using hyper-branched polyglycerol polymer. This newly synthesized nano-particle was found to be very suitable in heavy metals removal because it shows a higher adsorption rate of 0.700, 0.451, and 0.790 $mg.mg^{-1}$ for copper, nickel, and aluminum respectively. Therefore, it establishes itself as a promising sorbent for heavy metals sorption (Khan *et al*., 2020; Torres-Caban *et al*., 2019).

Modified natural zeolites

The use of natural zeolites as adsorbents for remediation purpose of heavy metals from the aquatic environment provides a low cost and readily available approach. Generally, zeolites are hydrated alumino-silicates of tetrahedral alumina and silica, arranged in a 3-D structure. Recently, researchers use the natural modified zeolite "clinoptilolite" as a low-cost heavy metal ions adsorbent which shows its high potential in capturing lead, chromium, cobalt, and zinc metal ions from contaminated wastewater system (Izzo *et al*., 2019).

Photo-catalysis

This process involves an advanced oxidation process. The mechanism of photo-catalysis is very interesting, well known for its excellent working in the remediation processes. Its use is advantageous as compared to other existed processes as it is widely working under varied temperatures and pressure conditions. It uses redox reaction and initiates chain reactions with heavy metal ions which ultimately leads to their molecular transformations. The photo-catalysis process uses the ultraviolet and visible light sources of wavelength ranges from 300-388 and 388-520 nm respectively (Tahir *et al*., 2019). This process carried forward using different semiconductors like TiO_2, ZnS, CeO_2, etc. Its schematic representation is given below:

$SM_{cond} \rightarrow SM_{cond} (h^+ + e^-)$

$M_{ion}^{n+} + e^- \rightarrow M_{ion}^{(n-1)+}$

$OH^- + h^+ \rightarrow OH$

$OH + RH \rightarrow R^0 + H_2O$

$Co_2 \rightarrow H_2O$ + Mineral acid

$2H_2O + 4 H^+ \rightarrow O_2 + 4H^+$

Where SM_{cond} represents semiconductor; M_{ion}^{n+} is a metal ion.

Fungal based electro-spun filtration membrane

Recent studies reveal the importance of fungi in pollutant bioremediation. Using fungi, fungal based biomaterials, and adsorption systems for filtering heavy metals have been developed. The fungal strain *Armillaria cepistipes* (Empa 655) was used by the researchers in developing reliable biosorbent filtration membrane for heavy metal remediation. The result of using this natural filtration membrane shows 90% of removal capacity of Pb, Ni, Cd, and Cr ions from wastewater (Tran-Ly *et al*., 2020).

Novel coordination polymers

The development of novel coordination complexes provides new insight in the heavy metals removal from the environment. These polymers developed by using different types of organic ligands including metal complexes. For e.g. 1,2,4,5-benzene tetracarboxylic acid is an effective chemical that allows ligand binding at its different receptor sites and therefore contributing to the synthesis of novel coordination complexes. As for their remediation potential, the latest researches found a higher level of adsorption power (99%) for elemination of Hg ions from wastewater (Zhao *et al*., 2020).

Capacitive deionization and electro-sorption

Recently, modified and improved version of capacitive deionization and electro-sorption has gained intense popularity against toxic metals and pollutants remediation from heavily polluted water. It is also a cost-effective option and efficient technological advancement for heavy metals remediation. The mechanism of electro-sorption involves the adsorption of metal ions under the influence of the generated magnetic field. This is process very energy efficient as compared to other techniques of heavy metals removal (Chen *et al*., 2020).

Conclusion

It is mandatory to have significant knowledge of the inception, environmental cycling, chemical speciation, and associated hazardous impacts of heavy metals on water sources. Upon examining the said variables, it is easy to select specific remedial processes for a specific heavy metal ion removal. Also, it helps in the development of more efficient and novel methods. Activated graphene, ionic liquid clay, lemon, biochar, and fungal based biomaterials, nanocomposite active layer, carbon nanotubes, and sheets, etc. are the latest and the best available processes for heavy metals removal from the contaminated water systems.

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Chapter [7]

Factors affecting watershed ecosystem: A case study of Mohand Rao watershed in Uttarakhand, India

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Abstract

Watershed is an area of land where all of the water that falls in it ends up in the same place. Water in the watershed comes from rainfall and stormwater runoff. The quality and magnitude of stormwater is affected by all the variations to the land use in mining, agriculture, roadways, urban expansion, and the activities of individuals within a watershed. Watershed health can be judged by the ecological environment of the watershed as well as the ecosystem services. Mohand Rao watershed, located in Haridwar district of Uttarakhand state in India, also faces ecological threat due to natural as well as anthropogenic processes which become root cause of watershed pollution. Main natural process in this watershed is the risk of seasonal flood and the major anthropogenic activity is mining of the riverbed material. Stormwater is contaminated by sanitary sewage, due to improper sewage lines in the villages. This leads to water contamination paving good environment for the pathogens to thrive. Thus contamination of water in the watershed is carried forward to the floodplain areas from highlands. Therefore, this book chapter emphasized on potential factors (especially water pollution) by which watershed ecosystem are getting deteriorated.

Keywords Ecological threat, Pollution, Riverbed mining, Sewage, Watershed, Wastewater

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Introduction

A watershed can be defined as a geographical area of land that drains all the streams and rainfall down slope until it reaches a common point or an outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel (Kamboj *et al*., 2010) Basically, watershed is a land area through which water flows across the land and drains into a collective body of water, whether a stream, river, lake, or ocean. Each smaller watershed drains into a larger watershed that ultimately flows to the ocean. Water in the watershed comes from rainfall and stormwater runoff. The quality and magnitude of stormwater is affected by all the variations to the land use in mining, agriculture, roadways, urban expansion, and the activities of individuals within a watershed (Ako *et al*., 2014). During human development of landscapes, native vegetation is removed, soils are disturbed, impermeable surfaces are constructed, leading to increased, rapid runoff and flash floods during storms (Konrad and Booth, 2005; Walsh *et al*., 2005; Scott *et al*., 2013). Human impacts on landscapes often diminish the capabilities for ecosystems to provide essential services for people, including clean air, water and natural products (Scott *et al*., 2013).

Watershed is synonymous with other terms, such as "drainage basin" and "catchment area." Area". Watersheds are usually parted from other watersheds by naturally elevated regions. Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani *et al*., 2008). The movement of water leads to the connections between watersheds. Thus, water is important, as it carries nutrients, sediments, and pollutants from higher to lower elevations. Water also moves through the subsurface and creates a moisture gradient in the soil. This is why highlands tend to have drier soils than lowlands.

Surface waters are degraded by a combination of natural as well as anthropogenic activities. Increase in excavation of riverbed, degrade the natural ecosystem of the river (Kamboj *et al.*, 2017). This disturbance was due to the loose soil resulting in soil erosion (Kamboj, 2013). The degradation of the river system is based on river bed material and environmental pollution such as wastewater, agricultural runoff, and also tourism activities. This causes the eutrophication condition due to the discharge of nutrients in excess amount (Kamboj *et al*., 2020). Such processes harm the use of surface water for drinking, industry, agriculture, restoration and other purposes (Simeonov *et al*., 2003). The sustainable development of resources is in threat as various regions of the world today, face several problems related to the occurrence, use and control of water resources. (Sohrab *et al.*, 2012). Stormwater is contaminated by sanitary sewage too, due to improper sewage lines in the villages. This leads to water contamination paving good environment for the pathogens to thrive. Thus, contamination of water in the watershed is carried forward to the floodplain areas from highlands. When sewage is discharged into nearby rivers, it will gradually diffuse into normal water bodies and nearby soil with the flow of river basins, resulting in pollution (Song *et al*., 2015). Stormwater contaminated by sanitary sewage from leaking sewer lines or cross connections can be a source of pathogens in urban areas (Sauer *et al*., 2011; Sercu *et al*., 2011, 2009) and has been associated with risks to human health (Gaffield *et al*., 2003). A significant association has been found between extreme rain events and gastrointestinal illness, which suggests that precipitation facilitates the delivery of waterborne pathogens from a variety of urban sources (Curriero *et al*., 2001; Drayna *et al*., 2010).

Watershed health can be judged by the ecological environment of the watershed as well as the ecosystem services. A healthy watershed is one that sustains ecosystem function and offers the human welfare and livelihood. Degraded watersheds cannot contribute quality water resources. Watersheds provide large benefits to our communities as well as to the environment. It is important to reflect on defending the integrity of our local watersheds. Maintaining the productivity and biodiversity of river systems is of utmost importance. The watershed intermediations increased the vegetative index, reduced the runoff, soil loss and land degradations. The biodiversity, thus improved in the delicate and fragile watersheds (Pathak *et al*., 2012). In India, watershed projects have matured recently, from mere technical involvements to restore degraded lands and vegetation to more precise poverty mitigation enterprises (Lodha and Gosain, 2008).

Status of Mohand Rao watershed ecosystems in Uttarakhand, India

Watersheds play a vital role in our ecosystem. These primarily serve the habitats based near them. Indian states have several watershed regions. Uttarakhand, being a hilly state is considered a hub of watersheds. Many watersheds take shape from the Himalayan range here and drain their water into the rivers in the floodplain areas. Mohand Rao watershed is located in Haridwar district of Uttarakhand state. It occupies part of the Rajaji National Park range and is therefore of utmost importance. This watershed also faces ecological threat due to natural as well as anthropogenic processes. The major anthropogenic activity here is mining of the riverbed material. This alters the watershed characteristics thus making a huge impact on the watershed ecosystem functions. So, the present study was carried out in Mohand Rao watershed from September 2016 to September 2018, to understand the impact of these activities on the watershed health. This study was carried out in Mohand Rao seasonal hill river watershed of Shiwalik foothill area in district Haridwar of Uttarakhand state. The Shiwalik foothills were formed by the erosion caused during the rise in the Himalayas, where Haridwar lies in the south western part of Uttarakhand state in the Indian subcontinent. The Mohand Rao watershed is located in between the latitude of 30°3′37 N″ to 30°15′ N and 77°E (Figure 1 and 2). Mohand Rao watershed is formed of Mohand Rao and its tributaries namely Sukh Rao and Chilla Rao. This watershed extends in an area of 30.5 sq. km approximately. This covers some portion of Rajaji National park forest area and nearby villages i.e. Shekhwala and Banjarewala.

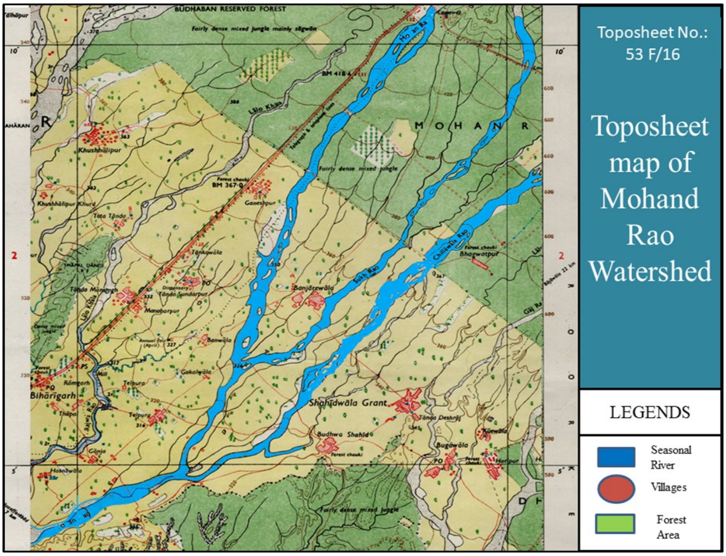

Figure 1. Toposheet map of Mohand Rao watershed in Uttarakhand, India.

Figure 2. Visuals of Mohand Rao watershed in Uttarakhand, India.

Factors affecting Mohand Rao watershed ecosystem

Mohand Rao watershed, situated in Shivalik foothills of the Himalayas has a diversified ecosystem. Changes in its ecosystem can be seen due to some sensitive factors (Figure 3). These major factors

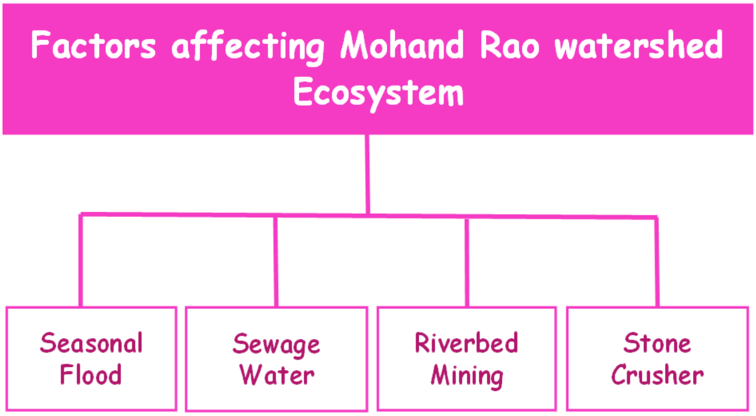

Figure 3. Factors affecting Mohand Rao watershed ecosystemin Uttarakhand, India.

affecting Mohand Rao ecosystem are:

***Seasonal flood*:** A flood is a condition when a river or stream overflows its banks. Seasonal floods are the norm in many rivers, for example when rains or snowmelt increase the flow. In flood condition, the river channel is totally filled and water travels on the floodplain and later decelerates. This water carries the runoff, cutting down the river banks and increases the bed load in the lower reaches of the river. The speed of the river carrying bed load is quite high due to excessive rainfall. Mohand Rao watershed receives heavy rainfall in monsoon season.

***Sewage water*:** Sewage water is wastewater from residents existing in a community. It is the water released from households after use for several purposes like washing dishes, laundry, and flushing the toilet. The term sewage is no longer frequently used and is now replaced with "wastewater". This wastewater due to improper sewerage lines is directly thrown into the rivers of the watershed. It is the main cause of watershed pollution as this wastewater carries pathogenic bacteria and later results in many diseases as in lowlands this untreated water may be further used by villagers.

***Mining of riverbed material*:** Extraction of riverbed material for minor minerals i.e., sand, gravel and boulders from the river is referred to as riverbed mining. Growth of urbanization, infrastructural and economic development activities all over the world have increased the demand of riverbed material for construction purposes (Kamboj and Kamboj, 2019). The environmental effect of sand and gravel mining on land and soil display the destruction of landscape, deforestation, water pollution, loss of farm and grazing lands and the collapse of river banks as the physical environmental impacts associated with mining of these materials. Kamboj *et al.* (2012) studied the positive and negative impact of illegal mining of Ganga River at Haridwar and found that it has very alarming impact on the environment. Mining of the riverbed material started for construction in the name of development. Rightly so, the riverbed material is highly in demand for the same purpose. Due to enormous rise in population, the

Figure 4. River bed mining and stone crashers at Mohand Rao watershed ecosystem in Uttarakhand, India.

demand of houses, buildings etc. is increasing, but the natural resources are not being replenished by the same rate (Figure 4a). Kamboj *et al.* (2018) examined the water quality of the active mining area and found the area severely affected.

Stone crushers: These are the machines installed near the riverbed mining area to crush the big boulders into different sized pebbles, gravel and sand. Crushing of boulders produces large quantity of dust, which further floats in air and spreads in the surrounding area of the stone crusher. Inhalation of the fine dust leads to severe respiratory health problems (Figure 4b). Pebbles are further differentiated into various sizes and are sold at different rates accordingly to the contractors for construction purposes. Trucks in large numbers carry the bedload to the crusher units. The condition of the road is

Figure 5. Trucks carrying riverbed load and Cutting of riverbank changing channel morphology at Mohand Rao watershed ecosystem in Uttarakhand, India.

thus very pitiable. Ponds and ditches can be seen (Figure 5a and 5b).

Impact of major factors on health of Mohand Rao watershed

All the above factors laid their major impact on the ecology of the Mohand Rao watershed as follows.

Channel morphological changes: Seasonal flood plays a major role in changing the channel morphology. The morphology of the Calora River in Italy changed from transitional to single-thread (Magliulo *et al.*, 2013). In monsoon, the water brings heavy load of substrate material or the runoff with it to the lower reaches (Figure 5b). This results in flood like condition. Due to this, major soil erosion takes place (Kamboj, 2013) and the banks of the rivers are cut off at varied angles which further increase the river width as well as the bank height at several areas of the watershed. In Mohand Rao watershed channel morphological parameters as depth, bank height, river width, drainage area, slope, substrate

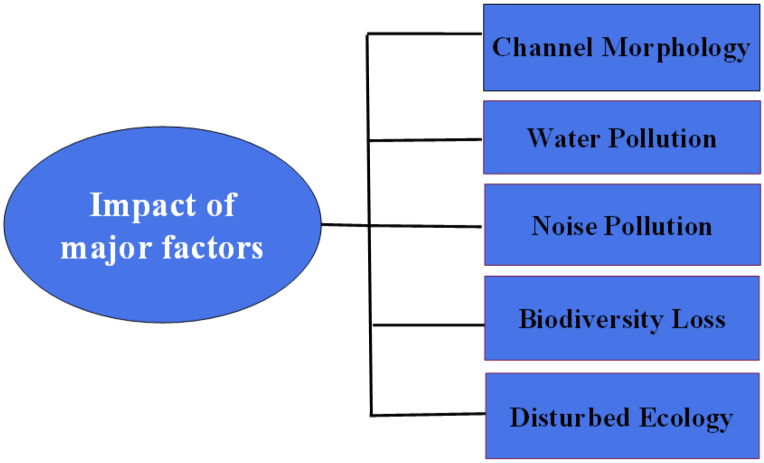

Figure 6. Impact of major factors on Mohand Rao watershed ecosystem in Uttarakhand, India.

structure at different sites were studied.

During the study period from 2016-2018 river depth, bank height, river width and slope were increased in the region where more mining occurred. The drainage area was increased in Mohand Rao and Sukh Rao river due to excessive mining in these rivers. The enlargement was more in Mohand Rao than Sukh Rao as Mohand Rao is the main river used for mining activities (Figure 6). The substrate characteristics were differentiated on the basis of size into boulders, cobbles, pebbles, gravels and sand (Kamboj *et al*., 2017). These characteristics showed that huge amount of substrate was brought down by the rainwater in the monsoon as runoff. Thus, all these parameters changed the overall morphology of the rivers forming the watershed. Instream mining causes instability to the river channel. It disturbs the existing stability of the channel form and causes undercutting of the river banks by incision (Kamboj *et al*., 2020)

***Water pollution*:** Water pollution in the rural watersheds mainly occurs due to two reasons. The wastewater or sewage discharged from the household in the form of faeces and urine, carrying bodily waste, washing dishes, laundry and food preparation are classed as domestic or sanitary sewage. Surface runoff also known as storm flow, is the share of rainfall that runs hastily over the ground surface to a defined channel. Precipitation absorbs gases and particulates from the atmosphere, dissolves and leaches materials from vegetation and soil, suspends matter from the land, washes spills and debris from urban streets and highways, and carries all these pollutants as wastes in its flow to a collection point. The Mohand Rao watershed during the study revealed that the villages Banjarewala and Shekhwala were lacking proper sewage lines and thus this domestic wastewater ultimately reached the rivers.

***Noise pollution*:** Noise pollution is the regular exposure to raised sound levels that may lead to adverse effects in humans or other living organisms. Mohand Rao watershed, in the study period of 2016-2018 due to riverbed mining activity has total of twenty-eight stone crusher units throughout. These stone crushers work day and night in crushing big boulders extracted from river into smaller ones. Later, these are transported through different modes of transport using trucks, tractors, bullock carts etc. Thus, these roads have ditches which are filled with water in rainy season and experience casualties. They produce a lot of noise in the area. It affects the fauna of that area. Study reveals that the faunal diversity reduced with increase in the number of these units. The birds and mammals avoid these areas because of the loud noise made by the stone crusher. The noise pollution affects the birds in many ways such as damages of ears, changing in reproductive and vocal communication, disturbance in ability to hear the predators and important sounds.

Loss of biodiversity**:** The changes in the biodiversity of the watershed were also evident after an extensive study of the flora and fauna (Tables 1-3). The floral diversity included the study of trees, herbs and shrubs. Herbs and shrubs were much disturbed in the mining zone of the watershed in comparison to the Rajaji forest area (Sharma and Kamboj, 2019).

This disturbance was due to the loose soil resulting in soil erosion (Kamboj, 2013). Very few species of

Table 1. Status of trees diversity in Mohand Rao watershed (+ present; - absent).

Botanical name	Common name	Family name	Forest area	Active mining area
Dalbergia sisso	Shisham	Fabaceae	+	+
Tectona grandis	Teak	Verbenaceae	+	-
Butea monosperma	Dhak	Fabaceae	+	+
Pithecellobium dulce	Jungle Jalebi	Mimosaceae	+	-
Odina wodier	Mohin	Anacardiaceae	+	-
Ficus virens	White Figure	Moraceae	+	-
Koenigii	Sweet neem	Rutaceae	+	+
Acacia nilotica	Babool	Mimosaceae	+	-
Bombax ceiba	Simbal	Bombeaceae	+	-
Syzygium cumini	Jamun	Myrtaceae	+	+
Tamarindus indicus	Imli	Caesalpiniaceae	+	-
Eucalyptus globulus	Blue-gum (Safeda)	Myrtaceae	-	+
Populus nigra	Black Poplar	Salicaceae	-	+
Phoenix dactylifera	Khajur	Arecaceae	+	-
Azadirachta indica	Neem	Meliaceae	+	-
Ficus religiosa	Peepal	Moraceae	+	-
Ficus benghalensis	Banyan	Moraceae	+	-
Aegle marmelos	Bael	Rutaceae	+	-
Shorea robusta	Sal	Dipterocarpaceae	+	-
Cassia fistula	Amaltas	Fabaceae	+	-
Holoptelea integrifolia	Papri	Ulmaceae	+	-
Mallotus philippensis	Rohini	Euphorbiaceae	+	-

Table 2. Status of shrubs diversity in Mohand Rao watershed (+ present; - absent).

Botanical name	Common name	Family name	Forest area	Active mining area
Ricinus communis	Castor	Euphorbiaceae	+	-
Lantana camara	Raimuniya	Verbenaceae	+	+
Smilax aspera	Salsa	Smilacaceae	+	-
Ipomoea carnea	Morning Glory	Convolvulaceae	+	-
Clerodendrum viscosum	Bhant	Lamiaceae	+	-
Ziziphus ziziphus	Jungli Ber	Rhamnaceae	+	-
Solanum torvum	Bhurat	Solanaceae	+	-

Table 3. Status of herbs diversity in Mohand Rao watershed (+ present; - absent).

Botanical name	Common name	Family name	Forest area	Active mining area
Ageratum conyzoides	Chick weed	Asteraceae	+	+
Alternanthera sessilis	Garundi	Amaranthaceae	+	-
Malvastrum coromandelianum	Kharenti	Malvaceae	+	-
Anagallis arvensis	Biliputi	Primulaceae	+	-
Cyperus rotundus	Nut Grass	Cyperaceae	+	+
Parthenium hysterophorus	Congress grass	Asteraceae	+	+
Melilotus indicus	Yellow sweet clover	Fabaceae	+	-
Oxalis latiforia	Khatmithi	Oxallidaceae	+	+
Oxalis corniculata	Amrul	Oxallidaceae	+	+
Achyranthes aspera	Latjira	Amaranthaceae	+	-
Mecardonia procumbens	Makardana	Plantaginaceae	+	-
Chenopodium album	Bathua	Amaranthaceae	-	-
Cannabis sativa	Bhang	Cannabaceae	+	+
Vetiveria zizanoides	Khas khas	Poaceae	+	-
Tinospora cordifolia	Amrita/giloy	Menispermaceae	+	-
Imperata cylindrica	Cogon grass	Poaceae	+	-
Eulaliopsis binata	Sabaigrass	Poaceae	+	-
Rauwolfia serpentina	Sarpgandha	Apocynaceae	+	-
Solanum villosum	Kovidaraha	Solanaceae	+	-
Solanum nigrum	Mokoi	Solanaceae	+	+
Saccharum spontaneum	Kaans	Poaceae	+	+
Eclipta alba	Bhringaraj	Asteraceae	+	-
Juncus tenuis	Poverty rush	Juncaceae	+	+
Sacchrum munja	Munja	Poaceae	+	+
Malva sylvestrus	Gurchanti	Malvaceae	-	-
Rumax dentatus	Toothed dock	Polygonaceae	+	-
Acalypha indica	Kuppi	Euphorbiaceae	+	-
Euphorbia hirta	Asthma weed	Euphorbiaceae	+	+
Cynodon dactylon	Dub grsass	Poaceae	+	+
Euphorbia prostrata	Red euphorbia	Euphorbiaceae	+	+
Ischaemum rugosum	Ribbed murain-grass	Poaceae	+	-

shrubs and herbs could be found here. Similarly, the avian and mammalian fauna under study was affected due to mining in the riverbed mining prone area of the watershed. Sharma *et al*. (2019) studied the effect of riverbed mining on floral diversity of Mohand Rao watershed and concluded loss of floral diversity in the active mining area as compared to the forest.

***Disturbed ecological equilibrium*:** Ecological equilibrium of a watershed is to sustain a state of dynamic stability within a community of organisms so that the ecosystem diversity remains relatively stable, subject to gradual changes through natural succession. A stable balance is needed in the numbers of each species. Increase in excavation of riverbed, degrade the natural ecosystem of the river (Kamboj *et al*., 2017). The study showed a disturbed ecological equilibrium throughout the watershed.

Conclusion and recommendations

Unscientific riverbed mining practices have proven to be harmful for the ecological equilibrium of the watershed ecosystem. The watershed health is at high risk. The changing morphology of channels results in degradation of water quality. In Flood-plain mining area, the riparian vegetation has also degraded due to the transportation of the riverbed materials. The transportation and mining activity reduced the floral and faunal biodiversity. Sewage water running in the channels shows improper functioning and causes diseases. From the above conclusion, it is recommended that the mining activity should be banned near the ecologically sensitive area and should be allowed in those rivers only where replacement rate of material is high. The extraction should be performed in a sustainable manner. Proper facilities for sanitation and wastewater should be practiced. General awareness campaigns for the people involved in mining activity as well as wastewater should be carried out time to time.

Conflict of Interest: The author declares that there is no conflict of interest.

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Chapter [8]

Wastewater pollution induced detrimental impacts on aquatic biodiversity: A review

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Abstract

Freshwater is the most transformed and endangered ecosystem on Earth due to many threats. Water pollution is one of them, which involves both point and non-point sources of human activity. Disposal of polluted water by humans is the root cause of stress for aquatic ecosystems. Industrial, municipal, agricultural activities have been identified as the major contributors to environmental stress, affecting all the components of the aquatic ecosystem. Water pollution along with overexploitation, climate change, flow modification, exotic species invasion, and habitat loss are among the six major threats of aquatic biodiversity loss. Here, we review the major types of pollutants emerging from different anthropogenic sources and their adverse effects on the water quality of the lotic and lentic ecosystem, its harmful effects on aquatic biodiversity, identification of a particular type of pollutant through bio-indicator or bio-monitor. Also stating about biodiversity maintenance, which is the prime key to retain ecosystem services, and how to deal with these situations when it has become an ultimate challenge for mankind so that biodiversity rejuvenation could follow a growing trend.

Keywords Aquatic ecosystem, Biodiversity, Wastewater disposal, Water pollution

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Introduction

Since the beginning of the twenty-first century, humanity is facing several types of severe problems and one of them is related to water quantity or quality issues (WWA, 2009). Water is the most important natural resource for the emergence of life which is present on this earth. According to several reports, only 3% of the total water is drinkable, out of the 3 % of that water surface acquire only 1% of water rest is in a frozen state or underground (Tahir and Soaib, 2020). Even though water is the most important need for any living system, continuous anthropogenic activities have made it harmful and polluted for the life present in water as well as on the land. Presently water pollution is considered one of the top priority universal challenges facing by developing as well as developed countries (Bassem, 2020). The problem of water pollution will become more aggravated in the future by climate change, which results in high water temperatures, increasing sea levels, melting of glaciers, etc. Humans are the major known source of water pollution. Urbanization, human settlements, industries, agricultural practices ultimately affect the water quality of many natural water resources (UNEP, 2016).

Ecosystem services are free and equal for all, making it a major cause for humans for its overexploitation, leading to massive destruction with an unpleasant impact on human health and livelihoods (UNEP, 2016). Continuous increase in the growth of population, economical activities, and climate changes participated in the spoilage of water resources. Several toxic and potentially toxic chemical compounds are released daily into the environment due to continuous human activities. So, it has become requisite to save the water sources from industrial pollutants, fecal contamination, and agricultural wastes. In developing countries, about 90 to 95% of total sewage and about 70% of industrial wastes are disposed of untreated into surface water (Obiakor *et al*., 2012) while according to some study, 80% of municipal wastewater is released untreated into water bodies globally. It has been reported earlier that the freshwater ecosystem is rich in biodiversity has a fast rate of decline than the marine water or land ecosystem making them the world's most threatened ecosystem and vulnerable habitats; their sustainability is being affected by humans (Obiakor *et al*., 2012). Pollutants affect the immune system of fishes either directly or indirectly by altering the water quality (Kumar *et al*., 2019), presence of heavy metal in water sources give rise to the problem of bio-magnification or bio-accumulation when these metals accumulate in the fishes and cause a harmful effect to their body as well as to humans when they take these fishes as food for a healthy diet (Kumar *et al*., 2020; Fatima *et al*., 2020). Wastewater releases from various sources can critically harm the aquatic ecosystems which result in a shift in the diversity of aquatic organisms and even cause the extinction of some aquatic species (Niu *et al*., 2019). Genotoxic pollutants present in water bodies affect the cellular genetic material and its integrity in fishes and other aquatic organisms and finally cause mutation due to its mutagenic activities. It also affects the germ cells and can pass genetic changes down to progeny so, it is considered against the sustainable development principles by WHO (Obiakor *et al*., 2012).

Pollutants are generated by many sources, as far as the aquatic life is concerned the prime sources of pollutants are Industrial effluents (industrial waste and heavy metals), agricultural runoffs (herbicides, pesticides), municipal sewage, etc. According to (Mohamed *et al*. (2013) effluents coming out from industries are highly toxic and contain heavy metal which combines with suspended solids present in domestic wastewater and forms muck. Discharge of pollutants in the water stream causes widespread toxic pollution, organic pollution, and eutrophication along with severe ecological destruction (Miao *et al*., 2012). Removal or treatment of pollutants in water bodies or aquatic sediments is a difficult, challenging, and very costly task because the diversity and amount of persistent toxic pollutants are so high and increasing continuously (Doust *et al*., 1994). Also, it is necessary to save water resources from fecal contamination and agricultural wastes. Hence, there is an urgency to find a better way to cope with the environment and find a sustainable or eco- friendly way of fighting the increasing levels of pollution for our better tomorrow and the long-lasting sake of our non- renewable resources.

Water pollution threat to aquatic biodiversity

Freshwater is the most important aspect of life, without it, the existence of life cannot be imagined. As a result of over-exploitation of natural resources, human has created numerous environmental problems for us as well as for the flora and fauna all over the world (Fent, 2008). Water pollution is one of them and is now a worldwide challenge for both the developed and developing countries, imposing numerous side effects on humans along with environment. All of this is a result of poor management of wastewater and polluted water in most parts of the world resulting in the scarcity of fresh water globally and many environmental issues. Upon discharging the polluted water, it reaches the water bodies where it is diluted, transported downstream, or gets infiltrated into the aquifers, thereafter affecting the quality of freshwater. The 2030 Agenda for Sustainable Development, admitted the degradation of water quality all around the world and stressed the policies that would ensure control on the water pollution at national and international levels (UNWW, 2017).

Anthropogenic activities are the major cause of water pollution which includes improper human settlements, poor management of waste products released by industries, and agriculture runoff. The sources of water pollution are basically of two types: Point source and Non-point source. Point sources are those sources which dispose pollutants directly into the water (factories, power plants, oil wells, coal mines, etc.) while non-point sources are those whose source of disposing of pollutant are not specific (runoffs from agricultural fields, gardens, household wastes, etc.). Basically, there are 2 forms of water pollution: (1) Change in the type and amount of material carried by water, (2) change in the physical properties of water (temperature, color, odor, etc) (Gupta *et al*., 2008) and this contamination is majorly caused by four types of pollutants (Physical, Chemical, Radioactive, and Biological) resulting as a by-product or waste product from three major sources which are; industrial effluents, agricultural runoffs, domestic sewage. In addition to these, natural events such as volcanic eruption, algal blooms, and earthquakes are also the cause of water pollution to some extent.

Agricultural Activities; agricultural activities are known to be the major source of surface water pollution. Agricultural uses around 70% of the total freshwater which results in 50% (primary source) of total surface water pollution and third most for the estuaries (Islam and Tanaka, 2004; Agrawal *et al.*, 2010). The major waste products produced by the agricultural practice which results in water pollution are paddy husks, sugarcane bagasse, animal excreta, pesticides, insecticides. The water bodies receive this waste as a result of erosion of soil (containing organic pollutants) and post precipitation run-off of chemicals used as fertilizers and pesticides etc. (Nagendran, 2011). As the world population had increased exponentially, farmers started using fertilizer to great extent in all parts of the world due to easy availability and low cost to increase productivity. Fertilizers are the major non-point source of nitrogen and phosphorus. The United States of America saw an increase in the use of nitrogen-based fertilizers by 20 times between the period of 1945 to 1993. In figures, this number was from 0.5 million metric tons to 1.9 million metric tons per year. Studies estimate that farmers use fertilizers in excess by 24% - 34% more than that is required due to the uncertainty of weather and nutritional status of the soil (Puckett, 1995, Lu *et al*., 2015).

Few Asian countries (India, China, Bangladesh, and Myanmar, etc.) with higher agricultural productivity contribute significantly to aquatic pollution from agricultural sources. Bangladesh uses 9000 metric tons of different types of pesticides and 2 million metric tons of fertilizers annually (Islam and Tanaka, 2004). Fertilizers, pesticides, and various chemicals are also carried by wind over a long distance, contaminating water bodies a thousand miles away (For instance, pesticides used in tropical regions were found in Arctic mammals). Runoff of these chemicals leads to contamination of water bodies and its biota in various ways like eutrophication, affecting the health or the reproductive efficiency of the fishes and other aquatic animals. Pesticides and their derivatives are one of the most devastating agents for the aquatic biodiversity and ecosystem affecting the food chain from top-level to the lowest (Islam and Tanaka, 2004).

Animal manure is another pollutant that is responsible for water contamination produces by agricultural activities. In the USA itself, around 5.9 million and 1.9 million metric tons of nitrogen and phosphorus are released by the manure every year. The cattle's grazing freely scatters manure all over the land making a non-point source for water pollution while farms, where cattle are not allowed to freely move, are the point source for water pollution. This organic waste material affects the quality of water in various ways like alteration in the turbidity, odor, and color of the water. It is one of the major sources of pathogens in the water which not only affects the native population of the water but is also deadly for humans (Karcı and Balcıoğlu, 2009).

Industries are responsible for the destruction of our environment. The waste produced by industries affects all aspects of the environment, be it water, air, soil, or biodiversity. They are a major point source for aquatic pollution. Unchecked effluents released by the industries directly into the water bodies are the major reason for water pollution through industries. These effluents consist of a variety of pollutants that vary from industries to industries. The effluents are majorly released by industry oils, heavy metals, and organic chemicals. Pollution through oil has to gain attention since the end of the 20th century with an increase in industrial effluents, oil tanker operations, oil usage, and marine tanker accidents resulting in spillage of oil (Moiseenko *et al*., 2017). Coastal refineries are another source of oil pollution as crude oil purified and processed to produce a variety of products, during these operations small scale pollution occurs continuously through leakage, breakage, and sills (Soromotin, 2011). A study by Nelson (2000) suggests that in addition to spills as a result of various regions, an estimated volume of 16,000 tons of oil reaches the aquatic ecosystem as run-off and waste from land-based industries in Australia only. Similar results were expected from developed European and Asian countries (Moskovchenko *et al*., 2020).

Heavy metal and trace element are the by-products of various industrials processes which reaches water sources through land-based or water-based effluents (Nordstorm, 2002). The other source of heavy metals which pollutes the water source is natural. This occurs due to weathering of rocks of sedimentary rocks releasing various metals such as Iron, Zinc, Calcium, Chromium, Cadmium, etc. Industries majorly discard more dangerous heavy metals (Mercury, Lead, Iron, Nickel, Manganese, etc.) as compared to natural processes (Saha and Paul, 2016). Ni, Fe, And Mn reach the aquatic system by corrosion of metal pipes and containers. Paints, petroleum compounds, and aerosols are the major source for the lead contamination of water. Cadmium and Chromium reach through metallurgical industrial discharge, refractories, and breakdown of galvanized pipes and containers. The major portion of heavy metal pollution is through acid mine drainage (AMD) which releases high levels of sulfides, As, Cd, Cu, and Zn, etc. Saha and Paul (2016) and Razo *et al*. (2003).

Synthetic Organic chemicals are other industrial effluents that are of great concern for the aquatic as well as terrestrial biodiversity due to high-level toxicity and high persistence in the biological system. The major synthetic organic chemicals are Organochlorines, Organophosphates, Organometals, HCH, and PAHs (Islam and Tanaka, 2004). Now a day the traces of these xenobiotic compounds can be found in every part of the aquatic life system from the Antarctic to Artic and from intertidal to abyssal. These synthetic organic chemicals are non- biodegradable which increases the concern for its presence in the environment (Loganathan *et al*., 2020).

Sewage is a well-known participant in water pollution as it contributes to the greatest volume of water waste. Highly populated cities produces a humongous amount of sewage containing all sources like municipal waste, industrial waste, slaughterhouse waste, animal farm waste and all sorts of domestic wastes including fecal matter and many more (Islam and Tanaka, 2004). These effluents either are purposely dumped into the freshwater bodies or are washed off with the rain. One of the major problems conceived due to sewage is the increased BOD levels hence, decreasing dissolved oxygen.

Sewage, being organic is highly subjected to bacterial decay (Islam and Tanaka, 2004). This oxygen deficit water is not only unhealthy for consumption but also creates a negative ecosystem for the existing aquatic flora and fauna. Not only the sewage itself but the sewage treatment plants (STPs) are a major threat to the marine ecosystem. Some of the well-functioning urban citizens efficiently treat the sewage waste before releasing it into the water bodies. But sadly the separation of efficiency from their plants gets dumped into seas and oceans. Other disease-causing agents that may be present in sewage include enteric viruses, *Salmonella*, and the Hepatitis A virus (Tewari *et al*., 2017). Plastic also contributes significantly to marine contamination. They are dumped in huge quantities everywhere around the world which reaches water bodies. The survey on the beaches of two countries (Japan and Russia) reported that plastic waste contributes up to 72.9% (by number) and 53.8% (by weight) of the total waste in the beaches (Islam and Tanaka, 2004; Sigler, 2014).

Impact of industrial wastewaters on the aquatic ecosystem

Industrial waste contamination has seen steady growth and the marine ecosystem is the worst affected. Chemical waste is a major contaminant, whether it is air, land, or the water environment. Town sewage and industrial waste dumped into the rivers are the most polluting of these. Industrial waste is characterized as waste generated by fabrication or industrial processes. Cafeteria garbage, dirt, and gravel, masonry and concrete, scrap metals, rubbish, oil, solvents, chemicals, weed grass and trees, wood and scrap lumber, and the like are among the types of industrial waste produced. An industrial waste - which may be solid, liquid, or gases held in containers - is divided into hazardous and non-hazardous waste. Hazardous waste can result from fabrication processes or other industrial processes. Some commercial goods may also be classified as hazardous waste, such as cleaning fluids, paints, or pesticides discarded by commercial establishments or individuals (Lawson, 2018). Non-hazardous industrial waste is that which does not follow the definition of hazardous waste by the EPA (Environmental Protection Agency) which is not municipal waste. Since the Industrial Revolution industrial waste has been a concern this may be toxic, flame retardant, corrosive, or reactive if treated poorly, this waste can have harmful implications for health and the environment. In the United States, the amount of hazardous waste produced by the country's manufacturing industries grew from an estimated 4.5 million tons per year after World War II to some 57 million tons by 1975. By 1990, the number had fired at around 265 million tons. This waste is produced in the manufacturing process, use, and disposal of the manufactured products at every point. Thus, the advent of many modern home and office goods-computers, medications, textiles, paints, and dyes, plastics-also brought hazardous waste into the environment, including toxic chemicals. These, too, need to be handled with great caution to prevent adverse effects on the environment or human health. In 1980, the EPA estimated that more than 70,000 different chemicals were manufactured in the U.S., with some 1,000 new chemicals added each year. The human health and environmental impact of many of these chemicals are largely unknown. High levels of toxic pollutants have been found in animals and humans, particularly those who are constantly exposed to these waste streams, such as farmworkers and oil and gas workers. Wastewater from industrial processing or chemical processes leads to water contamination.

Industrial wastewater typically contains different chemical compounds that can be readily identified. Within a few subsectors, water pollution is concentrated mostly in the form of toxic waste and organic pollutants. A significant portion of this can be attributed to industrial chemical production and the food goods industry. Most major companies have industrial effluent treatment facilities but this is not the case with small-scale factories that can not afford huge investments in pollution control equipment because their profit margin is very slim. The consequences of water contamination are harmful not only for humans but also for wildlife, fish, and birds. Contaminated water is unsuitable for drinking, leisure, farming, and industry. The visual standard of lakes and rivers is reduced. More importantly, contaminated water is killing aquatic life and reducing its reproductive capacity. This is essentially a threat to public health. No one may avoid the consequences of polluting water.

The dry-cleaning fluids and the embalming fluids are two forms of industrial waste of particular concern. Dry cleaning fluids have polluted groundwater sources in all parts of the USA. PCE (perchloroethylene, or tetrachloroethylene, $Cl_2C = CCl_2$) is one of the most dangerous pollutants. PCE must be eliminated from the water to very small levels, as a potential carcinogen (Domestic, and Fast, 1986).

The minimum contaminant level (MCL) for PCE in drinking water in the United States EPA is 5 ppb (5 parts per billion, or 5 mg / L). States such as New Jersey have set MCLs at public water supplies as low as 1 ppb for PCE. Cemeteries can be a source of contamination of the groundwater caused by the degradation of organic matter and embalming fluids. There are a variety of historical records of water-well contamination in the area of cemeteries. Carcinogens involve embalming fluids. The possibility of contaminating the water supply by embalming fluids has caused several cities to reduce the size of the proposed large cemeteries. There's no question with our aging population that embalming fluids will become increasingly a source of water contamination unless anything changes.

How marine life is impacted by toxic waste?

Bioaccumulation allows toxic chemicals to accumulate in the tissues of aquatic plants and animals at high concentrations. They are not disintegrated into marine species and instead remain preserved in their bodies, which ultimately leads to death. Owing to bioaccumulation, aquatic life consumes even toxic metals like copper, mercury, and lead. Thermal pollution in oceans happens when there are rapid changes in the temperature of the water. This is mainly caused due to factories and power plants discharging hot or cold water in oceans. This threatens marine life's survival, as most species have different temperature requirements and cannot tolerate sudden temperature changes (Help Save Nature, 2009). It can also affect the behavior and reproductive patterns of animals such as fish. For example, fish reproduction may still occur but excessive temperature can cause the release of immature eggs or impede the healthy development of certain eggs. When chemicals are discharged into the aquatic environment, they are absorbed easily into the web of aquatic food. This can result in harmful mutations in marine organisms as well as serious diseases that lead to changes in tissue matter, biochemistry, and development.

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Pollution caused by industrial wastewater can increase the turbidity of the water as a result of which the sunlight cannot reach the bottom of the bodies of water. Thus marine plants inhabiting the lower layers are unable to perform the photosynthesis process (Domestic and Fast, 1986). And animals like fish will suffer from the excessive turbidity of the water. It can obstruct the fish's gills and make consuming Dissolved oxygen or DO from the surrounding water hard for them (Figure 1). The extraction of offshore oil and the shipping of oil by sea are causing oil spills in oceans. When this oil floats on the surface it blocks sunlight which prevents the use of sunlight for photosynthesis by marine plants. Oil also threatens the coral reefs that are home to many marine creatures. It clogs up fish gills, consumes plankton, and also hurts the sea birds.

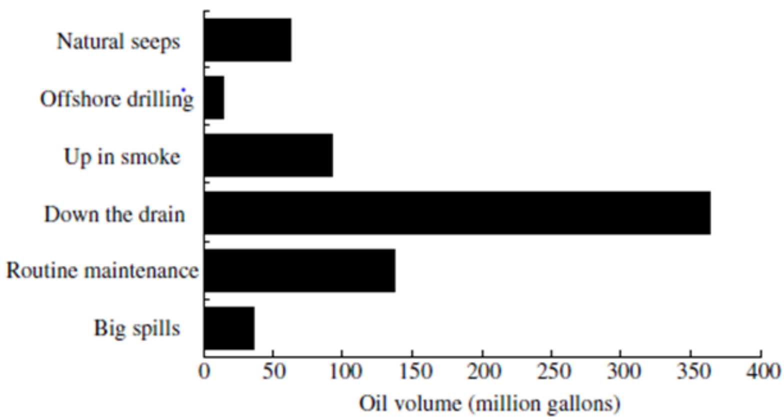

Figure 1. Oil spillage into the coastal and marine ecosystem worldwide each year from various sources in million gallons (Source: Islam and Tanaka, 2004).

Pollutants may harm the DO concentration. This is because most chemicals cause low levels of oxygen, making it impossible for marine species to live. After all, animals like fish die when the DO levels drop below 5 ppm (Sanger, and Reed, 2000). Proper waste management and recycling will help to reduce the waste from the oceans. Strict policies and efficient waste management implementation will help to significantly curb and avoid pollution of the oceans (Table 1). Affordable emission control equipment and competitive opportunities will help motivate companies to take appropriate steps to control the amount and quantity of waste that they are disposed of. Through concerted efforts from businesses and governments, small measures will bring about a sea shift.

Case study of a wide range of Mediterranean mollusc assemblies

Potential effects of sewage discharge in the Mediterranean subtidal rock ecosystem on spatial patterns of highly diverse mollusks can assemblies have been studied. Nine squares of approximately 20 cm were removed from each of the three sites (80m-100m apart) in a potentially affected area near a sewage outflow.

Table 1. Hazardous waste generated by industries (Sanger, and Reed, 2000).

Waste producer	Types
Chemical manufacturers	Acids and bases
	Reactive waste
	Spent solvents
	Waste water containing organic constitute
Printing industry	Heavy metal solutions
	Waste inks
	Solvents
	Ink Sludge's containing heavy metals
Petroleum refining industry	Wastewater containing
	Benzene and other
	Hydrocarbons
	Sludge from refining process
Leather products manufacturing	Toluene and benzene
Paper industry	Paint waste containing
	Heavy metals
	Ignitable solvents
Construction industry	Ignitable paint waste
	Spent solvents
	Strong acids and bases
Metal manufacturing	Sludges containing heavy metals
	Cyanide waste
	Paint waste

Source: Environmental Protection Agency, Solving the Hazardous Waste Problem: EPA's RCRA Program (Washing Washington, DC: EPA, 1986)

The mollusc diversity of Shannon was marginally lower but no distinction was observed between locations for the total number of species. There was a strong difference between the layout of the assembly at me and the control location improves water quality by partitioning of niches (Gomes-dos-Santos *et al*., 2020). Excessive nutrient loading of water bodies is the leading cause of global water pollution. Many environmental programs are primarily aimed at controlling nutrient levels in watersheds. Ecosystems with more species are more effective in extracting soil and water nutrients than those with fewer species. Many environmental programs are primarily aimed at controlling nutrient levels in watersheds. Research has shown that species-rich habitats are more effective in the extraction of soil and water nutrients.

Role of bioindicators in water pollution monitoring

Worldwide anthropogenic stresses have been subjected to various aquatic ecosystems, which result in a change in nutrients input, food and habit availability, an increase in nutrient inputs, and exposure to contaminants (Belore *et al*., 2002). For a biological assessment of the water quality, there is a need for bioindicators. Bioindicators are the types of biotic resources (i.e. animals, planktons, plants, and microbes) that are used to screen the health of the natural ecosystem in the environment. These are mainly used to examine environmental health and biogeographic changes (positive or negative) that occurred in the environment (Belore *et al*., 2002). Bioindicators are slightly different from biomonitors, during environmental studies the quality of change is determined by bioindicators while the quantitative information on the quality of the environment is determined by biomonitors (Chakrabortty and Paratkar, 2006). Some factors which govern the existence of bioindicators in the environment are- water, temperature, the transmission of lights, and suspended solids (Khatri and Tyagi, 2015).

Below are some major advantages of bioindicator

- To observe the synergistic and antagonistic effects of pollutants on a living entity.
- Biological footprints can be determined.
- Prior diagnosis as well as detrimental effects of toxins or pollutants can be monitored on living organisms.
- The economically applicable alternative concerning other specialized measuring systems.

Plant indicators

Plants are considered a sensitive tool for forecast and recognition environmental stress. Marine plants give important information regarding the status of the oceanic environment because they are immobile and quickly obtained equilibrium with their surroundings (Klemm, 1990). *Wolffia globosa* a flowering plant commonly known as Asian water meal or duckweed is an important tool for identifying cadmium contamination because it shows sensitivity to cadmium. Changes in the diversity or population of phytoplankton *(Euglena clastica, Trachelonanas, Phacustortus,* etc.) indicates pollution in marine ecosystems (Parmar *et al*., 2016). Phytoplankton has a specific place in terms of bioindicators because they react quickly to environmental changes, require short growth time, fast reproduction rate, and hence viewed as an excellent indicator of water quality (Parmar *et al*., 2016). Phytoplankton or microalgae are identical to terrestrial plants (contains chlorophyll) require sunlight for growth and development that's why they are light and swims on the upper portion of the water so that they can get light. These microalgae are very sensitive to contaminants like heavy metals and this thing is reflected in their population when there is a diversity change is observed in planktonic species it indicates pollution of the marine ecosystem (Hosmani, 2014, Panthari, 2017).

Animal indicators

A decrease in the number of individuals of a particular species indicates the harmful changes arise due to pollutants into the ecosystem. Negative changes in population density indicate the presence of pollutants but it may result in competition for food resources (Parmar *et al*., 2016). Animal indicator plays an important role in detecting the amount of toxin present in animal tissue. Frogs are the important bio-indicators as they are influenced by changes that occur in their freshwater and terrestrial habitat, on the other hand, zooplanktons like *Cyclops, Mesocylops, Aheyella,* etc. are zone-based pollution indicators (Hosmani, 2014). Several invertebrates and diatoms can act as bioindicators. Invertebrates live near the benthic region (also called benthos or micro invertebrates) and are a powerful indicator of watershed health because they are not distinguishable in the lab, have restricted motility, live more than a year, and integrators of ecological conditions (Khatri and Tyagi, 2015). Belore *et al*. (2002) compared the effectiveness of diatoms and micro invertebrates as indicators of environmental conditions in the lotic ecosystem and found both as potential bioindicators. Cooper *et al*. (2009) reported that coral reefs (symbiotic association between plant and animal) can also act as bioindicators of water quality.

Microbial indicators

Microorganisms are frequently used as a pollution indicator in terrestrial as well as in the aquatic ecosystem due to their abundance, easy availability, and simple testing. Some microorganisms develop stress proteins when they come in contact with heavy metals or unfavorable environments, these stress proteins are treated as early warning signs of pollution (Parmar *et al*., 2016). A group of gram-negative, rod-shaped, aerobic or facultative anaerobic bacteria known as coliforms, are the strong indicator of polluted or contaminated water with feces. Mukherjee *et al*. (2020) reported that a decrease found in the level of total coliforms in Ganges water during the COVID-19 lockdown period (April 2020) resulted in a sudden increase in water quality due temporary halt in anthropogenic activities (Adelodun *et al*., 2020). Microorganisms are also an important part of marine ecosystem biomass, they possess a rapid growth rate and have the ability to react even low concentrations of contaminants. By using bioluminescent bacteria one can easily monitor the presence of toxins in the water. Toxins disturb the food utilizing the abilities of microbes which result in alteration in the amount of light emitted by bioluminescent bacteria (Parmar *et al*., 2016).

Future aspects

Population growth, economic development, urbanization, and climate change would have a major impact on water issues by 2050. Around 780,000 people die every year from drinking dirty water, compared to 1,100 from drought and 6,000 from floods. When chemicals and other foreign pollutants leach into the atmosphere, air, and water, pollution occurs. These pollutants contain toxins that adversely affect the environments within them and the living creatures. According to the Environmental Protection Agency, between 1975 and 2015, an estimated 11% of all marine species will be extinct every decade. Water contamination is caused by industrial and agricultural runoff and, in addition to posing a danger to aquatic organisms; water pollution also impacts humans-because the loss of marine species adversely affects the food chain. When the amount of contaminants increases, human exposure to toxins may also increase. The Environmental Protection Agency states that exposure to toxins is directly linked to cancer and heart disease. Air pollution is a primary problem in urban areas and for people living near major roads, as vehicles produce high concentrations of pollutants. When air pollution increases, researchers expect that the adverse health effects of exposure will also increase. There are often negative connotations of the term "greenhouse effect" but the greenhouse effect is a natural and beneficial mechanism in which Earth's ozone prevents heat from escaping into the atmosphere. Because carbon dioxide causes Earth's temperature to rise, the ability of the ozone layer to hold heat close to the surface can cause global warming as pollutant levels rise.

Pollution may have a huge impact on the world economy due to its potential to cause disease in humans. The World Health Organization maintains that the increased risk of illness due to contamination places a financial burden on insurance providers, the government-funded health services, and the people themselves. Moreover, the more people who fall ill, the less efficient workers are available to carry out the tasks required to keep a company running. Students who are absent from school due to pollution-related illnesses that lose educational opportunities that they may otherwise have enjoyed — further increasing the potential economic burdens that communities may face as a result of pollution.

Conclusion

Freshwater is the most transformed and endangered ecosystem on Earth due to many threats. Water pollution is one of them, which involves both point and non-point sources of human activity. Water contamination poses many threats, and shielding freshwater habitats from this is the greatest challenge. The natural world makes human life possible, and the cultural climate helps to determine who we are. It is therefore necessary for our population and economic development to be environmentally sustainable. The most optimistic outlook for our future is one in which we have the right balance between:

- Continue to support and implement effective policies, programs, and resources (e.g. community engagement and volunteering programs, IMOS, India's Biodiversity Conservation Strategy 2010-2030, the Great Barrier Reef Science Strategy, the Reef 2050 Sustainability Plan, NESP, the Terrestrial Ecosystem Research Network, the Australian Heritage Strategy, the National Reserve System, the National Representative System of Marine Protected Areas, Indigenous Protected Area programs)
- Further development, testing and, where appropriate, implementation of innovative approaches and initiatives currently under development (e.g. policies, technology and management that decouple the economy from environmental harm, environmental-economic accounting and valuation, initiatives to reduce plastic pollution in coastal and marine environments, initiatives to reduce air pollutants in urban areas).
- Develop and incorporate new policies, processes, frameworks, and tools in the medium to longer-term, including greater integration of policies and management strategies across jurisdictions and sectors; (e.g. green or blue economy approaches, development of a sophisticated investment impact market, regulatory reform to provide a rapid response to new incursions of potentially harmful invasive species and diseases).

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Chapter [9]

Impacts of e-wastes on water resources and their management

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Abstract

Waste electrical and electronic equipment (WEEE) or e-waste refers to obsolete, unwanted Electrical/Electronic devices that have reached end of life. Broadly, e-waste consists of plastics, glass, printed circuit boards, ceramics, rubber, ferrous and non-ferrous metals, elements like lead, mercury, cadmium, silver, gold, platinum etc. Owing to the lack of sufficient facilities for the safe management of waste in developing countries, this waste is buried, burned in the open air or dumped into surface water bodies. e-waste disposal in landfills and incinerators does permanent damage to the atmosphere by water and soil pollution and air contamination. In sediments of water bodies near e-waste disposal sites, heavy metals (e.g., lead, cadmium, copper and zinc) and organic pollutants (e.g., PCDD / Fs and PBDEs) were found in quantities that greatly exceed the background levels. The aquatic organisms that live in the affected water bodies are highly exposed to these toxic, bio-accumulative, and persistent contaminants. This study presents an overview of toxic substances present in e-waste, their potential impact on water bodies and human health together with its management.

Keywords e-waste, Electrical and electronic equipment, Heavy metals, Human health

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Introduction

The rapid pace of urbanisation is a challenge to urban environmental management in most developing countries. Industrial revolution accompanied over the last century by developments in information technology has dramatically altered the lifestyle of the people. Electronic waste (e-waste) is one of the main waste management issues facing some urban areas. e-wastes consist of the disposal of electronic devices such as computers, telephones and mobiles. The increasingly rapid evolution of electronic technology combined with rapid obsolescence of the product has compounded the issue of e-waste (Otsuka *et al*., 2012). Much of electrical and electronic equipment (EEE) has a short lifespan and fast turnover. Frequently, obsolete or damaged EEE is not recycled or repaired, but, more likely, is simply thrown away. Thus, the amount of waste electrical and electronic equipment (WEEE), such as superseded personal computers, mobile phones, entertainment equipment, and electronic consumer equipment has proliferated immensely during the last decades. e-wastes are considered harmful, since certain components of some electronic devices contain hazardous materials, depending on their condition and density. Some highly toxic elements, such as chlorinated and brominated compounds, toxic gases, radioactive metals, biologically active materials, acids, plastics and chemical additives, are found in personal computers (PCs). The dangerous material of these items poses a threat to the environment and health. (Jain, 2009).

Today, the production of electrical and electronic device waste is the fastest growing waste source worldwide about 4% growth each year and accounts for up to 8% of all urban waste (Streicher-Porte *et al*., 2005). Globally produced e-waste is rising at a rate nearly three times faster than total solid municipal waste (Schluep *et al*., 2009). The global e-waste generation by various devices is shown in Figure 1.

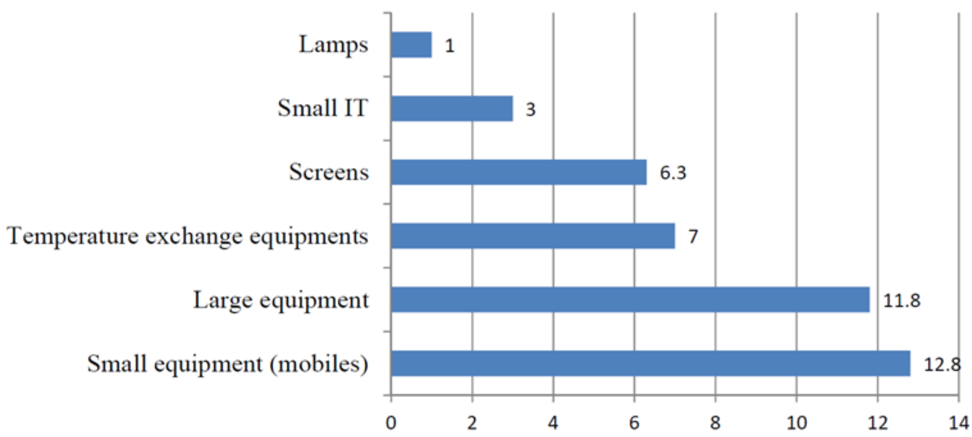

Figure 1. Global e-waste generation by different equipment
(Source: Garg and Adhana, 2019)

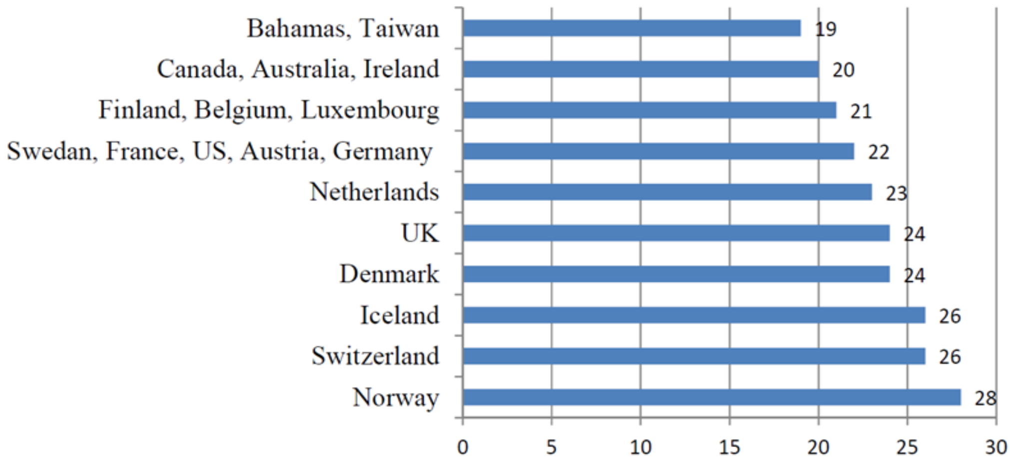

Figure 2. Highest e-waste generating countries (Source: Garg and Adhana, 2019)

The rapid obsolescence of many electronic products is triggered by the continuous introduction of new designs, smart functions and technology over the last 20 years. The service life of many electronic products has been reduced considerably due to advances in electronics, enticing consumer designs and marketing and compatibility problems. For example, a new computer's average lifespan has declined from 4.5 years in 1992 to an estimated 2 years in 2005 and is declining further (Widmer *et al.*, 2005) resulting in much higher volumes of computers for disposal or export to developing countries. The big issue with e-waste in developing countries stems from the importation of e-waste and electronic products from developed countries because it is the older, less eco friendly equipment that is discarded from these Western countries that exports 80 percent of all e-waste in developed countries (Hicks *et al.*, 2005). According to UNEP (2010), the annual e-waste generated worldwide is estimated to be 20–50 million tons (t). between 50% and 80% of such e-waste is prospectively exported to developing countries like Ghana, China, India and Nigeria (Puckett and Smith, 2002; UNEP, 2005; Frazzoli and Orisakwe, 2010; Environmental Investigation Agency, 2011; Lundstedt, 2011). In a survey, the Basel Action Network (BAN) reported that 50%-80% of e-waste collected by the United States is exported to India , China, Pakistan, Taiwan and a number of African countries (Puckett *et al.*, 2002). The largest e-waste producing countries are described in Figure 2. Few protections, legislation , policies and regulation of the safe disposal of imported e-waste and electronic products in those countries have caused significant human and environmental problems.

Electronic products frequently contain many persistent, bioaccumulative and toxic substances like heavy metals such as lead, nickel , chromium and mercury, as well as persistent organic contaminants (POPs), such as polychlorinated biphenyls (PCBs) and brominated flame retardants. In e-waste, the proportion of iron , copper, aluminium, gold and other metals is over 60%, while plastics account for about 30% and dangerous contaminants account for just about 2.70%. (Widmer *et al.*, 2005). The Basel Action Network (BAN) reports that the world's 500 million computers produce 2,87 billion kg of plastics, 716,7 million kg of lead and 286,700 kg of mercury, respectively. The typical 14-inch monitor uses a tube which is estimated to contain 2.5 to 4 kg lead. The lead will penetrate landfills into the groundwater thereby contaminating it. It releases poisonous fumes into the air if the tube is compressed and burned (Jain, 2009; UNEP, 2010). If these electronic devices are discarded along with other household waste, the toxics pose a threat to both ecological health and critical components. Thus, when disposing or recycling e-wastes, proper management is necessary. These substances can pose major human and environmental health risks if poorly handled.

Status of e-waste in India

The amount of "e-waste" or electronic waste in India has now become a major concern. Since this ever-increasing waste is potentially very complex and is also a rich source of metals such as gold , silver and copper that can be recovered and brought back into the production cycle, e-waste trade and recycling partnerships thus provide jobs for many groups of people (Baud *et al.*, 2001). Alone in Delhi, about 25,000 employees including children are involved in crude dismantling units where 10,000–20,000 tonnes of e-waste are treated by bare hands per year (Monika and Kishore, 2010). Improper dismantling and e-waste processing renders it harmful to human health and our environment. In 2005, the total waste generated by obsolete or damaged electronic and electrical equipment was estimated at 1,46,000 tonnes (CPCB, 2008). In 2007, India produced 380,000 tonnes of e-waste, according to the Greenpeace Report, and only 3% of this went to the facilities of approved recyclers. In 2009 it was recorded that e-waste produced was 69926 tonnes more than previous record. In 2011 the production of e-waste increased to 487515 tonnes showing rise of e-waste over the years with an alarming pace. Another study estimated that in India, companies and individual households annually obsolete approximately 1.38 million personal computers (Puckett *et al.*, 2002), escalating the rate of e-waste generation, which is about 10 per cent, which will impact environmental health indicators annually (Mehra, 2004).

India has emerged as the world 's fifth biggest producer of electronic waste. In 2016 , India discarded about 1.85 million tonnes of e-waste, which is about 12 percent of the world's e-waste volume. Computer equipment accounts for almost 70% of e-waste, with a share of 12% from the tele-communications industry, 8% from medical equipment and 7% from annual e-waste output. Almost 75% of e-waste is generated by the government , public sector companies and private sector companies; only 16% is the contribution of individual households. Maharashtra, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh, and Punjab are the top states, in order of the highest contribution to WEEE. The city-wise ranking of largest WEEE generators is Mumbai, Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat, and Nagpur. Table 1 shows quantity of WEEE generation in different states in India (Wath *et al.,* 2010).

E-waste categorization and contaminants

The composition of the e-waste is complex and very varied. There are over 1,000 compounds in e-waste that can be categorised as hazardous and non-hazardous compounds. The electrical and electronic equipment can be classified as follows (EU, 2002):

- Large household appliances (refrigerator, freezer, washing machine, cooking appliances, etc.)
- Small household appliances (vacuum cleaners, watches, grinders, etc.)
- IT and telecommunication equipment (PCs, printers, telephones, telephones, etc.)
- Consumer equipment (TV, radio, video camera, amplifiers, etc.)
- Lighting equipment (CFL, high intensity sodium lamp, etc.)
- Electrical and electronic tools (drills, saws, sewing machine, etc.)
- Toys, leisure, and sport equipment (computer/ video games, electric trains, etc.)
- Medical devices (with the exception of all radiotherapy equipment for implanted and contaminated products, cardiology, dialysis, nuclear medicine, etc.)

Table 1. Quantity of WEEE (Waste Electrical and Electronic Equipment) generated in Indian states (Source: Wath *et al*., 2010)

States	WEEE (Tonnes)	States	WEEE (Tonnes)
Andaman and Nicobar Islands	92.2	Lakshadweep	7.4
Andhra Pradesh	12,780.3	Madhya Pradesh	7,800.6
Arunachal Pradesh	131.7	Maharashtra	20,270.6
Assam	2,176.7	Manipur	231.7
Bihar	3,055.6	Meghalaya	211.6
Chandigarh	359.7	Mizoram	79.6
Chhattisgarh	2,149.9	Nagaland	145.1
Dadra and Nagar Haveli	29.4	Orissa	2937.8
Daman and Diu	40.8	Puducherry	284.2
Delhi	9,729.2	Punjab	6,958.5
Goa	427.4	Rajasthan	6,326.9
Gujarat	8,994.3	Sikkim	78.1
Haryana	4,506.9	Tamil Nadu	13,486.2
Himachal Pradesh	1,595.1	Tripura	378.3
Jammu and Kashmir	1,521.5	Uttar Pradesh	10381.1
Jharkhand	2,021.6	Uttarakhand	1,641.1
Karnataka	9,118.7	West Bengal	10,059.4
Kerala	6,171.8	**Total**	146,180.7

- Monitoring and control instruments (smoke detector, heating regulators, thermostat, etc.)
- Automatic dispensers (for hot drinks, money, hot and cold bottles, etc.)

The composition of the e-waste is strongly dependent on its type; there is high variation among the 10 different categories of WEEE. e-waste contains numerous hazardous chemicals and materials like heavy metals, metalloids, halogenated hydrocarbons, and other persistent and hazardous. In addition to these toxic compounds, e-waste consists of a broad range of other material, such as glass, ceramics, plastics and rubber, rare earths, non-ferrous metals (aluminum, copper, and lead), ferrous metals (steel and iron), and precious metals (platinum group metals, gold and silver) (Lu *et al.*, 2015). Some of the types of chemicals found in e-waste are identified in Table 2. Moreover, with technological advancement and pressure on producers from regulators and NGOs, the composition of e-wastes is shifting. Replacing CRT monitors with LCD displays will reduce the concentration of CRT lead, but mercury, indium and zinc are included in the LCD displays. Likewise, fibre optics may include fluorine, lead, yttrium, and zirconium, which may replace some copper wires. The rechargeable battery composition has also drastically changed, from nickel-cadmium to nickel metal hydrides and lithium-ion batteries (Robinson, 2009). In addition, there are concerns about the huge quantities of epoxy resins, fibreglass, PVC, thermosetting plastics, zinc, tin, copper, silicon, beryllium, carbon, iron and aluminium, and the trace amounts of germanium, tantalum, vanadium, terbium, gold, titanium,

Table 2. The nature of chemical contaminants that exist in e-waste (Source: Huang *et al*., 2014).

Chemical	**Source of these components**
Lead	Glass of cathode ray tubes (CRT), lead-acid batteries, polyvinyl chloride (PVC) cables
Arsenic	Integrated circuit boards
Beryllium	Connectors; Mother boards and finger clips
Polychlorinated biphenyls (PCBs)	Electrical transformers, capacitors, PVC
Cadmium	Switches, solder joints, Housing, PVC cables, cathode ray tubes, rechargeable Batteries
Polybrominated diphenyl ethers (PBDEs)	Casings
Polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs)	Formation during thermal processes
Nonylphenol (NP)	Insulators, Housing, Casing
Triphenyl phosphate (TPP)	Casings of computer monitors
Polychlorinated Naphthalenes (PCNs)	Capacitors, insulated wires
Mercury (Hg)	Batteries, flat screen electronic displays, switches, relays, Housing
Barium	CRT, Vacuum tubes

ruthenium, palladium, manganese, bismuth, niobium, rhodium, platinum, carbon, americium, antimony, arsenic, barium, boron, cobalt, europium, gallium, indium, lithium, manganese, nickel, palladium, ruthenium, selenium, silver, tantalum, molybdenum, thorium and yttrium (Chi *et al.*, 2011).

Effect of e-waste on water bodies

e-waste disposal is a particular problem faced in many regions across the globe. The irrigation canals, riverbanks, wetlands and reservoirs also end up with several tonnes of e-waste material and repair residues. This is due to the disposal of recyclable materials such as acids, sludges, etc. in rivers that transport water from remote towns to meet the population's demands. For example, due to the pollution of water supplies, Guiyu, Hong Kong, a flourishing region of illegal e-waste recycling, faces acute water shortages. Landfilled computer waste creates polluted leachates that ultimately contaminate the groundwater. When plastics-containing brominates are filled with flame retardant plastic or cadmium, both polybrominated diphenyl ethers (PBDE) and cadmium can leach into the soil and groundwater. Metals and metalloids can directly diffuse into soils and groundwater from landfills as a result of natural processes or rudimentary recycling techniques via chemical or biological seepage and thus contaminate soils, agricultural crops, and drinking water resources. As rain water flows into landfills, dumpsites and open dumps, or ash and cinnamon resulting from open burning processes, hazardous substances flee into the soil and water bodies used for domestic purposes, posing risks to human health and the environment (Fent, 2004). Significant quantities of lead ions, such as the cone glass in cathode ray tubes, are dissolved from broken lead containing glass, are mixed with acid water and are a natural occurrence in landfills (Rao, 2014). In addition, the dumping of electrical waste next to ponds is very common, and metals in these scraps might reach aquatic systems with rainwater. The metals Cd, Cr, Cu, Pb, Hg, and Tl and the metalloids As and Sb affect aquatic species in surface water bodies even at low concentrations. A study conducted by Greenpeace International (2008) at the Agbogbloshie scrap yard showed that some samples contained Cd, Hg and Pb in quantities that are considered especially toxic to aquatic life. Amoyaw-Osei *et al.* (2011) also noted that the Odaw River, formerly an important fishing ground, has become dead due to extensive pollution caused by unregulated dumping and crude e-waste processing in the region.

Luo *et al.* (2011) found a high concentration of metals in the pond area in Guangdong province of south China. e-waste combustion locations are typically near to ponds and streams in the e-waste disposal sites, since these provide a convenient water source for metal extraction processes. Large concentrations of metals can be leached from the sites and contaminate the water and sediment of the pond. The pollution of heavy metals in sediments is an important environmental issue due to the toxicity, non-degradation and fast bioaccumulation of heavy metals (Bozkurt *et al.*, 2000). In the sediments, common heavy metal pollutants include Cr, Cu , Ni , Cd, Zn and Pb (Monikh *et al.*, 2013; Nithya *et al.*, 2011).

These sediment-fixed metals can be returned to water bodies by chemical and biological processes, and subsequently transferred to downstream rivers (Liu *et al.*, 2009). Sediment is therefore the most critical heavy metal sink and can serve in estuary systems as a carrier and source of heavy metals. (Luo *et al.*, 2008; Yang *et al.*, 2012). During acid leaching processes, the acid waste and waste water produced are released into nearby streams, while solid waste is deposited on site with no or very little pollution control steps. For this reason, a thorough assessment of heavy metal contamination in sediments from acid leaching sites is critical for the environmental management and control of rivers' pollution. Considering their strong toxicity even at low concentrations, heavy metals receive special concern (Marcovecchio *et al.*, 2007). They exist in colloidal, particulate and dissolved phases of water (Adepoju-Bello *et al*., 2009) with their presence in water bodies being either of natural origin, (e.g., eroded minerals in sediments, leaching of ore deposits and extruded products of volcanism) or of anthropogenic origin (i.e. solid waste disposal, industrial or household waste) (Marcovecchio *et al.*, 2007). The Nemerow Pollution Index (PN) may represent the effect on the sediment environment of heavy metal contaminants and is commonly used to determine the overall pollution status of heavy metal sediments. (Cheng *et al*., 2007; Hu *et al*., 2013; Quan *et al*., 2014). PN is calculated as:

$$P_N = \frac{\sqrt{{P_{imax}}^2 + {P_{iave}}^2}}{2}$$

$$P_i = \frac{C_i}{C_b}$$

where Pi is the pollution index for a single pollutant; C_i and C_b are the measured concentration of a heavy metal in sediment and its background value, respectively. P_{imax} and P_{iave} are the maximum and average pollution indices of an individual heavy metal, respectively. The degrees of heavy metal pollutions in the sediments can be classified into the following categories:

- Not polluted: $P_N < 1.0$
- Slightly polluted: $1.0 < P_N < 2.0$
- Moderately polluted: $2.0 < P_N < 3.0$
- Heavily polluted: $P_N > 3.0$

e-waste processing sites are usually located in fields adjacent to land used for agricultural purposes. Heavy metals released from salvaging useful materials and from the uncontrolled open burning of electronic waste could penetrate the soils where vegetables and crops are grown by contaminated irrigation water (Luo *et al*., 2011). Bakare (2012) investigated the potential of raw and simulated e-waste leachates to induce cytotoxicity and DNA damage in Allium cepa in a WEEE dumpsite at the Alaba, Lagos State, Nigeria. Onion bulb roots were cultivated in five concentrations: 1, 5, 10, 25 and 50 % (v / v;

leachate / tap water) of each leachate sample, tap water (negative control) and 0.25 ppm (positive control) of lead nitrate. The results of the study indicate that e-waste leachate contained substances capable of inducing cytotoxicity and somatic mutations in *A. cepa* by inhibiting root growth and cell proliferation, and inducing genotoxicity at the chromosomal level. Alabi and Bakare (2014) conducted a research to study the cytogenotoxic effects and reproductive abnormalities induced by e-waste contaminated underground water in mice. The results showed that some of the physicochemical characteristics of the well waters were significantly higher than acceptable limits by USEPA (2009) and NESREA (2009). This is an indication of severe degradation of groundwater quality by e-waste activities and precludes its use for domestic water supply purposes. The high BOD level indicates that organics measured as BOD can cause taste and odor problems and oxygen depletion in the groundwater, thereby posing threat to those who drink it. The high concentration of TDS suggests a downward transfer of leachate into groundwater (Mor *et al.*, 2006; Al-khaldi, 2006; Longe and Enekwechi, 2007). High concentrations of TDS decrease the palatability of water and may also cause gastrointestinal irritation in humans and laxative effects particularly upon transits (WHO, 1997).

Effect of e-waste on human life

e-waste disposals affect human health in two ways, which include: (a) food chain issues: contamination from disposal by toxic substances and primitive processes of recycling that contribute to the introduction of by-products into the food chain and thus pass to humans; and (b) direct effect of occupational exposure to hazardous substances on employees employed in primitive recycling areas. If these electronic devices are discarded along with other household waste, the toxics pose a threat to both ecological health and critical components. Breathing difficulty, respiratory discomfort, coughing, choking, pneumonitis, tremors, neuropsychiatric issues, convulsions, coma , and even death are human health hazards from e-waste (Yu *et al.*, 2006). Table 3 shows various e-waste sources, their constituents, and impact on the health.

e-waste workers are often exposed to other dangers, such as asthma, skin diseases, eye irritations and stomach disease, leading to physical injuries and chronic conditions (Raghupathy *et al.*, 2010). Particulate matter collected from recycling areas of e-waste can cause inflammatory reaction, oxidative stress and damage to DNA (Yang *et al.*, 2011). Qu *et al.* (2007) examined the sensitivity of workers to PBDEs in China's e-waste recycling areas and found elevated levels of PBDEs with the highest BDE-209 concentration at 3436 ng / g lipid weight in the serum of the study groups. This is the highest levels of BDE-209 reported in humans so far. In the blood of children near e-waste recycling regions, high levels of Pb (Huo *et al.*, 2007; Zheng *et al.*, 2008) and Cd (Zheng *et al.*, 2008) were found. Most of the activities related to the e-waste collection, handling, dismantling, and recycling are mainly being performed by the unorganized or informal sectors lacking the technical and infrastructural abilities and knowledge

Table 3. E-waste substances, their sources and health impacts (Source: Kiddee *et al*., 2013; Rao, 2014)

E-waste substances	Sources	Health effects
Lead	Soldering in printed circuit boards, glass panels, and computer display gaskets	Damage to central and peripheral nervous systems, circulatory systems, and kidney damage Adverse effects on brain development of children; causes damage to the circulatory system and kidney
Cadmium	Chip resistors, semi-conductorsinfrared detectors, printer inks and toners	Toxic irreversible effects on human health, particularly to the kidneys
Mercury	Batteries, backlight bulbs or lamps, Relays and switches, printed circuit boards	Chronic damage to the brain. Respiratory and skin disorders due to bioaccumulation in fishes.
Nickel	Batteries, computer housing, cathode ray tube and printed circuit boards	Can cause allergic reaction, bronchitis and reduced lung function and lung cancers
Arsenic	Gallium arsenide is used in light emitting diodes	Has chronic effects that cause skin disease and lung cancer and impaired nerve signalling
Brominated flame retardants	Plastic housing for electrical gadgets and circuit boards.	Disrupts endocrine system functions
Beryllium	Motherboard, Power supply boxes	Carcinogenic (lung cancer) Inhalation of fumes and dust. Causes chronic beryllium disease or beryllicosis. Skin diseases such as warts.
Antimony	A melting agent in CRT glass, plastic computer housings and a solder alloy in cabling	Has been classified as a carcinogen. Causes stomach pain, vomiting, diarrhoea and stomach ulcers through inhalation
Plastics including PVC	Cabling and computer housing	Burning produces dioxin. It causes Reproductive and developmental problems Immune system damage Interfere with regulatory hormones

about the serious implications of the e-waste handling and disposal on environment and human health. The occupational and public exposure and the bioaccumulation of toxicants that are emitted and leached from e-waste, especially if they are stored and burned in the open air, can lead to acute and chronic health disorders. These disorders include skin and eye irritation, respiratory diseases (such as coughing, choking, pneumonitis and lung cancer, tuberculosis, and asthma), mental disorders, and diseases of the central nervous system (tremors, convulsions, and cancer) (Yu *et al.*, 2006).

e-waste management

e-waste is the fastest growing waste stream globally. A study estimated that more than 44.7 million tonnes or on average 6.1 kg/capita of e-waste was generated globally in 2016, an increase from 5.8 kg/ capita in 2014. By 2021 the annual generation of e-waste is expected to increase to 52.2 million tonnes, or 6.8 kg/capita (Balde *et al.*, 2017). It is estimated that 75% of electronic devices are retained due to uncertainty of how to treat them (Rao, 2014). Most of it is likely illegally dumped, but it is more likely that most of it is traded internationally and destined for "recycling" in developing countries where manual labor is cheaper and environmental and work protection standards are relaxed (Balde *et al.*, 2017). The potential environmental disaster over e-waste flow into developing countries will be increased not only due to the huge amount of the e-waste but also by the improper treatment methods. All EU countries have a common waste management strategy and guidelines on how to decrease the environmental impact of waste. It is called the "waste management hierarchy" (Figure 3). The waste management hierarchy is as a strategy or guiding principle for manufacturers, governmental organizations, consumers and other actors in society on how to prioritize waste management approaches to decrease its environmental impacts and increase circularity.

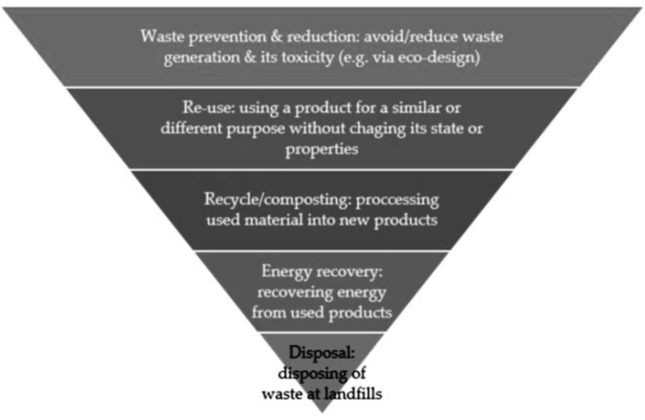

Figure 3. Waste management hierarchy (Source: Miliute-Plepiene and Youhanan, 2019)

Although there is large amount of e-waste generation in India, there is no systematized or formal system available for handling the e-waste in a scientifically as well as environmental-friendly manner. Large amount of e-waste is being treated and dumped as a municipal solid waste only. e-waste, being rich in ferrous materials, nonferrous materials, plastic, and precious materials, has turned out as a major business opportunity for many. Although understanding and readiness to incorporate changes are growing rapidly, the major obstacles to safely and efficiently managing the e wastes remain. These include the lack of reliable data that presents a challenge for policy makers who wish to implement an e -waste management strategy and the lack of a safe e-waste recycling infrastructure.

Recycling

Many of the discarded devices contain usable parts that could be preserved and assembled to create a working device with other existing equipments. It is labour intensive to extract, inspect, analyse and then reassemble components into full working machines. For the environmentally sustainable management of e-wastes, institutional facilities, including e-waste generation, transport, care, storage, recycling and disposal, needs to be developed at national and/or regional levels. e-waste recycling is environmentally sound and requires advanced equipment and procedures, which are not only very costly but also require specialised expertise and preparation for the activity. Adequate air pollution control devices are also required for fugitive and point source emissions. The most successful and scientific method of e-waste management is currently the EXIGO recycling process (Karim *et al.*, 2018). EXIGO is an Indian e-waste management company. The methodology for recycling involves:

- Collection: e-waste will be collected every week from various e-waste points.
- Transportation: The e-waste collected is transported in a safe and secure way using a closed container vehicle to the centralised recycling facility as per government standards.
- Segregation: Upon unloading, electronics waste segregation is done based on the size and available of components at the factory premises.
- Dismantling: After segregation of e-waste components dismantle separately.
- Recycling: After the storage of all important e-waste materials, the residual hazardous waste is recycled and disposed of by TSDF (EXIGO Recycling).

Volume reduction

Volume reduction involves certain approaches that remove a non-hazardous part of the hazardous portion of a waste. Usually, these techniques decrease the volume and therefore the expense of disposing of a waste material. The methods used to minimise the amount of waste streams can be classified into 2 general categories: source segregation and waste concentration. Wastes containing various kinds of metals should be handled independently so that they can recover the metal strength in the sludge. Concentration of a waste stream can increase the chance of the material being recycled or reused. Methods include filtration by gravity and vacuum, ultrafiltration, reverse osmosis, freeze vaporisation, etc. For example, a manufacturer of electronic components may use compaction equipment to reduce the volume of ray-tube waste cathode (Sepulveda *et al.*, 2010; Environmental Health Perspectives, 2004).

Sustainable product design

Efforts need to be made to design a product that requires less amounts of hazardous substances. For example, in some modern computer designs that are flatter, lighter and more integrated, the efforts to reduce material usage are reflected. Some companies are considering centralised networks similar to the telephone system. Bio-based plastics are plastics made not even from petrochemicals, but from plant-based chemicals or plant-produced polymers. There are more frequent applications of bio-based toners, glues and inks. Solar computers still exist, but they are very costly at present. Designers must ensure that the product is designed for re-use, repair and/or upgradeability since many of the products used are non-renewable. Some tech manufactures such as Dell and Gateway lease out their goods thus ensuring they get them back to further update and lease out again.

Extended producer responsibility (EPR)

Essentially, EPR is a legislative-based indirect European Commission policy designed to ensure that market pressures are harnessed through the management of EoL EEEE to achieve environmental protection. (Hume *et al.*, 2002). The Organization for Economic Cooperation and Development (OECD) has described the EPR as: an environmental policy approach in which the obligation of suppliers for a commodity stretches to the post-consumer stage of the life cycle of a product, including its final disposal (OECD, 2001; Widmer *et al*., 2005; Walls, 2006).

Collection networks need to be developed so that e-waste is collected from the right locations so that this directly falls to the recycling unit. Collection can be accomplished through collection centres. Collection Centres may only ship wastes to dismantlers and recyclers who are getting authorization for treating, handling, refining, refurbishment, and recycling meeting environmentally sustainable management guidelines. A majority of developing countries have either prepared their EPR regulations or created them. In a successful EPR system, the true cost of waste management is internalised within the retail price by the manufacturer. The goal is to provide an opportunity to produce less toxic equipment that is inexpensive and easy to recycle. The main goals of EPR are (Langrova, 2002):

- waste prevention and reduction;
- product reuse;
- increased use of recycled materials in production;

- reduced natural resource consumption;
- internalization of environmental costs into product prices; and,
- energy recovery when incineration is considered appropriate.

Conclusion

E-waste is a serious problem at both local and global scales. In developed countries, e-waste problems appeared initially and now eventually spread to other countries around the world. e-waste consists of several different materials, some of which contain a number of toxic substances which, if end-of-life management is not meticulously controlled, can contaminate the environment and endanger human health. Several case reports from e-waste recycling plants have reported that harmful chemicals such as heavy metals and POPs have polluted the atmosphere and continue to contaminate it. This results in considerable accumulation of hazardous substances into the ecosystem and which can adversely impact human health. The management and recycling of e-wastes has become a major global environmental problem as these could release considerable quantities of toxic heavy metals and organic compounds into the workplace environment, surrounding soils and watercourses. Heavy metals are among the major groundwater pollutants arising from manufacturing activities. Through leaching from dumpsites where processed or unprocessed e-wastes may have been stored, e-waste pollutants may enter aquatic systems. Similarly, the disposal of acid by hydrometallurgical processes used in the recovery of metals into water or soil, as well as the dissolution or settling of airborne contaminants during open fire, can often result in contamination of the aquatic environment. Therefore, there is urgent need for a concerted effort to be made by the relevant authorities to address the environmental and health hazards posed by the exposure to ewaste.

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Chapter [10]

Effect of untreated wastewater on soil quality: A case study in Ranipur Rao watershed in Haridwar region (Uttarakhand), India

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Abstract

The current study seeks to assess the sustainability of soil by identifying the effect of wastewater on soil nutrient quality by using the nutrient index approach in different land uses in Ranipur Rao Watershed in the Haridwar region of Uttarakhand state. The vast majority of the wastewater produced in urban areas is treated proceeding to irrigation, while in low-income nations wastewater treatment is not important. Clean water irrigated soil samples from forest area were taken as control. Wastewater irrigated soil samples were taken from industrial and agricultural areas. Soil organic carbon (%) of soil ranged from 0.70-0.84 at clean water irrigated sites in the forest area. Whereas, 0.48-0.75 at wastewater irrigated sites in the industrial area and 0.53-0.79 at wastewater irrigated sites in the agricultural area. The content of available nitrogen in soil of agricultural wastewater irrigated area indicates high status as compared to industrial and forest areas. The circumstance consequently requests the selection of fitting administration rehearses to support the fruitfulness status in study territory. These practices may include such practices as site-specific nutrient management, increased use of organic nutrient sources, sustainable land use and cropping systems, and appropriate agronomic practices.

Keywords Land use, Nutrient index, Soil fertility, Wastewater, Watershed management

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Abbreviations: %: Percent, GPS: Geographical Positioning System, pH: Potential of Hydrogen, EC: Electrical Conductivity, cm: Centimeter, mm: Millimeter, AN: Available Nitrogen, AP: Available Phosphorus, AK: Available Potassium, AS: Available Sulphate, Ca: Calcium, Mg: Magnesium, Zn: Zinc, Cu: Copper, Fe: Iron, Mn: Manganese, SNI: Soil Nutrient Index, dS/m: DeciSiemens per metre; meq/100g: Milliequivalent/100gram; SD: Standard Deviation, gm: Gram.

Introduction

The population in the world is currently growing at a rate of around 1.05% per year (down from 1.08% in 2019, 1.10% in 2018, and 1.12% in 2017). The current average population increase is estimated at 81 million people per year (Tilley *et al*., 2014). In developing countries, the increasing requirement for freshwater in agricultural production is not limited to, But needs per person and also supplies the needed irrigate resources industry needs and priorities of the urban communities in these areas (Mohson and Ali, 2017). The discharge of raw sewage in the environment, contaminating the quality of surface and groundwater streamflow (Abedikoopayee *et al.,* 2003; Karimzadeh *et al.,* 2012). So, the use of treated wastewater in agricultural areas decreases the use of water, which in addition to other practices, such as household works like bathing, washing, and maybe drinking (Alikhales and Smalzadeh, 2010; Kumar *et al*., 2018).

The vast majority of the wastewater produced in urban areas is treated proceeding to irrigation, while in low-income nations wastewater treatment is not important. Thus the combination of treated, partially treated, and untreated wastewater is commonly used for agricultural purposes (Hussain *et al.,* 2002). The World Health Organization estimates that nearly 20 million hectares throughout the world are irrigated using untreated wastewater (WHO, 1989).

In wastewater, the occurrence of organic, inorganic, and microbial contaminants is an earlier stage of depuration is necessary before reuse in irrigation. To evade the contamination of soil, crops, and adjacent water resources and accordingly the dispersion of waterborne diseases or the degradation of soil. The extent to which wastewater has to be treated before irrigation depends on the limitations established in local or international water quality criteria for irrigation (Kretschmer *et al*., 2002). Soil, the source of life, is the most essential and valuable natural resource which is not renewable quickly. Soil quality is a measure of the form of soil components with the necessities of at least one biotic species as well as to human need or use (Johnson *et al*., 1997). Soil fertility is a dynamic natural property that can alter through the impact of natural and human-derived factors (Kavitha and Sujhata, 2015). Changes in soil properties in different land use maybe because of dynamic collaborations among ecological factors like weather, parent material, geography, and land use, and land cover (Bharti and Kamboj, 2018). The fertility of the soil is determined by the presence or absence of nutrients which have agronomic importance (Lone *et al*., 2016). Soil nutrient composition plays a key role in determining the goodness of the soil. Healthy soil will have all the essential elements in the right proportions to support healthy plant growth throughout its life cycle (Art Efretuei, 2016). Degradation of soil quality has posed a threat to agricultural productivity, economic growth, and a healthy environment on a global scale (Eswaran *et al*., 2001). Different types of wastewater use in different land-use irrigation that also affect the biodiversity of soil (Bharti and Kamboj, 2020).

Maintaining soil health and sustainable agricultural production, replenishment of macro and micronutrients, and addition of soil amendments is a must in the soil to obtain good crop yields. If their status in the soil is known before the crop is sown, it provides a sound basis for determining the nutrient requirements for the desired production (Amara *et al*., 2016*)*. The extent of the beneficial impacts depends on the local conditions of the specific project. The fundamental negative part of reusing treated and untreated wastewater in agricultural areas is the contamination of soil systems, the likely defilement of yields and water resources, and the intrinsic risk of harmful impacts that pollution stances to the unprotected living beings (Juan *et al*., 2014). Nowadays, under freshwater scant conditions, it becomes almost obligatory for farmers to consider and use any sources of water, especially in many regions (Kumar *et al*., 2020).

So, Adoption of appropriate land use management practices and land use planning would help to minimize the degradation in soil physical quality and would ensure sustainable crop production and productivity (Ramesh *et al*., 2008). Therefore, this investigation was made to study the effect of wastewater on the soil in different land use in district Haridwar (Uttarakhand). The nutrient index was calculated to show the level of contamination in soils at wastewater-irrigated different land-use sites.

Study area

The present study was carried out in three different land-use types i.e. forest area, industrial area, and an agricultural area in Ranipur Rao seasonal hill river watershed area in the Haridwar region (Uttarakhand). The selection of the study area was based on their land-use patterns and type of irrigation in the land.

Sample collection, preparation, and preservation

The soil samples were collected from 0-15 and 15-30 cm. depth with the help of an auger from March 2017 to February 2018, using the GPS locations in 3 different areas. Composite soil sampling was done inside each land-use area and mixed thoroughly following a standard method for sample preparation (Andreas and Berndt, 2005). All the collected soil samples were air-dried after analyzed pH and EC and then soil samples were dried in shade, crushed with motor and pestle, and then sieved through a 2.0 mm sieve. The dried soil samples were stored for further analysis of the physical, chemical, and nutrient characteristics of soil samples.

Physico-chemical and nutrient analysis of soil

A total of 13 physico-chemical and nutrient characteristics, pH, electrical conductivity, organic carbon, available nitrogen, available phosphorus, available potassium, available calcium, available magnesium, available sulphate, available zinc, available iron, available manganese, and available copper were analyzed in the laboratory, following the standard methods (Jackson, 1958; Trivedy and Goal, 1998; Anderson and Ingram, 1993; Behera, 2014).

Soil nutrient index determination:

To evaluate the fertility status of soils in the study area, different soil physico-chemical characteristics that affect nutrient availability including pH, electrical conductivity, available N, P, K and S, exchangeable Ca and Mg, and available micronutrients (Zn, Cu, Fe, and Mn) were calculated based on the specific rating chart (Table 1) modified from Brajendra *et al.* (2014). Soil nutrient index (SNI) was worked out to depict the available status of each macronutrient at a series level by using the formula proposed by Parker's *et al*. (1951):

$$\mathrm{SNI} = \frac{(\mathrm{Nl} \times 1) + \mathrm{Nm} \times 2 + \mathrm{Nh} \times 3}{2\mathrm{Nt}}$$

Table 1. Rating chart for soil test values and their nutrient indices.

Soil property	Unit	Range		
Soil pH	pH unit	< 6.0 (Acidic)	6.1-8.0 (Neutral)	>8.0 (Alkaline)
Electrical conductivity	dS/m	<1.0 (Normal)	1.0-2.0 (Critical)	>2.0 (Injurious)
Organic Carbon	%	<0.5 (Low)	0.5-0.75 (Medium)	>0.75 (High)
Available Nitrogen (N)	kg/ha	<280 (Low)	280-560 (Medium)	>560 (High)
Available Phosphorus (P_2O_5)	kg/ha	<10 (Low)	10-25 (Medium)	>25 (High)
Available Potassium (K_2O)	kg/ha	<110 (Low)	110-280 (Medium)	>280 (High)
Available Sulphur (S)	Ppm	<10 (Low)	10-30 (Medium)	>30 (High)
Exchangeable Calcium (Ca)	meq/100g	<1.5 (Low)	1.5-4.5 (Medium)	>4.5 (High)
Exchangeable Mg	meq/100g	<1.5 (Low)	1.5-4.5 (Medium)	>4.5 (High)
Available Zinc (Zn)	Ppm	<0.6 (Low)	0.6-1.0 (Medium)	>1.0 (High)
Available Manganese (Mn)	Ppm	<0.07 (Low)	0.07-0.2 (Medium)	>0.2(High)
Available Iron (Fe)	ppm	<4.5 (Low)	4.5-5.5 (Medium)	>5.5 (High)
Available Copper (Cu)	ppm	<0.07 (Low)	0.07-0.2 (Medium)	>0.2(High)
Nutrient Index	Index	I	II	III

Table 2. Nutrient index with range and remarks.

Nutrient Index	Range	Remarks
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Where, Nt = total number of samples analyzed for a nutrient in any given area; Nl = number of samples falling in the low category of nutrient status ; Nm = number of samples falling in the medium category of nutrient status; Nh = number of samples falling in the high category of nutrient status ; An SNI value less than 1.67, between 1.67 to 2.33, and more than 2.33 indicates low, medium, and high fertility status of soil, respectively (Table 2).

Soil nutrient index of three different land-use areas was evaluated regarding pH, Organic Carbon, primary and secondary nutrients, and micronutrients, for example, Fe, Zn, Cu, and Mn. The results obtained are presented in Tables 3-6, and discussed in the following headings.

Effect of wastewater on soil pH

During the study year (2017–2018), soil from clean water-irrigated sites, i.e., forest area, showed pH values ranged from 5.78-6.76, whereas in wastewater irrigated sites i.e. industrial and agricultural area soil pH ranged from 5.72-6.90 and 7.0-7.67 (Table 3). Wastewater is a source of acidic constituents and diminishes the soil pH because of the decay of organic matter and materialization of organic acids containing elements in the soil system. (Vaseghi *et al*., 2005; Khai *et al*., 2008). The Forest area also showed slightly acidic pH because of the decomposition of plant litter residues. This indicates a low status of pH in the forest and industrial area and medium status in an agricultural area (Table 6). The fertility rating of the pH of agriculture was medium due to the continuous application of different types of fertilizers.

Effect of wastewater on soil electrical conductivity

Electrical conductivity (dS/m) of soil ranged from 0.36-0.85 at clean water irrigated sites in the forest area. Electrical conductivity ranged from 0.51-0.65 at wastewater irrigated sites in the industrial area and 0.64-0.89 at wastewater irrigated sites in an agricultural area (Table 3). The soil nutrient index of electrical conductivity indicates the medium status in all land use areas.

Effect of wastewater on soil organic carbon

Soil organic carbon (%) of soil ranged from 0.70-0.84 at clean water irrigated sites in the forest area. Whereas, 0.48-0.75 at wastewater irrigated sites in an industrial area and 0.53-0.79 at wastewater irrigated sites in an agricultural area (Table 3). This indicates the medium status of soil organic carbon

Table 3. Descriptive status of measured soil properties in Ranipur Rao watershed.

Soil reaction (pH)					
	Percent of samples falling within range				
Land use areas	**<6.0 (Acidic)**	**6.0 - 8.0 (Neutral)**	**>8.0 (Alkaline)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	5.78-6.76	6.3 ± 0.33
Industrial area	33.33	66.66	0	5.72-6.90	6.27 ± 0.48
Agricultural area	0	100.0	0	7.0-7.67	7.25 ± 0.26
Electrical conductivity					
Land use areas	**<1.0 dS/m (Normal)**	**1.0-2.0 dS/m (Medium)**	**>2.0 dS/m (High)**	**Range**	**Mean ± SD**
Forest area	100	0	0	0.36-0.85	0.60 ± 0.19
Industrial area	100	0	0	0.51-0.65	0.57 ± 0.05
Agricultural area	100	0	0	0.64-0.89	0.74 ± 0.08
Organic carbon					
Land use areas	**<0.5% (Low)**	**0.5-0.75% (Medium)**	**>0.75% (High)**	**Range**	**Mean ± SD**
Forest area	0	66.66	33.33	0.70-0.84	0.74 ± 0.05
Industrial area	16.7	83.33	0	0.48-0.75	0.60 ± 0.10
Agricultural area	0	83.33	16.7	0.53-0.79	0.65 ± 0.10
Exchangeable Ca					
Land use areas	**<1.5 meq/100g (Low)**	**1.5-4.5 meq/100g (Medium)**	**>4.5 meq/100g (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	2.65-3.35	2.99 ± 0.29
Industrial area	0	16.7	83.33	3.77-6.80	4.88 ± 1.04
Agricultural area	0	83.33	16.7	3.90-4.65	4.25 ± 0.27
Exchangeable Mg					
Land use areas	**<1.5 meq/100g)**	**1.5-4.5 meq/100g (Medium)**	**>4.5 meq/100g (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	1.89-3.55	2.55 ± 0.58
Industrial area	100	0	0	0.51-1.45	1.10 ± 0.33
Agricultural area	0	66.66	33.33	3.54-4.66	4.13 ± 0.45

in all land use areas. Due to wastewater irrigation, higher organic concentration can adverse effects on soil porosity and make anaerobic environments in the plant root zone.

Effect of wastewater on soil calcium and magnesium

Exchangeable calcium (meq/100gm) of soil ranged from 2.65-3.35 at clean water irrigated sites in the forest area. Whereas, 3.77-6.80 at wastewater irrigated sites in the industrial area and 3.90-4.65 at wastewater irrigated sites in an agricultural area (Table 3). This indicates the medium status of soil exchangeable calcium in forest and agricultural areas and high in the Industrial area due to the accumulation of calcium deposits through industrial and municipal wastewater irrigation. Soil

Table 4. Descriptive status of macronutrients in Ranipur Rao watershed.

Nitrogen (N)					
Location	**Percent of samples falling within range**			**Range**	**Mean ± SD**
	<280 Kg/ Ha (Low)	**280-560 Kg/Ha (Medium)**	**>560 Kg/Ha (High)**		
Forest area	0	66.66	33.33	281.2-573.88	429.2 ± 41.9
Industrial area	100	0	0	110.14-70.15	193.8 ± 68.86
Agricultural area	0	83.33	16.66	282.3-582.96	267.4 ± 39.4
Phosphorus (P_2O_5)					
Location	**<10 Kg/Ha (Low)**	**10-25 Kg (Medium)**	**>25 Kg/Ha (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	13.76-22.39	17.91 ± 3.37
Industrial area	33.33	66.66	0	8.96-13.74	10.25 ± 2.01
Agricultural area	0	100	0	17.85-22.23	19.8 ± 1.69
Potassium (K_2O)					
Location	**<110 Kg/ Ha (Low)**	**110-280 Kg/Ha (Medium)**	**>280 Kg/Ha (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	119.65-152.32	134.1 ± 14.07
Industrial area	100	0	0	78.32-95.14	86.81 ± 6.67
Agricultural area	0	100	0	125.32-168.65	140.7 ± 17.36
Available sulphur (S)					
Location	**<10 ppm (Low)**	**10-30 ppm (Medium)**	**>30 ppm (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	11.89-19.88	14.56 ± 3.32
Industrial area	0	0	100	53.14-75.88	62.83 ± 7.77
Agricultural area	0	0	100	31.71-42.88	37.63 ± 4.27

exchangeable magnesium (meq/100gm) of soil ranged from 1.89-3.55 at clean water irrigated sites in the forest area. Whereas, 0.51-1.45 at wastewater irrigated sites in the industrial area and 3.54-4.66 at wastewater irrigated sites in an agricultural area. This indicates the medium status of soil exchangeable magnesium in forest and agricultural areas and low in the Industrial area. Notably, wastewater irrigation alters the cation concentration in the soil which affects the nutrient and metal stability among solid and liquid phases of the soil system (Khalid *et al*., 2017b). However, the effect depends on the absorption of these cations in the applied wastewater (Table 5).

Effect of wastewater on soil macronutrient elements

AN, AP, AK, and AS are essential nutrients for plant growth. The contents of these elements were analyzed and were shown in Table 3. The content of AN in the soil of agricultural wastewater irrigated area indicates high status as compared to industrial and forest areas (Table 4-6). In wastewater irrigated soils, organic nitrogen is transformed into nitrates by soil microorganisms to a greater extent than that

Table 5. Descriptive status of available micronutrients in Ranipur rao watershed.

Zinc (Zn)					
	Percent of samples falling within range			**Range**	**Mean ± SD**
Location	**<0.6 ppm (Low)**	**0.6-1.0 ppm (Medium)**	**>1.0 ppm (High)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	0.54-0.988	0.77 ± 0.17
Industrial area	16.7	50	33.33	0.50-1.54	0.91 ± 0.35
Agricultural area	33.33	33.33	33.33	0.47-1.25	0.86 ± 0.30
Manganese (Mn)					
Location	**<0.07 ppm (Low)**	**0.7-0.2 ppm (Medium)**	**>0.2 ppm (High)**	**Range**	**Mean ± SD**
Forest area	66.66	33.33	0	0.06-0.11	0.07 ± 0.59
Industrial area	50	33.33	16.7	0.05-0.23	0.18 ± 0.83
Agricultural area	0	66.66	33.33	0.09-0.22	0.16± 0.44
Iron (Fe)					
Location	**<4.5 ppm (Low)**	**4.5-5.5 ppm (Medium)**	**>5.5 ppm (High)**	**Range**	**Mean ± SD**
Forest area	83.33	16.7	0	0.31-0.61	0.44 ± 0.10
Industrial area	50	16.7	33.33	4.26-5.86	4.49 ± 1.18
Agricultural area	16.7	50	33.33	4.19-5.89	4.94 ± 0.65
Copper (Cu)					
Location	**<0.07 ppm (Low)**	**0.7-0.2 ppm (Medium)**	**>0.2 ppm (High)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	0.02-0.20	0.08 ± 0.03
Industrial area	0	66.66	33.33	0.14-0.23	0.17 ± 0.02
Agricultural area	16.7	83.33	0	0.05-0.19	0.15 ± 0.17

observed in non–irrigated agricultural soils (Ramirez *et al*., 2002). This indicates the high status of AP in forest areas as compared to wastewater irrigated sites. AK was higher in agricultural areas as compared to the forest and industrial areas. AS indicates the high status in industrial areas due to the accumulation of sulphate deposits through various industrial plants. Industrial and domestic wastes of the industrial area (SIDCUL and BHEL) are discharged into the seasonal river Ranipur Rao, Haridwar that leads to the change in nutrient status of soil in the adjoining areas (Kamboj *et al*., 2013).
This indicates that wastewater irrigation will be of benefit to soils in elevating some of the nutrient elements. Forest planting, especially the use of wastewater for irrigation, can effectively elevate soil nutrient contents, improving soil fertility (Peiyue *et al*., 2014).

Table 6. Nutrient indices of major and micro nutrients in soils of Ranipur Rao watershed.

Parameters	**Units**	**Forest area**		**Industrial area**		**Agricultural area**	
		Nutrient index	**Fertility rating**	**Nutrient index**	**Fertility rating**	**Nutri-ent index**	**Fertility rating**
pH		1.0	Low	1.66	Low	2.0	Medium
Electrical conductivity	ds/m^{-1}	2.0	Medium	2.0	Medium	2.0	Medium
Organic carbon	%	2.33	Medium	1.83	Medium	2.0	Medium
Available nitrogen	Kg/ha	2.33	Medium	1.0	Low	2.16	Medium
Available phosphorus	Kg/ha	2.0	Medium	1.33	Low	2.0	Medium
Available potassium	Kg/ha	2.0	Medium	1.0	Low	2.0	Medium
Available calcium	meq/100 g	2.0	Medium	2.66	High	2.16	Medium
Available magnesium	meq/100 g	2.0	Medium	1.0	Low	2.34	Medium
Available sulphate	ppm	2.0	Medium	3.0	High	3.0	High
Available zinc	ppm	1.83	Medium	1.0	Low	1.83	Medium
Available iron	ppm	2.16	Medium	1.0	Low	2.16	High
Available manganese	ppm	1.33	Low	2.30	Medium	2.37	High
Available copper	ppm	1.0	Low	2.37	High	2.22	medium

Effect of wastewater on soil micronutrient elements

Zinc is essential in plants for several biochemical processes such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and the maintenance of membrane integrity (Halvin *et al*., 2010). The available zinc content was highest in the industrial area i.e. 1.54 mg/kg. The available manganese content was highest in the industrial area i.e. 0.23 mg/kg i.e. slightly high from safe limits. Iron is a vital micronutrient for almost all living beings. It plays an important role in metabolic processes like DNA synthesis, respiration process, and photosynthesis processes (Raut and Sahoo, 2015). The available iron content was highest in the agricultural area i.e. 5.89 mg/kg. Copper is also an important micronutrient, required for lignin synthesis and acts as a constituent of ascorbic acid, oxidase, phenolase, and plastocyanin in plants (Halvin *et al*., 2010). The available copper content was highest in the industrial area i.e. 0.23 mg/kg. The nutrient index indicates the high status of Cu in the industrial area, it creates several defects in the human system. The low status of Cu, Mn, and medium status of Zn and iron was found in the clean water irrigated forest area. In the agricultural area, Zn indicates medium status. Fe, Cu, and Mn indicate the high status due to wastewater irrigation and recommended fertilizer applied. Long-term irrigation with raw effluents causes amassing of high concentration of heavy metals in soil and therefore in crop plants (particularly leafy vegetables), which can be phytotoxic to crop plants and wellbeing risk to animals and humans.

Conclusion

The results of the current study concluded that long-term application of wastewater in Ranipur Rao Shivalik hill watershed areas, nutrients, and total organic matter increasing in the soils; but there is anxiety related to soil EC increment and the accumulation of possibly toxic elements, like Pb, Cu, and Ni. To avoid unnecessary destructive impacts from the wastewater applied to the soil, regular evaluation of soil quality in such regions is essential. Furthermore, remediation techniques along with management strategy are needed in the study area which is considering a key point for soil quality improvement.

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Chapter
[11]

An overview on enormous effect of hazardous wastes on water components and their management

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Abstract

Hazardous waste substances are reaching an alarming level with the increasing pace of development, thus posing a severe threat to different segments of the environment. There are different sources from where hazardous substances are getting into the system such as electronics, thermal and nuclear power plants, mining practices, metallurgical departments, weapons, biomedical, etc. The waste generated by the above said activities enter into the water system, they start deteriorating the quality consequently bringing about the greater extent of change. Therefore, proper management practices should be adopted for storage, segregation, transportation, and disposal. In today's scenario, few land-spill sites for the disposal of hazardous waste are available in-country, rest all the wastes dumped into the nearby water bodies. Certain rules and regulations are mentioned by the central governing bodies in India, to reduce the hazardous waste generation and minimizing the effect of waste on which are still present and not handled properly. Thus, keeping the perspective on seriousness, in this chapter we reviewed and discussed various sources of hazardous waste and their impact on water bodies. Also, we mentioned about the remedial measures and conservation practices to be adopted.

Keywords Hazardous waste, Human health, Waste management, Water pollution

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Introduction

For the progress of any country, development is a key step, but the thing is that it must not affect the livelihood of the future generation. Due to the increased human populace and greater consumption of energy, lack of alertness is taking place. People are not focusing on the adverse effects of the deteriorating environmental conditions and expelling harmful substances into the environment to a greater amount (Li *et al*., 2019). When anything jumps above the required limit or the permissible limit, it gets blasted up and the good material started being called as "waste". There are different types of wastes depending upon their sources and origin and every waste has specific properties (Leelavathy *et al*., 2018). The material that banishes from the household and non-household area including harmful materials that affects the surrounding, can be called as "hazardous" (Fazzo *et al*., 2017). It may include substances like industrial solvents, extracts from thermal and nuclear plants, electronic waste, sludge from industries, chemical waste, batteries, electrical equipment, metallurgical extracts and medical equipment etc. There are various factors on which the degree of threat of hazardous waste depends such as complexity, corrosiveness, reactivity, quantity, mobility, persistence, toxicity, availability and local environmental conditions, etc. depicted in Table 1 (Misra and Pandey, 2005).

The sources are categorized into the following two categories one is point source that are the contaminants enter to the water body through the single or identifiable route which may be a pipe or ditch and other is non-point source that are multiple routes for the entrance to the water body or small amount of pollutants assembled from a huge area for e.g. leaching out of nitrogen compound from the fertilized land (Li *et al*., 2011). Whatever the source will be, once the hazardous waste enters the water body, it will alter the quality thus harming the life living under. Besides this, if human consume the water containing the contaminants in any form, will suffer from various health issues. Sometimes fatal conditions can also happen. Proper management techniques should be adopted before disposing the waste into open space or the aquatic system to limit the impact on ecosystem. Since hazardous waste poses a greater threat to the receiving body, so keeping this in mind we have studied and conferred about various sources of hazardous waste and their impact on water bodies. Also, we have mentioned the curative measures and conservation practices to be adopted.

Sources of hazardous waste

There are several sources by which hazardous wastes are being liberated into the environment including different water bodies. Some of them are listed below, which proves to be the major topic of concern illustrated in Table 2 and Figure 1. They are as follows:

Electronics sector

The electronic segment is one of the fastest-growing markets in the world. The rate at which the genera-

Table 1. Characteristic of hazardous waste and their effect on the environment and living beings.

Characteristics of hazardous waste	Hazards they convey to the environment and living beings
Corrosive	The liquid which has a pH of less than or almost 2 and more than or almost 12.5 can be called as corrosive liquid hazardous waste. Sodium hydroxide and Hydrochloric acid use to clean and degrease the metals before painting in many industries. When these liquids are disposed of, affect the receiving water bodies. The plants and animals also get affected severely when comes into direct contact. Rust removers, battery acids, acid or alkaline cleaning solvents, etc.
Infectious substances	The microorganism in hazardous waste and the toxins they contain are answerable for initiating various diseases in living beings. Sharps, cadavers, swabs, bandages etc.
Noxious	The wastes can cause death, severe damage to health if swallowed, taken inside through the pores of the skin and by direct contact. Besides this, it brings about the lethal conditions to the aquatic biota.
Combustible	The substances that bring about change in the surrounding by release of harmful gases at elevated temperature and pressure thereby causing fire hazards. The combustible hazardous waste substances according to EPA are coded as D001. Petroleum parts washer solvents, solvent-based paint waste, waste kerosene or gasoline, spent paint booth exhaust filters.
Oxidizing	The substances that liberate oxygen and are responsible for the combustion of other materials Chromate, bromate, hypochlorite, etc.
Eco-toxic	On the accumulation, these substances have direct or delayed impact on the environment and aquatic biota. Petrol, diesel, oils, paints etc.
Organic peroxide	The waste that contains –O-O- bond structure and can undergo a self-accelerating exothermic reaction. Butanone peroxide, ethyl methyl ketone peroxide etc.
Reactivity	Waste reacts with water and forms toxic substances that are explosively dangerous. It contains cyanides, sulfides that are released to the when exposed to alkaline or acidic medium. cyanide plating waste, waste concentrated bleaches, pressurized aerosol cans, metallic sodium, and potassium.

tion of electronic gadgets is increasing, with the same ratio of waste generation, is also hiking. In informal terms, electronic wastes are called the "e-waste" (Radha, 2002). E-waste can be defined as the materials that are being discarded after the utmost use or the gadgets that get broken up and thrown away directly without getting segregated and recycling. This may include laptops, computers, cellphones, printers, LEDs, LCDs, etc. that are made up of complicated mixtures of plastics, metals and other alloys (Osibanjo *et al.,* 2008). These are very complex with non-biodegradable properties and are dumped into the ground after being discarded. As time passes by, they appear as mountain heaps creating a burden to the mother earth. The electronic gadgets contain small amount of toxic substances such as BFRs, PCBs, Lead, Cadmium, Plastics, *etc.* that affect the soil quality when gets infiltrate thereby polluting the underground water. This, in turn, harm human life and environment as well

Table 2. Impact of hazardous waste from different source on water and human.

Source	Major contributors	Process that generates hazardous wastes	Effect on water bodies	Effect on human health	References
Electronic sector	Cathode ray tube, Circuit boards, Chips and gold-plated components, plastics from computer accessories, Secondary steels and copper from smelting unit, refrigerator, Television, mobile phones	Dumping, Breaking and removal of copper, open burning, chemical stripping along river banks.	Leaching of heavy metals contaminating the groundwater bodies, discharge of hydrocarbon ash in surface water bodies.	Silicosis, respiratory irritation, pulmonary edema, circulatory failure and death	Kumar and Tripathi, (2007); Dwivedy *et al.* (2010); Gupta *et al.* (2011) .
Nuclear power plant	Nuclear reactors, Nuclear fuel reprocessing	Near surface disposal and deep surface disposal, aqueous waste sorption, precipitation, evaporation etc.	The aquatic biota gets destroyed due to radiation	Mental retardation, mutation, cancer, fetus gets destroyed before birth, reduced fertility	Islam *et al.* (2014)
Mining practice	River beds, Dunes, Coal, Gold, and other activities	Underground mining of coal, acid mines, and sometimes river bed	Disturbed the water quality with higher turbidity, and also the effect on distribution and abundances of the aquatic organisms	In river bed mining the major caused socio-economically impacts, Acid drainage mine caused skin irritation kidney damage and neurological disease	Garland (2012); Kamboj *et al.* (2017); Kamboj and Kamboj (2019, 2020)

Table 2. *Continued...*

Source	Major contributors	Process that generates hazardous wastes	Effect on water bodies	Effect on human health	References
Agriculture hazardous waste	Pesticides, fertilizers, other chemicals like phosphate, nitrates, sulphides.	Runoff, direct consumption of crops that are growing using pesticides	Bioaccumulation, Eutrophication	Cancer, neurological disorder	Kumar *et al.* (2020a, b)
Hazardous heavy metals	Sewage and untreated waste water	Directly dumping or adding the untreated waste water in water re-sources	Contaminates the water quality, eutrophication condition, and affect on the food chain cycle of the water source	By bioaccumulation process, it can be affected by various diseases such as Diarrhea, Cancer	Lee *et al.* (2002); Musilova *et al.* (2016)
Thermal power plants	Spent catalyst, waste mineral oil, waste resin, lead-acid battery, waste asbestos, waste chemical, terminal concentrated brine, wastewater crystalline salt, and fly-ash.	Direct landfill, melting, so-lidification, crushing, separation, pressure fil-tration, distil-lation.	Leaching of heavy metals, Contamination in the nearby water bodies, bioaccumulation	Brittle hair, deformation of nails, neurological damage, cancer, lung and heart disease.	Vasistha (2014); Shao and Li (2019)
Biomedical waste	Syringes, medical sharps, vials, ampules, tubing, gloves and gowns, wasted drug, PPE kit.	By collection, segregation and transpor-tation	Dumping of these wastes directly affect the water quality by increase the number of pathogens and bioindicator species	Hepatitis B and C, HIV	Sharma and Chauhan (2008); Rajor *et al.* (2012)

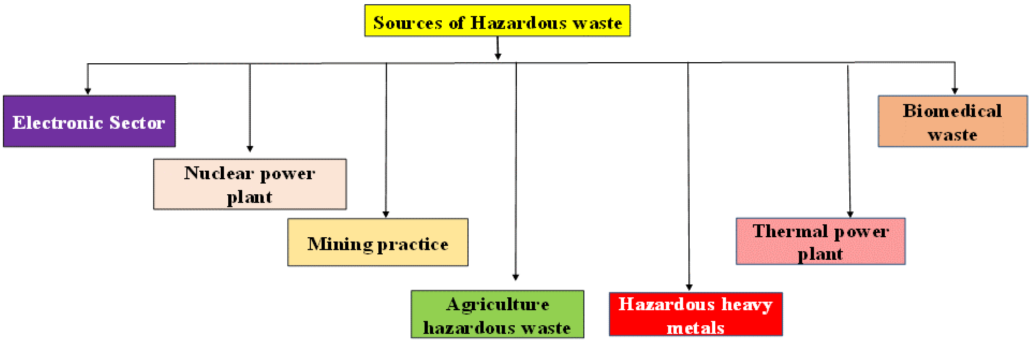

Figure 1. Sources of hazardous waste.

(Otache *et al.*, 2012). The rate of increase in the generation of e-waste is three times greater than that of municipal solid waste (DIT, 2003). It is estimated that every year 2.7 million tons of e-waste is generated in India. Since the disposal of e-waste is a big problem in India and becomes the 5th largest producer of this type of waste. In India, the proper disposable site for hazardous electronic waste are not up-to-date. The landfill sites are found to contain a prominent amount of heavy metals that get leached out in the ground, thereby contaminating the groundwater quality. The e-waste is not handled properly as municipal solid waste landfills have a linear system and sometimes fails to collect and remove the leachate ejected out. While in the developed country the e-waste is managed by inappropriate routes including open dumps, unsanitary landfills, recovery of the material, backyard recycling etc. (Osibanjo *et al.*, 2008). Figure 2 shows different stages of e-waste. We are moving toward the development and updating ourselves with new technologies. After the primary use the electronic gadgets are being disposed of into the landfill areas. When this waste comes in contact with rainfall, leaching process starts taking place. The leachate from the landfill areas starts moving below the ground and contaminates the groundwater quality. When the land gets irrigated using the ground water source get enriched with greater amount of nutrients. In some way it is good for the growth and yield of crops but on the other hand if the limit exceeds various nutrient related problem starts. And, when human consume the crops contaminated with heavy amount of nutrients, also get suffered from various diseases.

Nuclear power plants

The extra material after the utilization of the radioactive materials in the atomic reactor during the creation of atomic weapons is called as radioactive waste (Khelurkar *et al.*, 2015). The radioactive waste

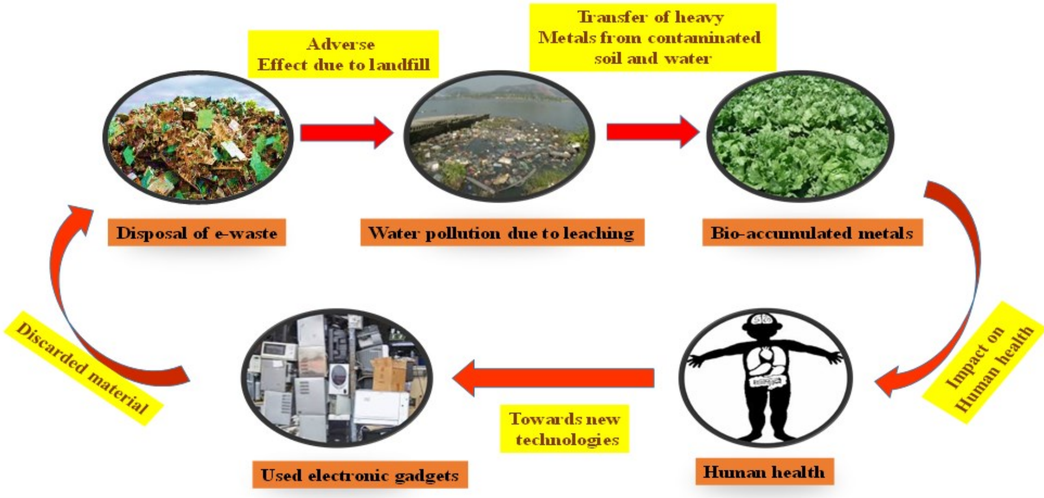

Figure 2. Different stages of hazardous e-waste formation.

a huge amount of radiation in the form of rays such as alpha, beta, gama and neutron radiation which directly affected the environment. If these are handled properly, have lesser harm but if not can destroy the whole population within a short span of time (Islam *et al.*, 2014). Mostly, the nuclear waste is disposed into the oceans and seas. When they are dumped, they release harmful rays which directly affect the reproduction and growth of the aquatic organisms (Khelurkar *et al.*, 2015).

Mining

The extraction of metals and other mineral substances from the earth is called mining (Hudson, 2012). In developing countries, mining is one of the most vital sources of the economy and employs many laborers working in the field (Sumi and Thomsen, 2001; Jhariya and Chaurasia, 2010). Mining whether on a small scale or at a larger scale extremely affects the environment by producing prominent amount of wastes that affect the environment for many years (Sumi *et al.*, 2001; Kitula, 2005). Mining results in the degradation of land and forest, loss of flora and fauna, soil erosion, breakdown of water channel, contamination of surface and groundwater (Kamboj *et al*. 2017). Due to the mining practice, surface and groundwater pollution takes place (Kamboj and Kamboj, 2019). In mining activity, huge amount of water is being used for extracting the material. Some of them reuse the water intake, while some dispose of the, left out water after the use of the nearby areas (Sumi *et al.*, 2001). Mainly the sulfides containing minerals are being thrown out into the air whereon reacting with water and form sulphuric acid (Sumi 2012; Hudson, 2012). The surface and groundwater greatly affected by the elevated concentration of hazardous chemicals like arsenic sulphuric acid and mercury (Kamakar *et al.*, 2012). The impact of adulteration in the mining area is due to the substances used in the mining process and the metals which are been extracted from the raw material (Hudson, 2012). A huge quantity of water obtained after the process of mine drainage, mine cooling, aqueous extraction and other such processes, contains massive amount of chemicals that contaminate the surface and groundwater (Dasgupta, 2012).

Agriculture hazardous wastes

With the increase in agriculture practices, the rate of use of fertilizers and pesticides, and other livestock products is increasing day-by-day, to enhance the yield. These products have a serious impact on the water bodies if discharged loosely without prior treatment. The water from the agrarian practices contains constituents such as nitrates, phosphates, sulfates, pesticides, etc. When the nitrate content reaches high above the permissible limit, it starts hindering the normal activities of water thus degrading the quality. Besides, these pesticides directly or indirectly emit harmful substances to the water bodies. The intensified level of both the substances directly affects the aquatic flora and fauna and life living on land that are plants and animals (Bharti and Kamboj, 2019; Kumar *et al.* 2020a). The pollution of land takes over a wider area, so it's difficult to define their source and identification becomes a tedious task. On the other hand, control of agriculture water pollution also becomes difficult. Predicting the degree of pollution in agriculture water varies with different parameters such as a pattern of rainfall, slope of the land, the chemical supplements used in the field, the features of soil, the type of crop used, production methods used, etc. Utilization of the fertilizers in the agrarian system and dumping of the animal and human waste into the land results in leaching of nitrate in high amounts, thus the groundwater quality gets changed. Overburden of the nutrients directly affects the surface water quality when water and soil containing nitrogen and phosphorus streams alongside overflow into close by waters Kumar *et al.* (2020b). In the modern trend of agriculture, farmers start using waste water for irrigation purposes. The water contains higher concentration of salts, nutrients and heavy metals too. Due to the increased concentration of these constituents, limitation of water uptake by plants takes place resulting in high-stress conditions and low crop yield. Further when the consumer consumes the food grown by contaminated water, suffers from high health risk.

Hazardous heavy metals

Aggregation of heavy metals in the biological system over an extensive period compared with the chemical concentration in the environment ends up being dangerous for water and human health (Verma and Dwivedi, 2013). Various sources are responsibly contaminating the water bodies like industrialization and urbanization that increases the heavy metal concentration. These heavy metals are migrated through the industries, municipalities and urban areas through runoff and get accumulated in the soil and sediments of the water bodies (Musilova *et al.,* 2016). Many of the heavy metals are found in water body in a very trace amount that is very toxic. This is because the toxicity level of a metal depends on factors such as the organisms which are exposed to it, its nature, its biological role and the period at which the organisms are exposed to the metal. Food chains and food webs symbolize the relationships amongst organisms. Therefore, the contamination of water by heavy metals affects all organisms. Humans, an example of organisms feeding at the highest level, are more prone to serious health problems because the concentrations of heavy metals increase in the food chain (Lee *et al.*, 2002).

Thermal power plants

Thermal power plants are the conventional means, used for the generation of electricity using coal as a raw material. In the whole process of electricity generation, various hazardous waste is being generated that proves to be harmful to water and human life. According to national hazardous waste list different hazardous waste materials such as spent catalyst i.e. Vanadium-titanium catalyst used for denitration, waste mineral oil used for rotating instrument and resin used to purify demineralized water, waste from lead-acid battery, asbestos waste pipe, tanks. towers etc. on the outer surface of power plants, needs to be covered by asbestos, different harmful chemicals, fatal concentrated saline water, wastewater, slats in crystalline form salts from desulfurization wastewater are being generated (Shao and Li, 2019). Huge amount of fly ash is generated near the thermal power plants. It contains heavy metals like lead, mercury, arsenic and chromium which depends upon the type of the coal used. The fly ash ejected from the plants are either use in building structures or are directly dumped into the ash pond. Ash ponds are small lake like structure which are present behind the brick wall. The affect of fly ash is on water bodies is that it spread over the water body and creates a thin layer of ash that hindered the passing of sunlight. If a proper sunlight is not entering in the water bodies such as ponds and lake. The less amount of sun light penetration increases the biochemical oxygen demand and affected the food chain process of that water body (Shao and Li, 2019).

Biomedical wastes

Biomedical wastes are those waste that incorporates different discarded materials from the clinics, nursing homes, hospitals, medical shops, etc. have variable physiognomies and composition. They are harmful to the environment if not managed properly and exposed directly to the populace (Manzoor and Sharma, 2019). The waste generated in these sectors contains 85%-90% of hazardous waste (i.e., the waste almost similar to domestic waste, free from body fluids) and 10%-20% of hazardous waste. These 10-20 % of wastes are a greater matter of concern as they are harmful and infectious depicted in figure 3 (Rajor *et al.*, 2012). Biomedical waste is either generated from the primary source or the secondary sources depending upon the amount of the waste generated. The major source sectors of biomedical waste include hospitals, labs, research centers, blood banks, animal research and nursing generate. While, the minor source sectors of biomedical wastes include dental clinics, vaccination centers, funeral services, cosmetic piercing and ambulance services (Sharma and Chauhan, 2008). Different medical representatives such as doctors, nurses, ward boys, workers in additional services, patients, visitors,

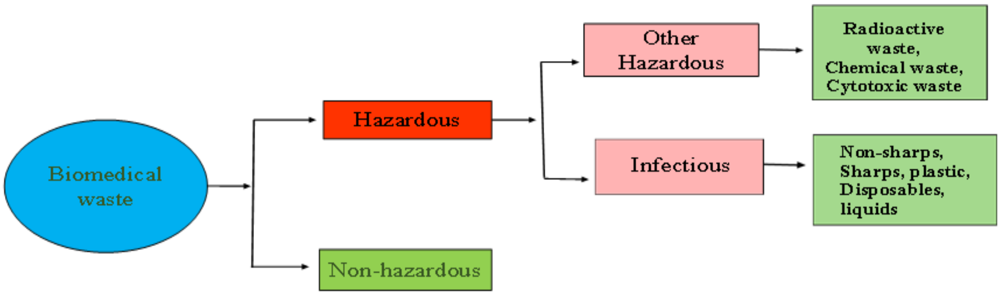

Figure 3. Types of hazardous wastes generated from biomedical practices.

workers dealing with waste disposal and treatment are very prone to have health-related issues. The three main infections commonly transmitted amongst the workers are hepatitis B, Hepatitis C, and HIV. It was estimated that out of 35 million health workers throughout the world, 3 million suffers from the greater exposure to blood-borne pathogens, 2 million affected by Hepatitis B and 0.9 million people from Hepatitis C whereas 1.7 million people from HIV. The workers involved in the collection, segregation, transportation also have a high risk of exposure (Blenkharn, 2006). When these wastes are dumped into the adjoining water bodies such as surface water bodies or in the lowland areas affects severely the water bodies either due to chemical, radioactive or biological materials respectively. Dumping of these waste results in the enrichment of the nutrients in the form of heavy metals and other nutrients thus causing the bioaccumulation and eutrophication (Sharma and Mathur, 2002). Due to which the dissolved oxygen in the water bodies gets hindered and the number of bio-indicator organisms such as *Euglena*, *Volvox*, *Vaucheria*, *Paramecium* etc. are high and the fresh water organisms such as *Spirogyra*, *Closterium*, *Cladophera*, *Daphnia* and *Diatoms* are found in fewer number thus resulting in the loss of aquatic life (Kamboj and Kamboj, 2020).

Impact of hazardous waste on water and human health

Due to the fast-moving rate of industries establishment together with the changing pattern of lifestyle, huge damage to the environment is taking place with the release of hazardous wastes. Many of the chemicals released from the anthropogenic activities such as the metals, metalloids, non-metallic substance, and wastes both organic and inorganic, our ecosystem sometimes fails to biodegrade and mineralized them. So, they remain unattended and gets accumulated in either water bodies both surface and ground or other components of the ecosystem. When the effluents containing the hazardous substances are released from different sources including industries, agrochemicals, biomedical unit, leachates from e-waste, etc. immensely pollutes the surface and groundwater bodies. In agriculture practice, the use of various organic substrates i.e., pesticides, fertilizers, fungicide, rodenticides, weedicides, herbicides, weedicides, bactericides, etc. brings about acute water pollution. These chemicals reach the nearby water bodies through the run-off from the fields. There are several chemicals such as DDT, BHC, Aldrin, Dialdrin, Chlordane, Endosulphan, etc. when get assimilated with the water bodies, brings about drastic chemical changes. Thus, resulting in severe health issues for men and animals. These chemicals have mutagenic properties and may bring about cancer-like disease.

Management of hazardous waste

Management of hazardous waste substances is a very tedious task that involves intensive labor and subsequently a larger area for the setup. Depending upon the origin and the source of the hazardous waste outlet, different managing techniques and conservation methods are being adopted. Some of them are list below:

Bioremediation

Deterioration of harmful toxic substances by changing them into harmless substances like carbon dioxide and water under the presence of certain micro-organisms is called bioremediation. It very well may be performed either on location (in-situ) in the existence of microorganisms or expansion of bacterial or fungal strains to the bioreactors (ex-situ) to detoxify the hazardous substances present. In other words, we can say that bioremediation is the process in which native microbial population, with or without any nutrient supplements are added or injection of exogenous substances into the site. When the microorganism is added by the external source, the process is known as "bio-augmentation". In both cases the harmful substances are being removed without the formation of any new toxin (Bennett *et al.*, 2002). Microorganisms assume a significant function in bioremediation as their metabolic rate is high and can degrade the polluted sample rapidly. It can be possible for them as they use energy for their development utilizing aerobic and anaerobic respiration, fermentation and co-metabolism under the presence of degradation inducing enzymes (Rose, 2002). The breakdown of chemical compounds under the presence of microbial colony is called as "biodegradation". When biodegradation process gets complete, "bio-mineralization" starts i.e. the breakdown of the complex chemical substances into simpler forms such as water, carbon dioxide and other inorganic end products. Biotransformation is frequently used as a synonym for bioconversion, in which one molecule (the predecessor) gets converted into another molecule (the products) catalytically through a single step biochemical way. When the breakdown of the chemical substances is done for the economical purpose, it will be called "bio-deterioration". It sometimes used for the substances that are resistant toward degradation such as plastics materials, metals substances, drugs, electrical gadgets, fuel and oil and other alike products (Rose, 1981, Bennett *et al.*, 2002). There are several bioremediation techniques have can be adapted to detoxify the harmful hazardous waste from water and other components of the ecosystem but it is broadly divided into two main categories: microbial bioremediation and phytoremediation. In microbial bioremediation the bacterial colony such as *Bacillus, Pseudomonas, Arthrobacteria, Flavobacterium, Deinococcus radiodurans* are used to convert harmful substances into mild byproducts through cellular metabolism. Besides, in phytoremediation the aquatic plants such as *Lemna, Pistia, Nelumbo, Eichornnea*, are used to remediate the heavy metals from the polluted wastewater (Thakur, 2006).

Mycoremediation

When fungi are used as a raw material for the remediation of a contaminated water system, then this type of remediation is known as mycoremediation. The extracellular cellular enzymes are secreted from the fungal cell which thereby helps to destroy the complex hazardous substances. They derive the energy for their growth and development through it. The extracellular enzymes have the potential to degrade the non-cellulosic substances such as plastics, hydrocarbon pollutants, various dyes, the agriculture supplements such as pesticides and fertilizers and the nutritional wastes (Singh *et al.*, 2008). In the whole process several fungal species are used such as *Phanerochaete chrysosporium*, *Pleurotus flordia*, *Trametes hirsute*, *Ceriporiopsis subermispora* etc, in order to degrade the hazardous wastes. The enzyme secreted by *Pleurotus* species are used mainly to use degrade the chemically derived dyes. It is due to their adaptable enzymatic framework (Benette *et al.*, 2002). A large number of fungal species have the ability to absorb the heavy metals such as Cd (Cadmium), Cu (Copper), Pb (Lead), Hg (Mercury), Zn (Zinc), etc. into their mycelium and spore chamber. It was seen sometimes that the dead mycelium stores quite large amount of these heavy metals than the living form. The system developed by using *Rhizopus arrhizus*, used for the treatment of U (Uranium) and Th (Thorium) (Treen-Seares *et al.*, 1984).

Phytoremediation

It is the process in which plants are used to remediate partly or considerably the specific contaminants from the surface, sub-surface water, soil, sludge, sediments, wastewater, etc. The plants used for the process may be aquatic, semiaquatic and terrestrial. The phytoremediation process is illustrated in the Table 3 (Kumar *et al*., 2019).

Bio-sorption

Expulsion of toxins from the water system by the utilization of the biological materials with the involvement of absorption, adsorption, and exchange of ions, surface complexation and precipitation are known as bio-sorption. The bio-sorbents have a benefit that their efficiency rate is high, easily

Table 3. Different types of phytoremediation used for hazardous waste treatment (Ghosh and Singh, 2005).

Method	Explanation	Media	Contaminants	Plants involved
Rhizodegradation/ phytodegradation	The microbial degradation stimulated by plants in the rhizosphere	Sediments, soils, sludge's	Aliphatic and aromatic petroleum hydrocarbons (Organic), pesticides, solvents containing chlorine	*Jatropha*, *Brassica*, S everal grasses, *Alfa alfa*, *Cassia*.
Phytostabilization	The contaminants gets stabilized through binding and complexation	Sediments, soils, sludge's	Heavy metals (Inorganic): Arsenic (As), Cd (Cadmium), Cr (Chromium), Cu (Copper), Pb (Lead), Zn (Zinc)	*Helianthus*, *Chenopodium*.
Phytoextraction	Accumulation of contaminants in the soil/ water bodies that roots uptake or the harvestable shoot	Sediments, soils, sludge's	Heavy metals (Inorganic): Arsenic (As), Cd (Cadmium), Cr (Chromium), Cu (Copper), Pb (Lead), Zn (Zinc) and radio-nuclides	*Helianthus*, *Brassca*, *Alyssum*, *Thlaspi*
Rhizofilteration	Contaminants are removed by the roots	Surface-water, groundwater and wastewater	Inorganic Metal and radionuclides (^{137}Cs, ^{230}Pb, ^{238}U)	*Eichhornia*, *Lemna*
Phytovolatilization	Contaminants gets volatilized from the leaves	Sediments and soil	Organic/inorganic Se (Selenium), Mercury (Hg), Arsenic (As)	*Scirpus*, *Poplar*, *Phragmites*

accessible and have capability of bind the heavy metals on its surface. They are most favorable option for removal of contaminants as they have high regeneration properties. In any case, at the point when the centralization of the feed solution is exceptionally high, the cycle effectively arrives at an advancement, consequently restricting further pollutant evacuation (Silvas *et al*., 2011; Adelodun *et al*., 2020).

Conclusion

The present book chapter discussed about the various sources and process of hazardous waste and their impact on water bodies and human health also. Due to the increasing population, the consumption of energy is hiking day-by-day and these energies are generated from various sources. In the whole process starting from harvesting up to generation, liberates prominent amount of wastes in different forms. The disposal of these waste is very difficult. If a proper management technique not used than it affects the local environment. In this chapter, we discussed about the various effects of these waste on water bodies and humans. Whenever this waste comes in contact with the water bodies than it affects the water quality by increasing the nutrient amount and increase the level of heavy metals. Also, it affects the aquatic organisms such as plankton species, benthic fauna and flora and also the fish diversity directly or indirectly. The consumption of these affected fishes is affecting the human health and cause diseases such as cancer. However, in this chapter, we reviewed and discussed about the management techniques to control and use of hazardous waste in sustainable way.

Conflict of interest: The author declares that there is no conflict of interest.

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Chapter [12]

Sustainable approaches towards wastewater treatment using algal technology along with management of post-harvest biomass

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Abstract Industries like food processing, pulp, and paper, dairy, poultry, leather, etc. generate a huge amount of wastewater. The generated wastewater has a high toxicity in terms of BOD, COD, TDS, nutrients, heavy metals, carcinogenic pollutants, etc. The discharge of untreated wastewater into water bodies leads to their pollution and eutrophication, which gives rise to algal blooms and ultimately causes harm to the aquatic organisms. The wastewater generated from industries causes harm to many life forms therefore, its treatment before discharge has become an issue of concern. As wastewater contains enough amount of nutrients hence, can be used for algal growth. Algae are autotrophic organisms that require nutrients and sunlight for their growth. Algae provide sustainable means for wastewater treatment. Apart from wastewater treatment, algal biomass can be used in biofuels production, as biofertilizers, CO_2 sequestration, and for the production of value-added products. This book chapter deals with algae-based wastewater treatment along with various ways of algal biomass management and how algal biomass can be used as potential bioenergy material.

Keywords Algal biomass, Bioenergy, Value-added products, Wastewater treatment

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Introduction

The rapid industrialization around the world has created problems of contaminants and pollutants. Every day, huge amount of wastewater is being produced from different industrial processes globally (Bansal *et al*., 2018). Discharge of untreated wastewater poses threat to both ecological and human health. Earth has limited freshwater resources that are not being used judicially and either water is being wasted or polluted through waste disposal. Besides this, the increase in the world population has increased pressure on water resources (Wollmann *et al*., 2019). Shortage in the availability of freshwater for domestic and industrial purposes is a major challenge throughout the world which has raised the concern of developing appropriate wastewater treatment methods (Piao *et al*., 2016). Various processes can be used to clean wastewater like primary, secondary and tertiary treatment processes, phytoremediation/bioremediation, biosorption, etc. (Lema and Martinez, 2017; Kumar *et al*., 2020).

Besides all wastewater treatment methods, bioremediation is gaining much more popularity because of its environment-friendly aspect. Bioremediation involves the use of naturally occurring living organisms like algae, bacteria, and plants (aquatic and terrestrial) for removing hazardous pollutants from the environment (Kshirsagar, 2013). In the case of different aspects of bioremediation, the phycoremediation process is the most preferred method. Phycoremediation is the use of algal species for wastewater treatment and has numerous benefits over other conventional remediation techniques including, cost-effectiveness, eco-friendly, low input and maintenance costs, etc. (Wells *et al*., 2017). Industrial wastewaters contain a high load of organic and inorganic nutrients and therefore, can be used as a culture medium of algae (Simate *et al*., 2011). Algae are aquatic, eukaryotic organisms that can be microscopic or macroscopic, and cosmopolitan in the distribution in both fresh and marine environments. Algae have a fast growth rate, high lipid content when compared with terrestrial crops and do not compete for land with food crops and also helps in carbon sequestering (Gilbert and Ashraf, 2017).

The algal biomass generated after the phycoremediation has wide utility in the field of bioenergy. The population explosion has increased the energy demands of the world drastically. To meet the global energy demands fossil fuels are being used in direct or indirect ways. The excessive combustion of fossil fuels causes many negative impacts on the environment such as global warming, emission of greenhouse gases, air pollution, acid rain, change in global weather patterns, etc. (Alatraktchi *et al*., 2014; Lee *et al*., 2008). As fossil fuels are non-renewable energy sources and are near about their depletion. There is an urgent need to find environmental friendly alternatives to current energy resources (Mathimani *et al*., 2015; Subsamran *et al*., 2018). There is a wide variety of renewable and sustainable energy resources like solar energy, biomass, wind energy, hydroelectricity, tidal energy, etc. that can generate clean energy but are less energy-efficient sources (Kabir *et al*., 2018). Biomass includes organic material such as aquatic plants, algal biomass, agricultural residues, animal, poultry, food processing, leather industry, municipal solid wastes, etc. (Alam *et al*., 2015; Maity *et al*., 2014; Sims *et al*., 2010). Out of them, algae are rich in carbohydrates, lipids, proteins, pigments, and act as a good source to produce value-added products, like biodiesel, bioethanol, biogas, biochar, biohydrogen, biobutanol, etc. (Jones and Mayfield, 2012). The exploration of the utilization of algae for the reclamation of a damaged environment presents one of the best methods of its conservation. Keeping in view, this book chapter deals with the integrated approach of wastewater treatment using algae along with different possible methods of their biomass management.

Algal wastewater treatment

Wastewater refers to liquid wastes generated after a final product is obtained from households, commercial complexes, workshops, and industries like dairy, food processing, textile, leather, pharmaceutical, etc. Wastewater has high pollutant loads (Simate *et al*., 2011) and the direct discharge of untreated wastewater in water bodies is creating lots of environmental issues especially, water pollution (Cai *et al*., 2013). Due to its nutrient richness wastewater are often used for growing algae. Algal species are capable of utilizing nutrients from wastewater for its growth and development, therefore, has immense potential for treating wastewater (Bansal *et al*., 2018). Nowadays, most industries are adopting algal-based wastewater treatment because it is a cost-efficient and eco-friendly technique. Some of the algal species being used in wastewater treatment (Figure 1).

Table 1 shows the various studies on the treatment of different pollutants from wastewaters using various algal species. Recently, numerous studies have been done for the reclamation of different types of wastewaters. Out of them, Valizadeh and Davarpanah (2020) in their parametric study on dairy wastewater treatment using *Chlorella vulgaris* obtained 42.57% of COD removal efficiency. Gaughy *et al*. (2019) through their study on the treatment of wastewater produced from hydrothermally treated septage using *Chlorella* sp. attained 98 % of ammonia and 50 % of other nutrient removal efficiencies. In another study by Fazal *et al*. (2017), the potential of various microalgal species for the bioremediation of textile wastewater was assessed. They reported that the microalgae use dyes as a carbon source which are further converted into metabolites, besides other processes microalgal wastewater treatment turned out to be most promising for the treatment of textile wastewater. Another study conducted by Kshirsagar (2013) on bioremediation of domestic wastewater using *C. vulgaris* and *S. quadricauda* showed a significant reduction in BOD, COD, nitrates, and phosphates. In a case study conducted by Posadas *et al*. (2014) on a fish farm and domestic wastewater treatment using algal ponds it was found that a significant amount of nitrogen (>70%) and phosphate (>80%) removal was achieved.

Furthermore, Higgins *et al*. (2018) conducted a study on winery wastewater using *Auxenochlorella protothecoides* and *Chlorella sorokiniana* which attained more than 90 % of nitrogen, greater than 50 % of phosphate, and 100 % of acetic acid removal. Wang *et al*. (2010) cultivated *Chorella* sp. on municipal

Table 1. Use of different algal species for the treatment of different pollutants from wastewaters.

Wastewater	Pollutants	Algal species	Removal achieved	Reference
Municipal wastewater	Phosphorus and COD	*Chlorella* sp.	83.2 % - 90.6 % phosphorus and 50.9 - 83.0 % COD removed	Wang *et al.* (2010)
Piggery wastewater	TN,TP and COD	*Chlorella zofingiensis*	68.96 % to 81.03 % total nitrogen, 98.17 % to 100 % total phosphorous, and 65.81 % to 79.84 % COD removed	Zhu *et al.* (2013)
Primary-settled wastewater	Biological pollutants	*Galdieria sulphuraria*	98 % removal of total bacteria and complete removal of *Enterococcus faecalis* and *Escherichia coli*	Delanka-Pedige *et al*. (2019)
Domestic wastewater	TN, TP and COD	Algal biofilm	TN, TP and COD removal reached 96.0 %, 91.5 % and 80.2 % respectively	Yang *et al.* (2018)
Winery wastewater	TN, TP, and acetic acid	*Auxenochlorella protothecoides* and *Chlorella sorokiniana*	> 90 % of nitrogen, > 50 % of phosphate, and 100 % of acetic acid removed	Higgins *et al.* (2018)
Secondarily treated domestic wastewater	Ciprofloxacin	Mixed	> 84 ± 9% removal	Hom-Diaz *et al.* (2017)
Dairy wastewater	COD	*C. vulgaris*	42.57 % COD removed	Valizadeh and Davarpanah (2020)
Textile wastewater	COD	*Chlorella vulgaris*	70 % COD removed	El-Kassas and Mohammad (2014)
Fish farming wastewater	N and P	Microalgal consortia	83 ± 10 % of nitrogen and 94 ± 6% of phosphates removed	Posadas *et al.* (2014)
Urban wastewater	N and P	*Nannochloropsis oculata*	95 % of nitrogen and 98% phoshorous removed	Caporgno *et al*. (2015)

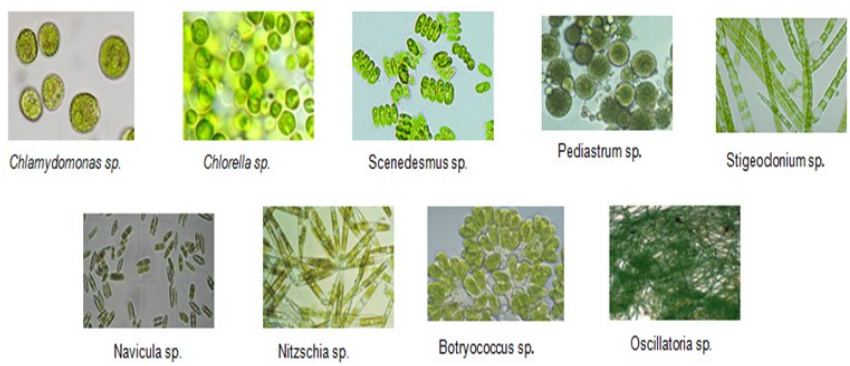

Figure 1. Some of the algal species being used in wastewater treatment.

wastewater for pollutant removal and achieved 83.2 % to 90.6 % phosphorus removal and 50.9 % to 83.0 % COD reduction.

Post-harvest management of algal biomass

The algal biomass harvested after the wastewater treatment process can be utilized in different ways (Figure 2). For example, algal biomass can be used to serve the purpose of biofertilizers, biofuels, biochar, etc. Moreover, various food products like nutraceuticals, protein animal feed, and various nutrient supplements can also be produced from waste algal biomass (Mathimani and Pugazhendhi, 2018).

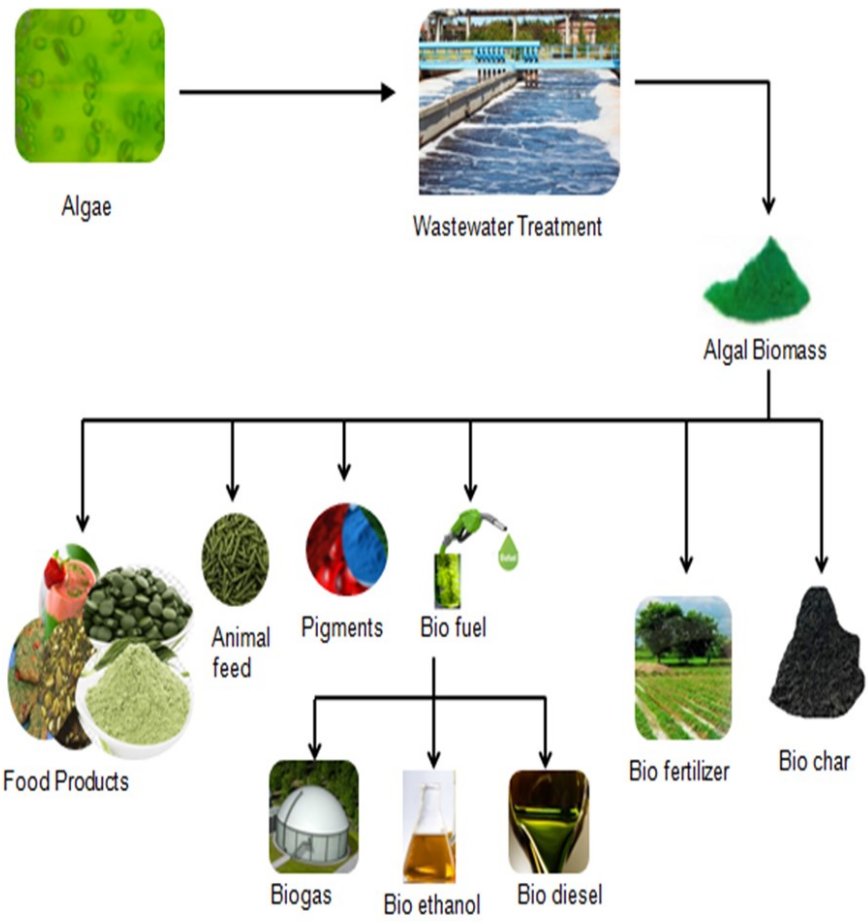

Figure 2. Different methods of algal biomass management.

Biofuels

Biofuels are produced from organic or biological wastes like lignocellulosic residues from agricultural, commercial, domestic, and industrial wastes. Biofuels are eco-friendly and pollution-free energy sources, moreover, it helps in reducing net carbon emission (Saad *et al*., 2019). Algal biomass is also a kind of organic waste and can be used to produce bioethanol, biodiesel, biogas, etc. Several countries like Brazil, Germany, United States, Sweden, and France are the leader in the production and consumption of these biofuels (Adeniyi *et al*., 2018).

***Bioethanol*:** Algal biomass can also be used to obtain bioethanol through the alcoholic fermentation of carbohydrates. Moreover, algal cellulose and hemicellulose can also be used to obtain bioethanol by converting them to sugars through various pretreatment processes. Fermentation is the conversion of sugars into bioethanol (C_2H_5OH). Bioethanol is a high octane fuel, and therefore, can be used as a petrol substitute or blended (10% to 20%) with commercial petrol in transport vehicles (Saad *et al*., 2019). In a study, Johan *et al*. (2010) reported the potential of various micro and macroalgal species for bioethanol production using different methods. Another study carried by Jalilian *et al*. (2019) on biofuel production indicated that *Chlorella vulgaris* FSP-E can be used as a potential feedstock for the production of bioethanol.

Biodiesel: Biodiesel is a kind of diesel fuel derived from a variety of lipid-containing feedstocks like oil crops (castor, sunflower), food crops (corn, soybean), algae, etc. Using food and oil crops for biodiesel production can lead to food security issues. High lipid content makes algal oil the most suitable feed-stock for biodiesel production (Rajkumar *et al*., 2014). Biodiesel is produced by the trans-esterification of algal bio-oil and can be used as vehicular fuel in pure form or as diesel additive. Marella *et al*. (2019) through their study showed the biodiesel production potential of algae cultivated on urban wastewater. A study carried by Caporgno *et al*. (2015) on the cultivation of microalgae *C. kessleri* and *C. vulgaria* in urban wastewater for biodiesel and methane production shows biodiesel yield of 7.4 ± 0.2 g/100 g_{vs} and 11.3 ± 0.1 g/100g_{vs} for *C. kessleri and C. vulgaria*, respectively. Furthermore, Mata *et al*. (2009), Gill (2013), and Jayakumar *et al*. (2017) also studied biodiesel production from various feedstocks (Table 2).

***Biogas*:** The wet algal biomass left after wastewater treatment can be converted into biogas. However, algal biomass has low digestion potential and the addition of activated sludge can help to increase the digestion rate (Dębowski *et al*., 2013). Organic matter of algal biomass breaks down through anaerobic digestion to produce CH_4 and CO_2 which are the main constituents of biogas. The biogas produced from algal biomass can be used for generating power by gas engines as well as an energy source for domestic cooking (Gilbert and Ashraf, 2017). Shchegolkova *et al*. (2018) conducted a study using microalgae for wastewater treatment and biogas production in which significant results were obtained and the biogas produced was composed of 57.0–59.7 % methane and 40.3–43.0 % carbon dioxide. Another study by Xiao *et al*. (2019) on biogas production from microalgal biomass via anaerobic

Table 2. Biodiesel production from various feedstocks (Source: Mata *et al*., 2009; Gill, 2013; Jayakumar *et al*., 2017).

Name of crop	Oil yield (L/ha)	Biodiesel production (kg biodiesel/ha-year)
Corn	172	152
Soybean	446	562
Canola	1190	862
Sunflower	1070	946
Palm Oil	5366	4747
Jatropha	741	656
Castor	1307	1156
Microalgae (wet biomass)	58,700	51,927
Microalgae (Dry biomass)	136,900	121,104

digestion showed that the highest exergy efficiency (40.85 %) was achieved by solar-driven hydro-thermal pretreatment followed by biogas production with hydrothermal pretreatment (35.98 %) and without pretreatment (26.2 %).

Biofertilizers

Microorganisms, like, bacteria, fungi, and algae that are capable of degrading organic wastes and complex nutrients to simpler forms, and this final product can be used to enhance soil quality, nutrient transfer, crop growth, and yield which are known as biofertilizers. Algal biomass can also be used as biofertilizers. Blue-green algae are the most commonly used algal group as biofertilizers. Biofertilizers helps in promoting sustainable and organic farming (Castro *et al*., 2020). In a study conducted by Garcia -Gonzalez and Sommerfeld (2016), the authors investigated the use of *Acutodesmus dimorphus* extract as a foliar spray application at 3.75 g/L for tomato plant resulted in improved plant height, increase in flowering rate, and branches per plant. The *Acutodesmus dimorphus* extract can be employed as a seed primer at 0.75 gM/L as it triggered faster seed germination. Ronga *et al*. (2019) through their study on various microalgal species established the potential of microalgae as a biostimulant and biofertilizer for improving crop productivity and contributing towards agricultural sustainability and reduced environmental impact. Some of the algal species being used as biofertilizers are given in Table 3.

Biochar

Biochar is a dark-colored carbon-rich organic substance obtained from the pyrolysis of waste biomass. Biochar can be used as a soil conditioner as it improves soil pH, increases soil carbon and nitrogen exchange rates, and therefore, helps in increasing crop yields (Rizwan *et al*., 2018). Moreover, biochar can be used as an adsorbent for various treatment processes, as an energy source for the generation of heat and power, and as a carbon sequestration agent (Amin *et al*., 2016). Algal biomass is an ideal waste for the production of biochar as revealed from recent studies. Yu *et al*. (2018) from their study on biochar production from *Chlorella vulgaris* FSP-E suggested that the biochar yield obtained was 21.55

Table 3. Contribution of various algal species used as biofertilizers (Source: Castro *et al*., 2020)

Algal class	Name of species	Contribution
Blue-green algae	*Nostoc, Anabaena, Aulosira, Tolypothrix, Nodularia, Cylindrospermum, Scytonema, Aphanothece, Calothrix, Anabaenopsis, Mastigocladus.*	Produce growth-promoting substances
Red macroalgae	*Phymatolithon calcareum,Lithothamnion corallioides*	Trace elements
Brown macroalgae	*Laminaria digitata, Saccharina latissi-ma ,Fucus vesiculosus ,Ascophyllum nodosum,Ecklonia maxima,*	Rich in N P, K, Carbohydrates, enhance plant growth, drought and salt tolerance and resistance to fungi, bacteria, and virus.

wt% to 38.4 wt% The microalgal biochar showed an HHV of 23.42 MJ/kg and can be used as an alternative to coal for energy production. Through their study on biochar produced from microalgae, *C. vulgaris* Arun *et al*. (2018) showed the potential of algal biochar as a source for the removal of pollutants from wastewater. In another study, Torri *et al*. (2011) indicated that about 44 ± 1 % biochar and 28 ± 2 % biofuel were obtained from the pyrolysis of the biomass of microalgae *Chlamydomonas reinhardtii*, and also the obtained biochar was rich in nitrogen content.

Animal feeds

Due to their high protein, carbohydrate, and oil contents, algae are being used as feed for cows, pigs, cats, dogs, poultry, as well as in fish farming. Using algal nutrition even in small amounts results in an improved immune system, increases egg-laying capacity, growth promotion, and also improves reproductive performance (Madeira *et al*., 2017). Altomonte *et al*. (2018) in their study investigated the use of microalgae in ruminant nutrition and concluded that the use of an appropriate amount of microalgae in animal feed can improve omega 3 content in the milk of ruminants. In another study, Shah *et al*. (2018) explored the potential of microalgae in aquafeed as a supplement or feed additives as algae are a rich source of protein, lipid, pigments, vitamins, etc. Also, the presence of EPA and DHA in microalgae increases the significance of microalgae for its use in aquafeed.

Food products and other supplements

Algae are a rich source of proteins, vitamins, minerals, polyunsaturated fatty acids, antioxidants, etc., therefore, can be used in making health drinks, cookies/biscuits, protein bars, as thickening agents in ice-creams, marmalade, jellies, etc. (Piwowar and Harasym, 2020). Nowadays, various food supplements are being prepared from microalgal biomass. For example, a protein supplement is available in the market in the form of capsules, tablets, and powder which is derived from microalgae

Spirulina (Kovač *et al*., 2013). In their study by Ścieszka and Klewicka (2018), the potential of algae in the food industry in food supplements *like* dietary supplements and as additives in food products like in marmalade, dairy products, cereal-based products due to their enriched protein, lipid, pigment, vitamin, carbohydrate contents have been reported. Torres-Tiji *et al*. (2020) from their study suggested that algae have the potential to become a new food crop and with the implementation of the newest genetic engineering tools algae can efficiently meet the world's food and feed demand shortly.

Pigment extraction

Pigments like chlorophylls, carotenoids, and phycobiliproteins, etc. are responsible for giving beautiful colors to different algal species (Prasanna *et al*., 2007). Various applications of different algal pigments are given in Table 4. Being non-toxic and eco-friendly, pigments from some algal species can be used for a variety of purposes like natural coloring agent for food products (chewing gum, ice creams, soft drinks, desserts, cakes, milkshakes, etc.) (Suganya *et al*., 2016). In the pharmaceutical industry, these pigments are widely used as antioxidants, anti-inflammatory, anti-cancer, and anti-allergic materials (Chew *et al*., 2017). In the cosmetics industry, these pigments are used for giving color to soaps, skin, and hair care products due to their antiageing properties (Wang *et al*., 2015). Besides this, they can also be used in the textile industry as fabricating and dyeing agents. Huangfu *et al*. (2013) suggested that astaxanthin pigment obtained from alga *Haematococcus pluvialis* can extend the life span of fruit flies by complementing with the defective antioxidant defense system of fruit flies. Chakdhar and Pabbi (2017) in their study showed the importance of various algal pigments for improving human health as well as the commercial importance of algal pigments for the cosmetic industry.

Future scope and research recommendations

Algal species are rich in various colored pigments that are being used in various food products, cosmetics, and medicines but still there is much more in the field of algal pigments, the full potential of algal biomass concerning algal pigment is yet to be explored. Although algal biomass is widely being used for the production of biogas the complete biogas production potential of algal biomass has still not

Table 4. Applications of various algal pigments (Source: Li *et al*., 2019).

Algae	Pigment	Applications
Mutants of Dunaliella	Lutein	Food colorant, antioxidant
Dunaliella sp.	Carotenoids	Food colorant, pro vitamin-A, bioactive compound
Chorella, Spirulina	Chlorophyll	Cosmetics , antioxidant
Haematococcus sp.	Astaxanthin	Cosmetics, food colorant
Spirulina sp.	Phycocyanin	Diagnostic agent, bioactive compound (anti cancer), cosmetics
Porphyridium purpureum	Phycoerythrin	Cosmetics, food colorant

reached its full potential, the addition of suitable microorganisms can improve the biogas production potential of algal biomass. Phycoremediation has emerged as the most promising technique of wastewater treatment but genetic engineering can be applied to phycoremediation to improve its remediation efficiency. Algal biomass can be used in the synthesis of metal oxide nanoparticles which can provide an eco-friendly alternative to the toxic chemicals which are commonly used in the synthesis of metal oxide nanoparticles. Hybrid cultivation of algal biomass can be adapted which includes both open and closed pond systems as it can produce high biomass along with a reduction in contamination. The microalgae can be cultivated in membrane photobioreactors, it can reduce the requirement of dewatering. Besides this more exploration of potential of algal species can be done.

Conclusion

The discharge of untreated industrial wastewater causes serious environmental problems such as soil and water pollution. However, industrial wastewaters are rich in several nutrients so, can be used to grow algae. Therefore, algal species have great potential in wastewater treatment. Thus, this book chapter emphasizes the role of algal biomass after phycoremediation of wastewater, can be used as a good resource for bioenergy production and other value-added products. Algal based wastewater treatment is an eco-friendly and cost-efficient approach and serves dual approaches of environmental sustainability.

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Chapter [13]

An overview of water quality indices as promising tools for assessing the quality of water resources

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Abstract

The unsustainable interference of anthropogenic activities such as industrialization, urbanization, tourism, mining, agriculture sector deterioration the water resources. Day by day the quality of the water resources is declined and that creates many problems such as disturbing the aquatic life, human health, and other intended uses. In the middle of the 1960s, a tool i.e. water quality indices developed to assess the water quality of the water body simply and understandably. The WQI value depends on the water quality parameters such as physico-chemical, heavy metal, and biological parameters. Each water quality parameter plays an important role in describing the quality of the water resources. The monitoring of pollution sources i.e. point and non-point sources in the water body is expensive and difficult. Nowadays, a total of 33 WQI are available, who show the quality of a water body by ranking i.e. very good, good, poor, and very poor. Each WQI shows their property and some are developed on a regional or local area basis. So, in this chapter, we discuss the commonly used WQI throughout the world which is used for ranking the water quality. The present overview indicates the basic concept and steps, advantages, and disadvantages of the WQI.

Keywords ATI, CCME, NSF, OIP, Water quality indices, Water resources

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Introduction

As we know, of all-natural resources, water is the most precious and essential source in which life begins and nurtured. Water is important for the survival of all organisms. Although most of the plants, animals, and humans contain more than 70% of water. According to scientists, around 71% of the earth's surface is covered by the water and divided into two broad categories mainly freshwater (2.5 % of all this water) and saltwater (97.5 % of all this water). A 97.5 % of salt water is present in the oceans and seas which is unfit for the drinking. Besides, 2.5 % of freshwater, around 69 % present in the glacier and ice caps, 30 % is groundwater and 1 % is surface water and soil moisture seen in Figure 1. Freshwater is vitally important for the living being for their survival and daily needs. The major part of freshwater is tied up in glacier and with the melting of the glacier, the create the glacier-fed rivers or streams (Kamboj *et al*., 2020). In the whole world, most of the cities/ township is set up near the water body. Human beings used these water resources for their daily needs such as food, transportation, irrigation, industry. and a lot of things. In the last three decades, the demand for water resources is high due to population growth, urbanization, and industrialization (Ogunlela Adelodun, 2014; Kumar *et al*., 2018).

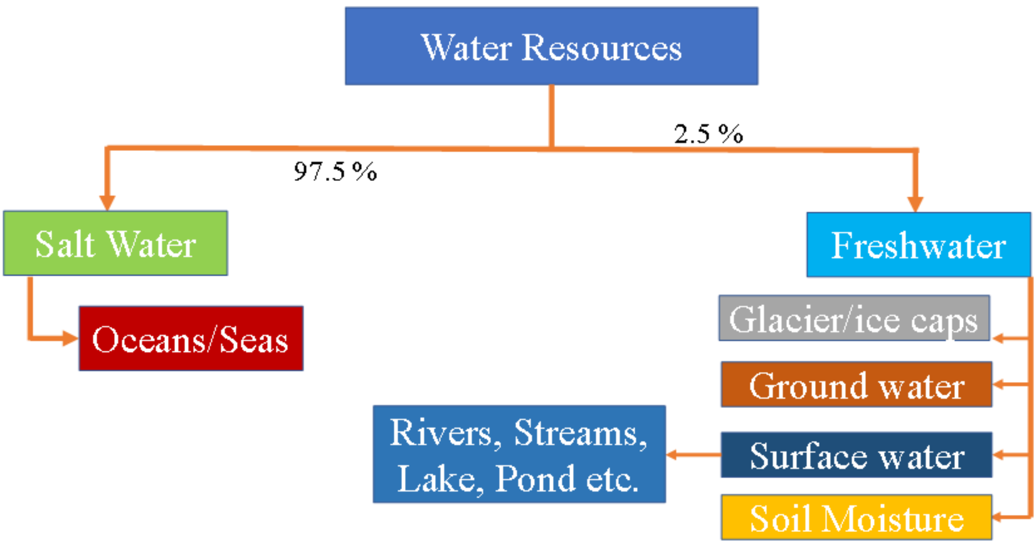

Figure 1. Distribution of water resources on planet earth.

The higher water demand depletes the quality and quantity of water resources. Waste generated by the urbanization and industrialization sector directly dumped and it affects the surface water resources. Besides, some industries dumped their untreated wastewater into the earth's surface which affects the groundwater aquifers (Kamboj and Choudhary, 2013; Choudhary *et al.*, 2014; Kamboj *et al.*, 2015). However, the direct dumping of sewage and industrial wastewater in the surface water resources such as rivers, streams, ponds, lakes, directly and indirectly, affects the quality of the water. Once the quality of surface water resources is depleted it affects the aquatic fauna and flora (Kamboj and Kamboj, 2020).

Water quality and water quality index (WQI)

Water quality is one of the vital components to maintaining water resources management. The water quality of a water body is classified on the three basic categories such as physical, chemical, and biological parameters. Each category contains several parameters that are assessed by the monitoring that provides the basic data for detecting the condition of water quality of the water resources (Gazzaz *et al.*, 2012). The monitoring of pollution sources i.e. point and non-point sources in the water body is expensive and difficult. The monitoring data of the pollution source showed the types of pollutants and their trend of a water body for the water quality authorities for making recommendations for the future prospective (Sutadian *et al.*, 2016). Besides, the monitoring of the water quality parameters difficulty defining the quality of water resources merely. This type of condition is creating due to the complexity of factors, and a large number of parameters are used for showed the water quality. However, in the mid of 1960s, an indexing tool called water quality index (WQI) is developed for show the water quality of the water resources basically for rivers, lakes, ponds, and groundwater. In the WQI tool, the monitoring data of selected parameters is aggregating in a simple form for expressing the water quality. Besides, the WQI tool has become important and mostly used for assessing the status of water quality of any water resources worldwide. Since the 1960s to till, a lot of WQI has been developed and formulated by many scientist and researchers.

Common steps for formulation and development of the WQI

For the formulation and development of a WQI, the common steps are following (Figure 2):

1. Selection of water quality parameters
2. Transformation of parameters on a common scale for obtaining sub-indices
3. Assigning weight of selected parameters
4. Sub-indices aggregation for the final index score

1. Selection of water quality parameters

The selection of parameters is the keen part of a WQI. As we know, water consists a lot of constituents

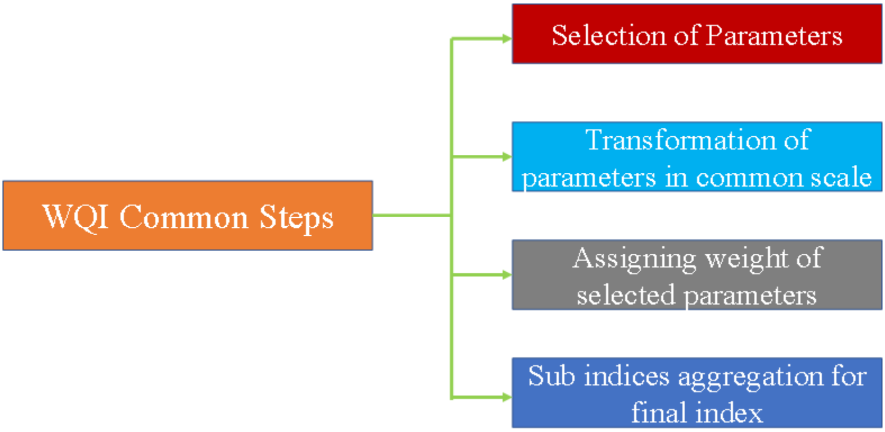

Figure 2. Common steps used for the computation of WQIs.

including elements in the form of metals, non- metal, metalloids, anions mainly carbonate and bi-carbonates, sulphate, nitrate, etc, organics such as pesticides as well as other organics and suspended particles (Abbasi and Abbasi, 2012). In WQI, the parameters have selected from a range of four parameters to twenty-six parameters. Abbasi and Abbasi (2012) told that no method show the 100% accuracy for parameters selection. According to the literature survey, mostly the selection of parameters for WQIs is based on the type of system used i.e. fixed, mixed and open system.

In a fixed system, a fixed set of parameters is used for a particular water resource. For e.g., if we compared the water quality of two rivers then we selected a fixed set of parameters for both rivers. Most of the WQIs have used a fixed set of parameters (Cude, 2001; Abbasi and Abbasi, 2012; Almeida *et al*., 2012). However, in an open system, we are selected a minimum number of parameters based on their characteristics and impacts on the environment. Most of the WQIs did not define the guidelines for parameters selection because the parameters are varied from one place to another place (Swamee and Tyagi, 2007; Sutadian *et al*., 2016). While in a mixed system, we are selected basic and some additional parameters i.e. toxic parameters. In this system, additional parameters are used when the addition parameters show the higher sub-indices value than the aggregated index value of basic parameters in the final index calculation (Hanh *et al*., 2011, Sutadian *et al*., 2016).

***Key points for parameters selection*:** Keeping the view of parameters selection for WQIs, there are some points is noted by the researcher before selection of parameters for a WQIs (Cude, 2001; Kannel *et al*., 2007; Hanh *et al*., 2011) are as follow:

- Parameters that show a higher influence on water quality.
- According to the survey of literature review.
- According to the data availability.

- Parameters that show the overall quality of the water resource.
- Expert judgement is the selection of parameters based on interactive groups, individuals' interview, and Delphi method (Linstone and Turoff, 2002; Juwana *et al*., 2010).
- Statistical method: In this method, Pearson's correlation and factor analysis or principal component analysis are used for the selection of significant parameters. In this, we are eliminated that parameters that show the highest correlation with others. In a study, ammonia and orthophosphate were eliminated due to the positive significant correlation with chemical oxygen demand (Debels *et al*., 2005). Besides, in the PCA/PFA method, only those parameters are selected which show the higher loading factors for subsequent analysis (Gazzaz *et al*., 2012).

2. Transformation of parameters on a common scale for obtaining sub-indices

In this part, the parameters are converting into a common scale for making sub-indices. The transforming of the parameters in a common scale is based on the two important factors: one is the difference in parameter's unit and second is the difference in the range of concentration of the parameters (Abbasi and Abbasi, 2012). In the water sample, the measuring unit of parameters is different. Physical parameters such as turbidity electrical conductivity and water temperature are measure in Nephelometric turbidity unit (NTU), micro-ohm (μm/S) and degree Celsius (°C), respectively, most chemical parameters measure in part per million (ppm) and microbial parameters measure in numbers. However, the range of concentration of the parameters is different. We all know, in a water sample, the range of the dissolved oxygen is 0 to 12 mg/l but parameters such as BOD, COD, Sodium and many others have present in different ranges. Besides, the presence of some elements such as mercury in the water sample is best for drinking purpose when the concentration is beyond 0.001 mg/l. If the concentration of mercury is twice or more than 1 mg/l is not fit for human consumption (Sutadian *et al*., 2016). So, for keeping these factors, converting the parameters to a common scale for making sib-indices is a need.

***Development and types of Sub-indices*:** In mostly WQI index, the sub-indices of each parameter are developed for converting the different parameters unit and their ranges in a single scale. The common steps for converting the parameters in a single scale is illustrated in Figure 3. In a water sample, the are many parameters. So, we assigned a series of parameters variable for example (X_1, X_2, $X_{3,...}$ X_n) and then for each parameter (X_n) a sub-index i.e. I_i is computed by using the function *f(x)* and the sub-index equation is given below:

$$Ii = F_n (X_n) \quad \text{Eq. 1}$$

After sub-index of parameters, the next process is the aggregation. In the aggregation process,

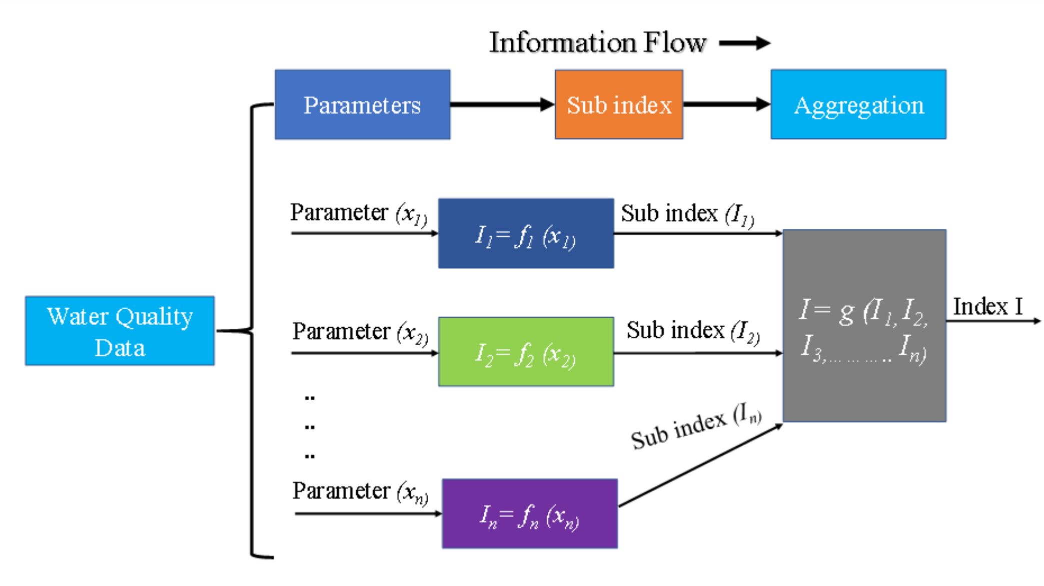

Figure 3. Basic development process of sub-indices for an index.

generally, we adding all the sub-index value and finalize a final index using Eq. 2.

$$I = g\ (I_1, I_2, I_3 \ldots I_n) \qquad \text{Eq. 2}$$

Types of Sub-indices: According to Abbasi and Abbasi (2012), the sub-indices is classified into four types such as Linear, Non-linear, Segmented linear and Segmented non-linear. The basic knowledge or features of all types is listed below:

- **Linear Sub-indices:** The linear equation is the simplest sub-indices function for converting the parameters into a single scale by the equation i.e. $I = ax + b$. Where I is the sub-index, x is the parameters variable, a and b the constants. This function method is easily computed and showed a direct proportion of exits between the parameter's variable and sub-index. The only limitation of this sub-index is limited flexibility.
- **Non-linear Sub-indices:** Non-linear sub-indices are applying when the cause-effect relationship of parameters does not vary linearly. When plotted this relationship on the graph sheet it seen like the curvature. Generally, two types of non-linear indices are describing such as implicit and explicit function. In implicit function, there is no mathematical equation is given but in explicit function mathematical equation is given. The basic formula used for the implicit function is $I_i = x^c$ where c is constant and it is ≠ 1, and x is the parameter variable (Brown *et al.*, 1970). The explicit or exponential function, the basic formula is used $I_i = C^x$, where C is the constant and x is the

parameter variables. In explicit function, generally in the base of logarithm constant used is either 10 or e (Abbasi and Abbasi, 2012).

- **Segmented linear function sub-indices:** The sub-indices are applicable when the two or more straight-line segments in the threshold level or point break level. It is more flexible and specially used for the standard limit provided by the agencies such as BIS, WHO. The important thing of the sub-indices in the step function. So, it also called a dichotomous function. The basic formula of the segmented linear sub-indices is

$$I_i = \frac{(b_{i+1} - b_i)}{(a_{i+1} - a_i)}\,(x - a_i) + b_i$$

Where, $a_i < x < a_{i+1}$; i = 1, 2, 3…n; a_i and b_i is the threshold level.
It also consists of a steps series, which gives the multiple state function seen in Table 1.
The sub-indices do not apply to the situation where the slope is increased by increase the pollution variables.

- **Segmented non-linear function sub-indices:** It consists of two or more-line segment in which one line segment is non-linear. Each segment consists of a different equation which covers a range of pollution parameter variables. It is the most flexible sub-indices which has been used most of the water quality sub-indices. The example of the segmented non-linear function sub-indices is illustrated in Table 2.

3. Assigning weight of selected parameters

This step plays a vital role in a water quality index. The assigning weight of the parameter is confusion task because of the selection of parameters. Some water quality parameters such as dissolved oxygen, turbidity, transparency, colour, *etc* are very important parameters for express the surface water quality while these parameters are not useful to express the quality of groundwater.

Table 1. Segmented linear function used by Horton (1965) for dissolved oxygen.

Segment	Range of I for x	Saturation
1	$I = 0$	<10%
2	$I = 30$	10%-30%
3	$I = 100$	>70%

Table 2. Segmented non-linear function used by Prati *et al*. (1971) for dissolved oxygen.

Segment	Range of x	Equation
1	$50 < x < 100$	$I_i = 8\,(100\text{-}Y)$
2	$x < 100$	$I_i = 8\,(Y\text{-}100)$

So, the weight of the parameters is assigned based on their importance and their effect on the water quality index value (Abbasi and Abbasi, 2012; Sutadian *et al.*, 2016). In mostly WQI, the equal weight of parameters is assigned when parameters are equally important whereas if the parameters are lesser or greater importance than the weight of parameter assigned unequal weight. Besides, the basic thing for assign the parameters weight is depending on the index developer, parameter selection and subjective opinion of water quality experts and policymaker (Sutadian *et al.*, 2016). However, there have been two methods are commonly used for weight assigning i.e. Delphi method (Abbasi and Arya, 2000) and the analytical hierarchy process (AHP; Crude 2001). The Delphi method is mostly used in various WQI for assigning the parameters weight by summing of expert opinion for minimizing subjectivity and enhance reliability. In this method, a temporary weight of highest significance rating i.e. 1.0 is assigned to the parameters and another temporary weight of parameter is obtained by dividing the highest rating i.e. 1.0 by the individual parameter mean rating i.e. the standard value of the parameters prescribed by the agencies such as WHO, BIS and many others. After that, each temporary weight of parameter is dividing by the summing of all parameters temporary weight for obtaining the final relative weight. It should be noticed that the sum of the selected parameters relative weight is 1.0 in mostly water quality index. The most used equation for calculating the relative weight as per Delphi method is given below (Brown *et al.*, 1970):

$$W_n = K/V_s$$

Where, W_n: relative weight, K: proportion constant, V_s: parameters standard. The value of K is obtained by the given equation

$$K = 1/(\Sigma\ 1/V_s)$$

Where K: proportion constant; V_s: parameters standard; 1: highest significance rating. Moreover, another method for assigning the weight of the parameters is the analytical hierarchy process (AHP). The AHP is an easy concept to assign the parameters weight and also allows the developers to incorporate the qualitative and quantitative aspect. In this method, the weight assigned through pairwise matrices, and also a responding group i.e. experts or public is required for giving their suggestion (Gazzaz *et al.*, 2012) and also it can be useful to determine the relative weight of individuals or aggregated parameters (Ocampo-Duque *et al.*, 2006; Sutadian *et al.*, 2016).

4. Sub-indices aggregation for the final index score

This is the final step of a WQI which is performed for obtaining the final index value. The final index value is obtaining by sub-indices aggregation. For aggregation, mostly three methods are used *i.e.*

Additive aggregation method, Multiplicative aggregation method and logical aggregation method.

Additive aggregation method

The additive aggregation method is the most off-used method in which we combined the transform value of parameters through summation. In this method, commonly three types of sum index are applied such as linear sum index, weighted sum index and root sum index described in Table 3. The additive aggregation method is used by Horton (1965), Brown *et al.* (1970) and Prati *et al.* (1971) in their WQI.

- **Linear sum index:** The linear sum index is commonly used in that condition when the addition of unweighted sub-index not raised to power than 1. The advantage of the linear sum index is the out -weighted and the disadvantage is the resulting of the poor water quality if one individual parameter is exceeding an acceptable level.
- **Weighted sum index:** The weighted sum index is mostly used index. The disadvantage of this index is eclipsing. The eclipsing means when the one parameter sub-index is higher than the acceptable limit then it reflects the poor water quality.
- **Root sum power index:** It is formed by using the non-linear aggregation function. The p-value shows the positive real number which is always greater than 1. The ambiguous region is smaller when p becomes large. This index is good for aggregation indices because it not required eclipsing region as well as the ambiguous region.

Multiplicative aggregation method:

In this method, the sub-indices are computed using product operation or geometric mean. The common multiplicative method is the weighted product. The equation of the weighted product is given below:

$$I = [\prod_{i=1}^{n} I_{i}^{wi}]$$

Table 3. Commonly used index in the additive aggregation method (Abbasi and Abbasi, 2012).

Index	Equation	Remark
Linear sum index	$I = \sum_{i=1}^{n} I_i$	I_i : sub-index i, n : number of parameters
Weighted sum index	$I = \sum_{i=1}^{n} W_i I_i$	I_i : sub-index i, n : number of parameters W_i :weight of the i^{th} parameters
Root sum power index	$I = [\sum_{i=1}^{n} I_{ip}]^{1/p}$	I_i : sub-index i, n : number of parameters p : positive real number i.e. >1

The disadvantage of this index is that if one sub-indices is zero, then the final index also zero and create the eclipsing condition. So, the geometric mean is used in the weighted product aggregation method using the equation:

$$I = [\prod_{i=1}^{n} I_i^{gi}]^{1/\gamma}$$

Where γ : $\sum_{i=1}^{n} g_i$

The multiplicative aggregation method used by Landwehr *et al.* (1974); Walski and Parker (1974); Bhargava (1985) in their WQI.

Logical aggregation method:
This aggregation method is based combination of sub-indices using logical operation. In the logical operation, two factors are used i.e. maximum and minimum operator index. The logical index is used by Smith (1990).

- **Maximum operator index :** This index is performed when the root sum power index *i.e.* p approaches infinity. The general equation is: I = max $(I_1, I_2, I_3, I_4 ... I_n)$; Where I: largest of sub-indices, if $I_1 = 0$, then $I = 0$. This index is ideally performed when one recommended limit is violated. The disadvantage of the index is that when fine gradations become apparent then the discrete events and also some sub-indices are to be aggregated.
- **Minimum operator index:** This index is performed when summing of sub-indices scale is decreased while the scale of maximum operator index increases. It is the good index method for performing the decrease aggregating scale of sub-indices. The general equation is: I = min $(I_1, I_2, I_3, I_4 ... I_n)$.

Most commonly used water quality indices

From the mid-1960s to till date, a total of 33 water quality index are developed, who show the quality of a water body. In the present study, only the 7 most popular water quality index are discussed that illustrated in Table 4. These 7 WQI are selected based on their higher frequency number in most of the water quality papers. Besides, in this section, we discussed all 7 WQI and their selected parameters, sub -indices scale, parameter weight, final index equation, and also discussed the advantage and disadvantages.

National Sanitization Foundation index

The National Sanitization Foundation (NSF) water quality index is developed by Brown *et al.* (1970). The modified version of this index has been applied in various countries such as India, Iran, Brazil, USA and many other countries (Effendi *et al.*, 2015; Misaghi *et al.*, 2017).

Parameters selection**:** In this index using the Delphi method a set of 11 parameters including physico-chemical parameters (8 parameters), micro-biological (1 parameter), pesticides and toxic elements are finalized (Table 4).

Sub-indices formation**:** In NSF WQI, Delphi technique is used to transform the selected parameters into a sub-indices scale. In this index, the formation of sub-indices of 9 parameters such as physico-chemical and microbial parameters is done using Delphi technique to produce the average curve. The sub-indices scaling of pesticides and the toxic element is formed using the categorical scaling of 0 and 1 (Sutadian *et al.,* 2016). In most cases, only 9 parameters are selected for the study, because the other two parameters showed the eclipsing if the range is exceeding from the permissible limit. In that case, water quality directly registered as the worst condition.

Assigning weight of parameters**:** The unit weight of parameters has been assigned using the Delphi technique. The weight of the parameters is unequal but the sum of all parameters weight is 1. The name of parameters and their final relative weight as follows; dissolved oxygen (0.17), pH (0.11), biochemical oxygen demand (0.11), faecal coliform (0.16), water temperature (0.10), total phosphorus (0.10), nitrate (0.10), turbidity (0.08) and total solids (0.07) respectively.

Aggregation for final index**:** In NSF WQI, generally, arithmetic or additive aggregation method is used (Brown *et al*., 1970). The general equation used for the NSF WQI calculation is given below:

$$I = \sum_{i=1}^{n} w_i q_i$$

Where, w_i : relative weight of the i^{th} parameters, q_i : sub-indices quality ratings of the i^{th} parameters. Besides, Brown *et al.* (1973) proposed NSF WQI in which they used the Multiplicative aggregation method using the following equation:

$$I = [\prod_{i=1}^{n} S_i^{wi}]$$

The purpose of using the multiplicative aggregation method is to decrease the uncertainty which is generated by a single bed parameter which directly affects the water quality. After calculated the index value, Brown *et al.* (1970) expressed index values ranged from 0 (very bad) to 100 (excellent) for the water quality illustrated in Table 4. Besides, Phadatare and Gawande (2016) also describe the category and colour for all the ranges that show the water quality. The following NSF WQI range status with category and colour (in brackets) are as follows such as excellent (A, Blue), good (B, green), regular (c, yellow), bad (D, Orange), and very bed (E, Red) respectively.

***Advantages of the NSF WQI*:** The index is easy to understand and easily calculated. The index showing the water quality in a good manner. The index used for evaluating the water quality of different areas.

***Disadvantages of the NSF WQI*:** The index represents only water quality, it does not represent the specific use of water. If one parameter of toxicity and pesticides parameters is exceeding than it showed the worst water quality. Due to this, the uncertainty and subjectivity is increase.

Canadian Council of Ministers of the Environment water quality index

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) is developed by the Canadian ministry of the environment in 2001 (CCME, 2001). The CCME- WQI used as a tool to assess the water quality status of river basins, metal mines and evaluation of drinking water quality and also it provided the report of water quality status information to management institutions, policymaker, and the public (Lumb *et al.*, 2011; Hurley *et al.*, 2012). This index has been applied in Canada (Abbasi and Abbasi, 2012) and also applied in various countries such as India, Iran, Chile, Spain and many other countries (Espejo *et al.*, 2012; Mostafaei, 2014; Wagh *et al.*, 2017; Ahmed *et al.*, 2019).

***Parameters selection*:** In CCME WQI, the selection of parameters in this index depends on the users due to its flexibility. The user selects the parameters based on local condition and their issues. For example, in two state i.e. New Brunswick state and the Alberta state of Canada, different parameters such as 14 parameters used in New Brunswick state and Alberta state parameters are categorised in four groups mainly metals (22 parameters), pesticides (17 parameters), nutrients (6 parameters) and microbial (2 parameters) respectively (Sutadian *et al.*, 2016).

***Sub-indices formation*:** In this index, the sub-indices formation is not used.

***Assigning of parameters weight*:** There is no need for establishing the parameters weight because the sub-indices formation is not used.

***Aggregation of final Index*:** The final index of CCME WQI is based on the three factors such as scope, frequency, and amplitude which are adopted from BCWQI. These three factors create a scale from 0 to 100 for showing the water quality. The three factors that used in the development of CCME WQI final index are as follows:

- **Scope:** The scope is denoted by the F_1 and it defines as the parameters which do not meet the water quality standards during the period of interest. The scope is calculated by using the given equation: F_1 = [(number of failed variables)/(total number of variables)]×100
- **Frequency:** Frequency is denoted by F_2 and it defines as the individuals which do not meet the objective during the period of interest. It is calculated by using the given equation: F_2 = [(number of failed tests)/(total number of tests)]×100

- **Amplitude:** This step is different from the previous steps. It is denoted by the F_3 and it defines as amount of failed test which does not meet their objectives. F_3 is calculated in three steps are as follows:

  First step:

  Ist step is the excursion that is referred to as the number of times by which an individual concentration is higher than the objectives and calculated using the equation:

  $excursion_i$ = [(*failed test value i/objective j*)] - 1

  Besides, another condition is that when test value must not fall below the objective, then excursion is calculated using the equation: $excursion_i$ = [(*objective j/ failed test value i*)] - 1

  Second step:

  In this step, we calculated the normalised sum of excursions that refers to the summing of excursion of the individual test from their objectives and dividing by the total number of tests including a test that meets and do not meet their objectives (Abbasi and Abbasi, 2012). The normalised sum of excursions is calculated by the given equation:

$$nse = \frac{\sum_i^n excursion_i}{total\ number\ of\ test\ (including\ meet\ and\ do\ not\ meet\ their\ objectives)}$$

  Third step:

  In this step, we calculated $F_{3,}$ using the asymptotic function that provides a scale from 0 to 100 by scales the *nse* (normalised sum of excursions) using the equation given below:

  F_3 = [(nse/ 0.01 nse + 0.01)]

Final equation of CCME WQI:

$$CCME\ WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

In the equation, 1.732 factor is used to minimize the vector length as maximum to 100. The rank scale of CCME-WQI ranged 0 i.e. very bad to 100 i.e. excellent water quality are described in Table 4.

Advantages of the CCME WQI**:** The index is easy to understand and easily calculated. In this index, we do not calculate the sub-indices and parameters weight. The index represents both water quality and specific use of water.

Disadvantages of the CCME WQI**:** In this index, minimum of 4 parameters are required for assessing the water quality status. A maximum number of parameters is not satisfied.

Bhargava water quality index

It is the first reported index which developed by an Asian scientist namely D.S. Bhargava in 1983

Table 4. Commonly used water quality indices.

Name of WQI	Developer Name and Year	Selection of parameters	Weight used	Range of WQI	Current studies in which they applied	Types of water resource in which used	References
National Sanitization Foundation Index	Brown *et al.* (1970)	Mostly used 11 parameters based on their importance Parameters – Rank DO – 1 BOD – 2 TU – 3 TS – 4 Nitrate – 5 TP – 6 pH – 7 Temp. – 8 FC – 9 Pesticides – 10 Toxic elements – 11	Unequal weight of all parameters. Sum of all parameters weight is 1	0-25= very bad 26-50= bad 51-70= regular 71-90= good 91-100= excellent	Aydughmush river (Iran); Ghezel Ozan River (Iran); Ciambulawung River, Banten Province	River system	Hoseinzadeh *et al.* (2015); Effendi *et al.* (2015); Misaghi *et al.* (2017)
Canadian Council of Ministers of the Environment Water Quality Index	Canadian Council of Ministers of the Environment (CCME, 2001)	Minimum 4 parameters are required. The maximum number of parameters is not satisfied.	Parameters weight is not used	0-44= Poor 45-64= Marginal 65-79= Fair 80-94= good 95-100= excellent	Shallow aquifers of Mathura district, UP; Groundwater suitability of Kadava river basin, India; Groundwater suitability of Cauvery deltaic region, Tamil Nadu	Groundwater	Venkatramanan *et al.* (2016); Wagh *et al.* (2017); Ahmed *et al.* (2019)

Table 4. *Continued...*

Bhargava Index	Bhargava (1983)	Developed Four groups i.e.		Unequal weight of all group's parameters. Sum of all group's weight is 1	Class	Status	Value	Netravathi River, Mangalore (South India), Suberna-rekha River (India); Euphrates river (Al-Najaf city), Vosvozis River (North Greece)	River	Avvannavare and Shrihari (2008); Parmar and Parmar (2010); Noori *et al.* (2017); Zotou *et al.* (2019)
					I	Excel-lent	90-100			
					II	Good	65-89			
		Groups	Type of parameters							
					III	Satis-factory	35-64			
		Ist group	TC, FC							
					IV	poor	11-34			
		IInd group	Toxicants and Heavy metals							
					V	unac-ceptable	0-10			
		IIIrd group	Physical parameters							
		IVth group	Organic and inorganic substances							
Oregon water quality index	Oregon Department of Environ-mental quality in 1970 And Updated by Cude, (2001)	Eight parameters used: DO, FC, BOD, Temp., pH, TS, TP, Ammoniacal nitrate		Equal weight	0-60= very poor 61-79= poor 80-84= fair 85-89= good 90-100= excellent			Big Lost River Watershed, (Idaho); Oregon river	River	Said *et al.* (2004); Sarkar and Abbasi (2006); ODEQ (2014)

Table 4. *Continued*...

Overall index of pollution (OIP)	Sargoankar and Desh-pande (2003)	Parameters used: Hardness, TDS, DO, pH, BOD, Turbidity, Fluoride, TC, Arsenic, Chloride, Sulphate, Nitrate, Colour	--------	Status	Class	Score	Kirmir Basin (Turkey); River Ganga; WQI of Ganga river at river bed mining-impacted area,	River system	Sargoankar and Desh-pande (2003); Dede *et al.* (2013); Kam-boj and Kamboj (2019); Matta *et al.* (2020)
				Excellent	C1	1			
				Accepta-ble	C2	2			
				Slightly polluted	C3	4			
				Polluted	C4	8			
				Highly polluted	C5	16			
Aquatic toxicity index	Wepener *et al.* (1992)	Parameters: pH, DO, TU, Ammonium, TDS, F, K and OP Hazardous metals such as Zn, Manganese, Cr, Cu, Pb, Ni	Unequal weight of parameters,	0-50 = unsuitable for normal fish life. 51-59 = Suitable only hard fish species, 60-100= suitable for all fish species			Olifants river (Kruger National Park); Kirmir Basin (Turkey)	River	Wepener *et al.* (1992); Dede *et al.* (2013); Gerber *et al.* (2015)
Groundwater quality assessment Index	Tiwari and Mishra (1985) and modified by Vasan-thavigar *et al.* (2010)	Parameters: TDS, Bicarbonate, Chloride, Sulphate, Phosphate, Nitrate, Fluoride, Calcium, Magnesium, Sodium, Potassi-um, Silicate	Parameter weight assigned with their importance	<50 = excellent water 50-100.1 = good water 100- 200= poor water 200-300 = very poor water >300 = water unsuitable for drinking			Water quality assessment of Pauri Garhwal (India); Groundwater quality of greater Noida sub-basin, India	Groundwater	Tyagi *et al.* (2014); Singh and Hussian (2016)

(Bhargava, 1983; Abbasi and Abbasi, 2012). This index is commonly used to assess the drinking water supply, suitability of surface water for drinking. This index has been applied by a various researcher in various country or region such as India (Avvannavare and Shrihari, 2008; Parmar and Parmar, 2010), Al-Najaf city (Noori *et al*., 2017), and Zotou *et al.* (2019).

Parameters selection: In this index, 4 groups of parameters were selected. The groups and types of parameters used are illustrated in Table 4. In ist group, microbial parameters such as TC, FC are selected for assessing the drinking water quality. In the 2nd group, toxic and heavy metals parameters are selected while in 3rd and 4th groups physical and inorganic or organic parameters were being studied respectively.

Sub-indices formation: The formation of sub-indices in the index is developed by a different equation. Each group parameters are transferred on a common scale by using the equation illustrated in Table 5.

Assigning weight of parameters: In this index, the weight of the selected parameter is different but the sum of all parameters weight is equal to 1.

Aggregation of final Index: In this index, the final index value is based on the multiplicative aggregation method i.e. geometric mean. The general equation used for the Bhargava WQI calculation is given below:

$$CCME\ WQI = 100 - \left(\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right)$$

Where, $f_i(P_i)$: sensitive function includes weighting of the of i^{th} variables, n: number of variables consider. After calculated final index value, the Bhargava WQI categorised the water quality in five groups with their status and rank value are illustrated in Table 4.

Advantages of the Bhargava WQI: The index is easy to understand and easily calculated. The index represents both water quality and specific use of water.

Disadvantages of the Bhargava WQI: The number of the parameter is defined, so in this index, we can only calculate the water quality status based on these parameters.

Table 5. Sub-indices equation used in Bhargava Index (Abbasi and Abbasi, 2012).

Groups	Sub-indices equation	C_{MCL}
Ist group	$f_1 = exp\ [-16(C-1)]$	Coliform bacteria/100 ml
IInd group	$f_1 = exp\ [-4(C-1)]$	0.05 mg/L each
IIIrd group	$f_1 = exp\ [-2(C-1)]$	1 TU 15 colour unit
IVth group	$f_1 = exp\ [-2(C-1)]$	250 mg/L each

Oregon water quality index

The Oregon water quality index is developed by the Oregon department of environmental quality in 1970 and then it modified or updated by the C.G. Cude in 2001 (Abbasi and Abbasi, 2012). The purpose of this index is the summarizing and calculation of the water quality status of rivers in Oregon. This index is mostly used by the Oregon department of environmental quality and also used by the Idaho department of environmental quality (IDEQ, 2002; ODEQ, 2014; Sutadian *et al.*, 2016). This index is also a part of WQI software namely QUALIDEX (Sutadian *et al.*, 2016).

Parameters selection: In this index, a total of 8 parameters such as dissolved oxygen, faecal coliform, biological oxygen demand, pH, total solids, total phosphorus, ammoniacal nitrate, temperature, are used. The purpose behind the selection of these parameters is the better understanding and the significant importance in water quality status.

Sub-indices formation: The formation of sub-indices in Oregon WQI is developed by using the non-linear regression curve for six parameters such as dissolved oxygen, biological oxygen demand, pH, total solids, and Ammonical nitrate (Cude, 2001). The rating curve for total phosphorus and temperature was developed by assessing the eutrophication condition of Oregon's stream and protection of the cold water fisheries respectively (Sutadian *et al.*, 2016).

Assigning weight of parameters: For assigning the parameter weight, Delphi technique is used. In the Oregon index, equal-weighted parameters are used. The parameter weight of six parameters are dissolved oxygen (0.4), faecal coliform (0.2) and weight of other parameters such as ammonical nitrate, pH, total solids and biological oxygen demand is 0.1.

Aggregation of final index: Previously in this index, the additive method is used for generating the final index value. But in the modified version of Oregon index (Cude, 2001), the unweighted harmonic square formula is used for finding the final index value. The general equation of the index is given below:

$$WQI = [\prod_{i=1}^{n} f_i(P_i)]^{\frac{1}{n}} \times 100$$

The interpretation of the final index value is categorised in five classes such as very poor class lies when index value ranges from 0 to 60, poor when index value ranges from 61 to 79, fair when index value ranges from 80 to 84, good when index value ranges from 85 to 89, excellent when index value ranges from 90 to 100.

Advantages of the Oregon WQI: This is the best method for assessing the effectiveness of water quality activities. We can also develop an environmental indicator for finding the percentage of sites with good water quality or not.

Disadvantages of the Oregon WQI: Mostly this method is developed and applied only the Oregon river system.

For adding the total phosphorus in Oregon WQI, firstly we assess the eutrophication condition of the water body.

Overall Index of Pollution WQI

The index is developed by the Sargoankar and Deshpande (2003) for assessing the surface water quality in Indian condition. In this method, a classification criterion was developed that is based on the standard providing by the water quality standards agencies such as world health organization (WHO), Bureau of Indian Standards (BIS), Central pollution control board (CPCB), European Community (EC). This method demonstrated the effect of pollution on water quality parameters. This method is applied in Indian rivers such as river Ganga (Kamboj and Kamboj, 2019; Matta *et al*., 2020), Yamuna river (Sargoankar and Deshpande, 2003) and Kirmir Basin, Turkey (Dede *et al*., 2013) for assessing the water quality status.

***Parameters selection*:** Sargoankar and Deshpande (2003) selected a total of 13 parameters such as pH, turbidity, colour, total dissolved solids, dissolved oxygen, biological oxygen demand, hardness, chloride, nitrate, sulphate, total coliform, arsenic and fluoride. These parameters are the key indicator parameters to assess the surface water quality and its deterioration due to the pollution activity.

***Sub-indices formation*:** In the OIP index, the formation of the sub-indices is developed by the concentration of the particular parameter. For each parameter, a mathematical equation is developed according to their concentration illustrated in Table 6.

***Assigning weight of parameters*:** In the OIP, there is no weight assigned for the parameter.

***Aggregation of final index*:** For obtained the final index value, the general equation is used to assess the overall index of pollution is:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$$

Where n is the total number of parameters, P_i is the pollution indices of the *ith* parameters. The calculation of P_i based on the sub-indices mathematical equation that is illustrated in Table 6. In OIP, the interpretation of the final index value is based on the classification, class and index score of the particular parameters.

***Advantages of the OIP index*:** This index indicates the responsible parameters that deteriorate the water quality of the water body. This tool used as formulating the pollution strategies in different areas of the water body. This index is easiest and simply understand to assess the water quality status.

Table 6. Sub-indices equation and classification of water quality index of overall index of pollution (Sargaonkar and Deshpande, 2003)

Parameters	**Range**	**Mathematical equation**	**Classification**				
			Excel-lent	**Acceptable**	**Slightly Polluted**	**Pollut-ed**	**Heavily Polluted**
			Class				
			C1	**C2**	**C3**	**C4**	**C5**
			Index Score				
			1	**2**	**4**	**8**	**16**
			Concentration range/limit				
pH	7	x = 1	6.5-7.5	6.0-6.5 and 7.5-8.0	5.0-6.0 and 8.0-9.0	4.5-5 and 9-9.5	<4.5 and >9.5
	>7	x =exp((y-7.0)/1.082)					
	<7	x =exp((7.0-y)/1.082)					
Turbidity (NTU)	≤5	x = 1	5	10	100	250	>250
	5-10	x = (y/5)					
	10-500	x = (y+43.9)/34.5					
Colour (Hazen)	10-150	x = (y+130)/140	10	150	300	600	1200
	150-1200	x = (y/75)					
DO (%)	<50	x = exp (- (y- 98.33) / 36.067)	88-112	75-125	50-150	20-200	<20 and >200
	50-100	x = (y-107.58)/14.667					
	≥100	x = (y-79.543)/19.054					
BOD (mg/L)	<2	x = 1	1.5	3	6	12	24
	2-30	x = y/1.5					
TDS (mg/L)	≤500	x = 1	500	1500	2100	3000	>3000
	500-1500	x = exp ((y-500)/721.5)					
	1500-3000	x = (y-1000)/125					
	3000-6000	x = y/375					
Hardness as $CaCO_3$ (mg/L)	≤75	x = 1	75	150	300	500	>500
	75-500	x = exp (y+42.5)/205.58					
	>500	x = (y+500)/125					
Chloride (mg/L)	≤150	x = 1	150	250	600	800	>800
	150-250	x = exp ((y/50)-3)/1.4427)					
	>250	x = exp ((y/50) + 10.167)/10.82					
NO_3(mg/L)	≤20	x = 1	20	45	50	100	200
	20-50	x = exp((y-145.16) / 76.28)					
	50-200	x = y/65					
SO_4 (mg/L)	≤150	x = 1	150	250	400	1000	>1000
	150-2000	x = ((y/50) + 0.375) /2.5121					
Total coliform (MPN)	≤50	x = 1	50	500	5000	10000	15000
	50-5000	x = (y/50)**0.30110					
	5000-15000	x = ((y/50)-50)/16.071					
	>15000	x = (y/15000) + 16					
As (mg/L)	≤0.005	x = 1	0.005	0.01	0.05	0.1	1.3
	0.005-0.01	x = y/0.005					
	0.01-0.1	x = (y+0.015)/0.0146					
	0.1-1.3	x = (y+1.1)/0.15					
F (mg/L)	0-1.2	x = 1	1.2	1.5	2.5	6.0	>6.0
	1.2-10	x =((y/1.2)-0.3819)/0.5083					

Aquatic toxicity index

The aquatic toxicity index is proposed by Wepener *et al.* (1992) to assess the effect of water quality on the aquatic organisms especially fish fauna. The ATI showed the health status of the aquatic ecosystem that is better of aquatic organisms or not based on their water quality health status. The aquatic toxicity index is applied widely to assess the suitability and health status of the aquatic ecosystem (Dede *et al.*, 2013; Gerber *et al.*, 2015).

***Parameter selection*:** In the ATI, the selection criteria for the parameter is based on their role and importance for the survival of the aquatic organisms. In this index, a total of 14 water quality parameter that is the combination of 8 physico-chemical parameters such as pH, turbidity, total dissolved solids, dissolved oxygen, ammonia, orthophosphate, fluoride and Potassium while 6 hazardous or toxic metals such as manganese, copper, lead, nickel, zinc and chromium (Table 4).

***Sub-indices formation*:** The formation of the sub-indices curve was developed based on the smith index. The equation used for transforming the parameters on a common scale for determining the index rating values is illustrated in Table 7.

***Assigning weight of parameters*:** There is no need for assigning the parameters weight.

***Aggregation of final index*:** In ATI water quality index, the aggregation of the final index is applied using the unweighted additive aggregation function method.

Table 7. Equation used for developing the sub-indices curve in aquatic toxicity index (Wepener *et al*., 1992).

Parameter	**Mathematical equation**
pH	$Y = 98 \exp[-(pH-8.16)^2 (0.4)] + 17 \exp[-(pH-5.2)^2 (0.5)] + 15 \exp[-(pH-11)^2 (0.72)] + 2$
Dissolved oxygen	$0 \le DO \le 5$; $y = 10(DO)$
	$5 < DO \le 6$; $y = 20(DO)-50$
	$6 < DO \le 9$; $y = 10(DO)+10$
	$Do > 9$; $y = 100$
Ammonium	$0.02 \le NH_4^+$; $y = 100$
	$0.02 < NH_4^+ \le 0.062$; $y = -500(NH_4^+) + 110$
	$0.062 < NH_4^+ \le 0.5$; $y = 40(NH_4^+ + 0.65)^2$
	$NH_4^+ > 0.5$; $y = -5.8(NH_4^+) + 32.5$
Turbidity	$Y = -220 \ln(0.001 \ln(NTU)+30) + 689$
Total dissolved solids	$Y = 117 \exp^{-0.00068(TDS)} - 7$
Potassium	$Y = 150 \exp^{-0.02(K)} - 8$
Orthophosphate	$Y = 100 \exp(P)(-2.4)$
Manganese	$Y = 0.115 \exp^{-0.05} \exp^{(Mn)0.0013} + 5$
Nickel	$Y = 28 \ln(1(Ni+10)) + 211$
Fluoride	$Y = -71 \ln(0.001(F+2.5)) + 235$
Chromium	$Y = -40 \ln(0.1(Cr+150)) + 210$
Lead	$Y = -30 \ln(0.1(Pb+30)) + 148$
Copper	$Y = -26 \ln(1(Cu+18)) + 180$
Zinc	$Y = -22 \ln(0.001(Zn-20)) + 16$

The general formula for calculating the ATI as follows:

$$ATI = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2$$

Where n is the number of parameters, q_i is the sub-indices of parameters. The interpretation of ATI water quality index is displayed in Table 4.

***Advantages of the ATI index*:** This index is very useful to assess the water quality is suitable for aquatic organisms or not. It also showed the responsible water parameter that affects water quality.

Groundwater quality assessment index

The groundwater quality assessment index is usually used for assessing groundwater quality (Tiwari and Mishra, 1985). In India, for assessing the groundwater quality, the WQI of Tiwari and Mishra (1985) is used. But this index is not specific groundwater quality index. But some researcher such as Vasanthavigar *et al.* (2010) modified the WQI of Tiwari and Mishra for assessing the groundwater quality (Abbasi and Abbasi, 2012). This index is used widely in India for assessing the groundwater quality status (Tyagi *et al.*, 2014; Singh and Hussian, 2016).

***Parameter selection*:** In WQI of Tiwari and Mishra, selection of parameter based on the experience and indicated parameters are selected. But the modified groundwater quality index (Vasanthavigar *et al.*, 2010), a total of 12 parameters has been selected based on their importance (illustrated in Table 4).

***Sub-indices formation*:** In this index, the quality rating scale is developed by dividing the concentration of parameters with their standard limits. The formula used for rating the parameters as follows:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100$$

Where, q_i: quality scale of ith parameters, C_i: actual concentration of the ith parameters, S_i: Standard value of *ith* parameters given by BIS and WHO.

***Assigning weight of parameters*:** In this index, the weight of the parameter is assigned based on their importance in the water quality. The maximum weight of parameters are assigned 5 and minimum are assigned 1. Firstly, we assigned the parameter weight and then we calculated the relative weight of the parameter (illustrated in Table 7) by the given formula.

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

Where, W_i: relative weight of ith parameters; w_i: assigned weight of the ith parameter.

***Aggregation of final index*:** The aggregation of the final index value is generally assessed by the given formula:

$$WQI = \sum SI_i$$

Where SI_i is the sub-index value of ith parameters and can be calculated using the equation:

$$SI_i = W_i \times q_i$$

Where, W_i: relative weight of *ith* parameters; Q_i: quality rating scale of ith parameters; The interpretation of the groundwater quality index is illustrated in Table 8.

***Advantages of the groundwater quality index*:** This index is a useful tool to assess groundwater quality. It also suggests the suitability of groundwater for drinking and irrigation purpose. It also showed the responsible water parameter that affects groundwater quality.

Conclusion and recommendation

The present chapter focusses on the water quality index tool that is used for assessing the water quality of any water body for their suitability condition for humans as well as aquatic organisms, and also suggests the uses of water in various work. In this chapter, we discussed the basic four steps that are used in the development of a WQI such as the selection of parameters, sub-indices formation, parameter weight and aggregation of the final index.

Table 8. Assigning the parameters weight according to BIS (2012) and WHO (2012) standards (Vasanthavigar *et al*., 2010)

Parameters	Unit	BIS standards	Assigning weight	Relative weight
TDS	mg/l	500	5	0.116
HCO_3	mg/l	244	1	0.023
SO_4	mg/l	200	5	0.116
PO_4	mg/l	-	1	0.023
NO_3	mg/l	45	5	0.116
F	mg/l	1.0	5	0.116
Cl	mg/l	250	5	0.116
Ca	mg/l	75	3	0.070
Mg	mg/l	30	3	0.070
Na	mg/l	200	4	0.093
K	mg/l	-	2	0.047
Silicate	mg/l	-	2	0.047
			$\sum w_i = 41$	$\sum W_i = 0.953$

Although, we select seven water quality index based on their popularity, used by many researchers throughout the world. These seven water quality index is discussed in detail with the selection criteria of parameters, the formation of sub-indices, assigned the parameters weight, aggregation of the final index, advantages and disadvantages. The main advantages of these water quality indices is indicated the ranking and status of the water body of any region or country. At last, we conclude that there are some restriction in these water quality indices such as selection of parameters. If we compare the water quality status of water body using two different water quality indices than we used a fixed set of parameters for both the indices.

Conflict of interest: The author declares that there is no conflict of interest.

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Chapter [14]

Distillery spent wash treatment technologies: A case study of the comparative efficiency of aerobic and anaerobic treatment processes

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Abstract

Effluent generated from distilleries is known as slop/spent or wash/vinasse/ stillage. The present study is carried out with the objective of characterization and treatment of distillery spent wash using aerobic and anaerobic treatment processes on the treatment plant of UP Co-operative distillery Jahangirabad, Anoopsahar (UP) form October 2019 to February 2020. Effluent of the distillery (RAW-DSW) was found highly polluted during all the samplings. Influent was observed highly acidic in nature (pH= 4.1-4.5). After the treatment, effluent becomes near neutral in case aerobic treatment and slightly alkaline in case of anaerobic treatment. For TSS aerobic treatment efficiency is 87.6% while in anaerobic treatment efficiency is 90.4%. In case of BOD, efficiency of aerobic treatment is 36.6% while in anaerobic treatment it is 71.7%. The parameters of outlet from both the treatment processes were found above the standards limits of discharge. Although anaerobic treatment processes improve the quality of outlet, yet the performance is not satisfactory and it requires further attention to improve the quality of effluent to meet the discharge limits.

Keywords Biogas, Ethanol, Distillery spent wash, Molasses, Sugar industry

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Introduction

Effluent generated from distilleries is known as slop/spent wash/vinasse/stillage (Nandy *et al.* 2002; Pathade, 2003; Singh *et al.*, 2004). From one litre of alcohol production approximately 8-15L of effluent is generated, therefore a typical distillery generates over half a million litres of spent wash effluent daily (Saha *et al.*, 2005; Pant and Adholeya, 2007; Mohana *et al.*, 2009). Due to widespread industrial applications of alcohol such as in pharmaceuticals, food, perfumery, etc., the alcohol distilleries are extensively growing. It is also used as an alternate fuel. Until 1931 India had only 29 sugar factories in operation, producing small quantities of molasses which did not cause a serious disposal problem. The number of sugar factories increased dramatically in 1935-36 to about 135 and the production of molasses increased to nearly 0.48 million tons (Singh and Nigam, 1995). A report suggests that there are 325 molasses based distilleries in the country producing 3.25 billion litres/year of alcohol and generating 45.0 billion litres/year of spent wash as waste annually (Ayub *et al.*, 2012; Pant and Adholeya, 2007). As per the Ministry of Environment and Forests, alcohol distilleries are listed at the top in the "Red Category" industries (CPCB, 2003; Chittaragi and Byakodi, 2018). India ranks 4th in the globe and 2nd in Asia in terms of ethanol production. Currently the 5% blending is only applicable in 10 States and three Union Territories and requires about 410 million litres of anhydrous alcohol. Increments in both % blending and geographical spread are anticipated. Feed preparation, fermentation, distillation and packaging are the four main steps in alcohol production in distilleries (Satyawali and Balakrishanan, 2008). Different biomass materials can be used in Ethanol production but the potential for their use as feedstock depends on the cost, availability, carbohydrate contents and the ease by which they can be converted to alcohol (Ogbonna, 2004). Nearly 61% of world's ethanol production is from sugar crops (Berg, 2004). Most Indian distilleries exclusively use cane molasses as raw material for fermentation (Handa and Seth, 1990). Distilleries in India are one of the most pollution creating industries, also consumes high volume of water. The diagrammatic process of ethanol production is presented in Figure 1. The agro based distillery outlet is very complex in nature, caramelized and cumbersome having high temperature (70-80^{0}C), dark brown colour, low pH, and high organic matter. The pollution load of the distillery effluent depends on the quality of molasses and the process operations of processing and recovery used (Pandey *et al.*, 2003) and its contribution is approximately seven times in terms of population in Indian. A good volume of Biogas can be generated form the distillery wastewater. Due to increasing awareness and government policies to check pollution load, different industries along with distilleries have been bounded for sustainable technologies for their waste treatment. To meet the standards and to achieve the zero discharge policy of CPCB (2003) distilleries have to look into their treatment methodologies in terms of their cost and sustainability (Mohana *et al.*, 2007). Approximately 1,200 million cubic meters of bio gas can be produced form 45 billion litres of distillery spent wash (DSW) produced in the country and approximately more than 85,000 tons of bio mass annually.

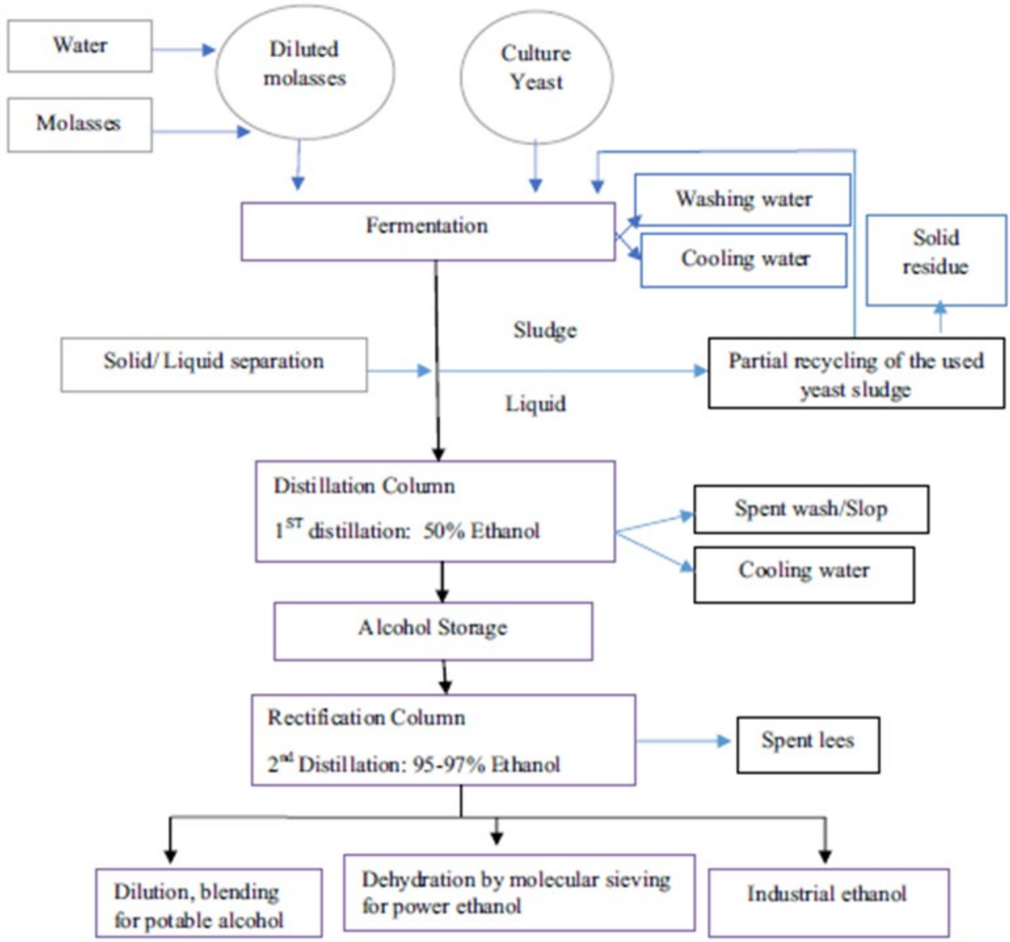


Figure 1. Ethanol distillery manufacturing process (Fito *et al*., 2019; Satyawali and Balakrishanan, 2008)

Environmental impacts of distillery spent wash

Spent wash or effluent generated from distillation process has very high polluting potential. In the areas, where the treated water of distillery is used for irrigation purpose, colour problem in ground water is observed to an extent that the industries have to provide the drinking water to the nearby villages. Different types of physicochemical and biological methods are applicable for the removal of colour from distillery spent wash was tried, but a cost effective and efficient treatment method is still awaited for the better achievement (Ogbonna, 2004). The variation in the quality of DSW is due to different processes and mixing of their wastewater, combination of all these wastewater makes DSW

(Tewari *et al*., 2007). DSW has very high BOD/COD ratio making it unsuitable for biological treatment and showing the non-biodegradable nature of pollutants. The release of this waste into water bodies cause the problem of eutrophication due to high amount of inorganic substances (Kumar *et al*., 1997; Sharma *et al*., 2007). The presence of compounds such as melanoidins, anthocyanins, caramel, tannins and different xenobiotic compounds makes it recalcitrant and toxic for many microorganisms. These compounds remain unbreakable and can be found in the out let of treatment plants (Pandey *et al*., 2003). The presence of compounds such as skatole, indole and other sulphur compounds provides unpleasant odour to the effluent and these compounds also passed out in the outlet without degradation (Acharya *et al*., 2008; Shivajirao, 2012). DSW is harmful to aquatic life as it reduces the amount of DO due to reduced process of photosynthesis by green plants because it makes the water opaque due to presence of coloured components (Ramakrithnan *et al*., 2005; Chaudhary and Arora, 2011; Arimi *et al*., 2014; Farid *et al*., 2010). Disposal of DSW on land is equally hazardous to the vegetation as it reduces soil alkalinity and availability of manganese, which results in less seed germination (Kumar *et al*., 1997). Kannan and Upreti (2008) reported high toxic effects of raw distillery effluent on the growth and germination of *Vigna radiata* seeds even at low concentration of 5% (v/v).

Various methods of distillery spent wash treatment

A number of technologies have been discussed in the literature for reducing the pollution load of distillery effluent. Based on the literature, different treatment methodologies and their sub methodologies available for the treatment of distillery spent wash (DSW) are presented in Figure 2. Ministry of Environment, Forest and Climate Change (MOEFCC), recommended the Reboiler, Bio-methanation, Reverse Osmosis (RO) System, Multi Effect Evaporator (MEE), Bio-composting and one time controlled land application, Ferti-irrigation, Turbo Mist Evaporation, and Concentration and Incineration technologies/processes for spent wash treatment.

Biological treatment

Biological treatment is considered as simple, inexpensive and environmental friendly for the degradation of wastes. Certain factors such as temperature, aeration rate, pH, and nutrients affect the performance of biological treatment (Ali *et al*., 2015). In biological processes, microbes used oxidize and degrade the organic materials and utilise the carbon and energy for their growth. The drawbacks of biological methods are its slow speeds and more uncertainty. Biological methods are of two types:

1. Anaerobic treatment

Anaerobic processes produces small amount of sludge and consumes less amount of energy and also generate useful biogas which makes it a profitable process (Mailleret *et al*., 2003). Organic shock

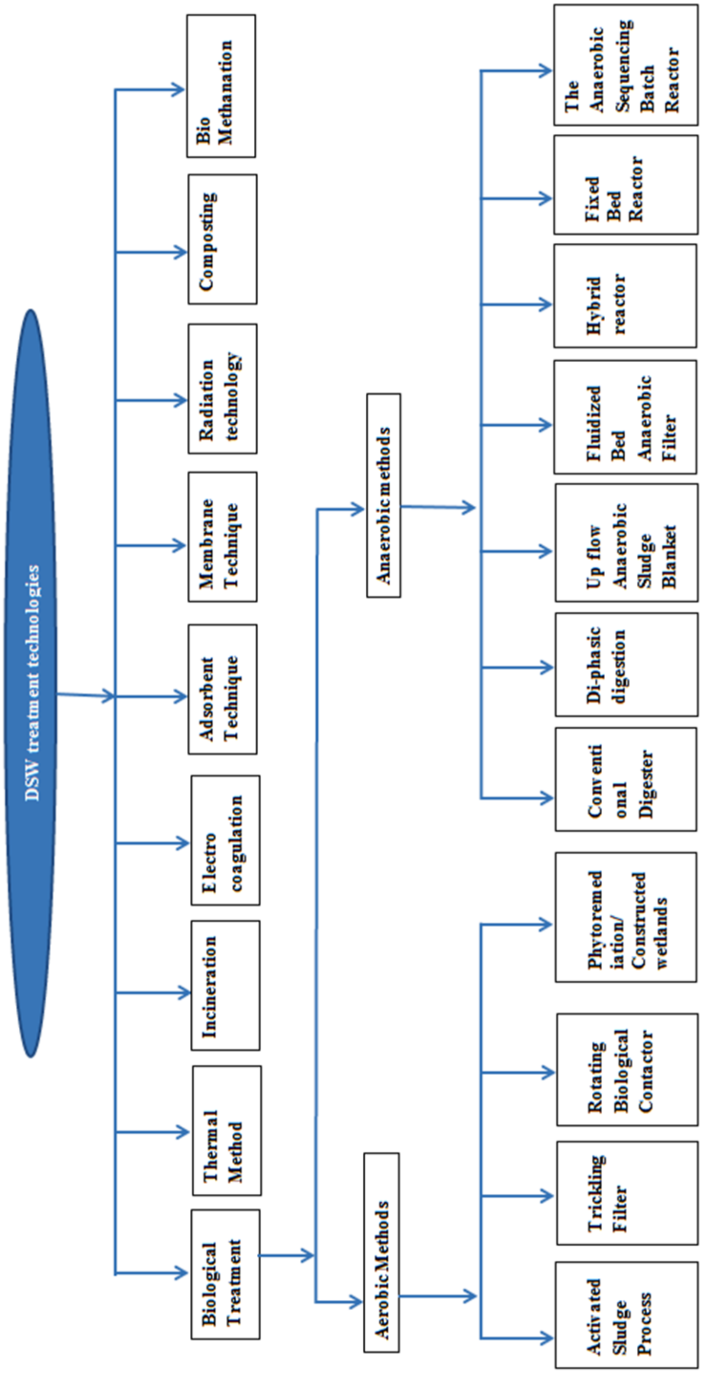


Figure 2. Different methodologies of distillery spent wash (Adopted from Bhardwaj *et al*., 2019).

loadings, low pH and show slow degradation, and longer hydraulic retention times (HRT) are some of the factors or drawbacks which affect the performance of anaerobic treatment processes. These entire drawbacks are continuously eliminated in different upgraded anaerobic treatment process.

***Conventional digester*:** In this process the wastewater is treated in a single tank using acidification, methane fermentation and sludge thickening processes without any heat and mixing (Bhardwaj *et al.,* 2019).

***Phasic digestion*:** In single phasic system, there is only one reactor while in biphasic system, there are two reactors. In biphasic system acidogenic and methanogenic reactions occur in separate reactors. The end products of acidogenesis phase are formate, acetate, lactate, ethanol, carbon dioxide, hydrogen and C3 and higher volatile fatty acids while the end products of methanogenesis phase are methane and carbon dioxide (Gosh, 1990; Seth *et al.*, 1995). A three phase fluidised bed biofilm reactor was also used for distillery effluent treatment (Kumaresan *et al.,* 2009; Lakshmikanth and Virupakshi, 2012)

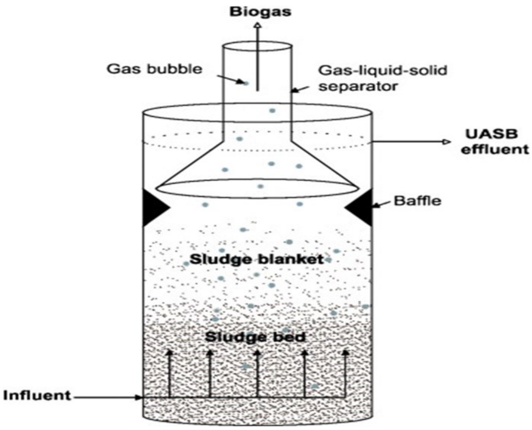
***Upflow Anaerobic Sludge Blanket (UASB)*:** This is high rate anaerobic, well-established wastewater treatment method applied for treatment of food industry, distilleries, tanneries and municipalities wastewaters. Three phase separators, sludge bed, and sludge blanket are the different components of the reactor (gas-liquid solid, GLS separator). Continuous recirculation process is used to kept the micro-organisms in the suspension form and for that an internal settler was used at the top of the reactor (Patyal, 2015). Treatment occurs as the wastewater comes in contact with the granules and/or thick flocculent sludge. This type of reactor treatment was studied by several researchers (Kansal *et al.,* 1998; Goodwin and Stuart, 1994; Florencio *et al.,* 1997; Harada *et al.,* 1996).

***Fluidized Bed Anaerobic Filter (FBR)*:** In this technology, the carriers for the biofilm are fluidised bed. The media used are small particle size sand, activated carbon and inert materials. In the fluidized state, each medium provides a large surface area for biofilm formation and growth. The energy demand in technology is very high.

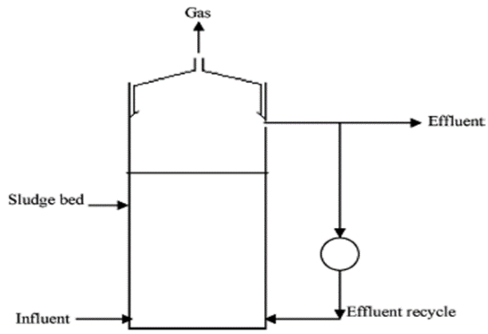
***Hybrid reactor*:** Hybrid, an anaerobic digester, filled with sludge bed at the bottom can be used for treatment of wastewaters of both high and low strength. Hybrid reactor is taller than the UASB reactor (Patyal, 2015).

***Fixed bed reactor*:** In this reactor, an inert plastic material is used as filter medium of high specific surface for the growth of biomass are used with external separation and recirculation of sludge.

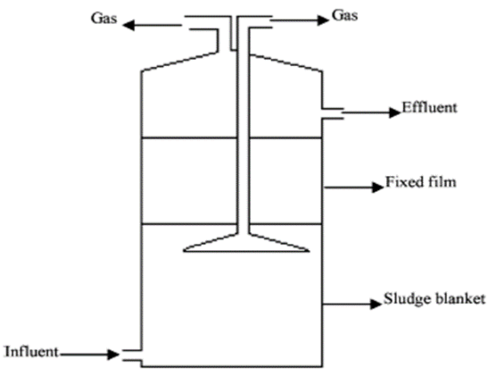
***Anaerobic Sequencing Batch Reactor (ASBR)*:** The main steps in anaerobic sequencing batch reactors (ASBRs) are feed, reaction, settling and decantation. The reaction and solid-liquid separation occurs in the same vessel. The first step involves the addition of substrate to the reactor where the contents are continuously mixed. The volume of substrate fed depends on a number of factors, including the desired hydraulic retention time (HRT), organic loading, and expected settling characteristics. The conversion of biodegradable organic matter to biogas is achieved. Banerjee and Biswas (2004) worked on these types of reactors.



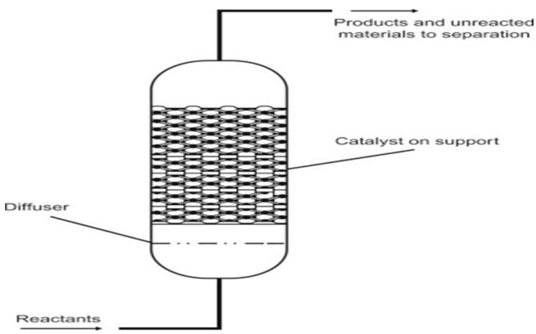
Upflow anaerobic sludge blanket (UASB)



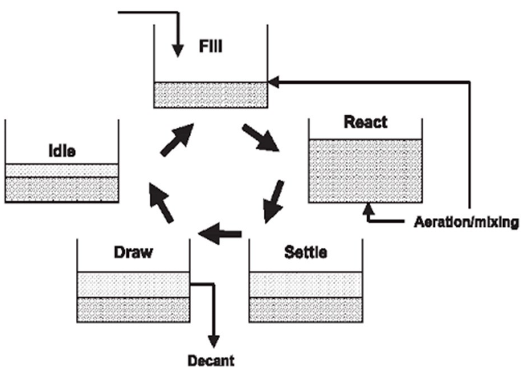
Anaerobic fluidized bed reactor



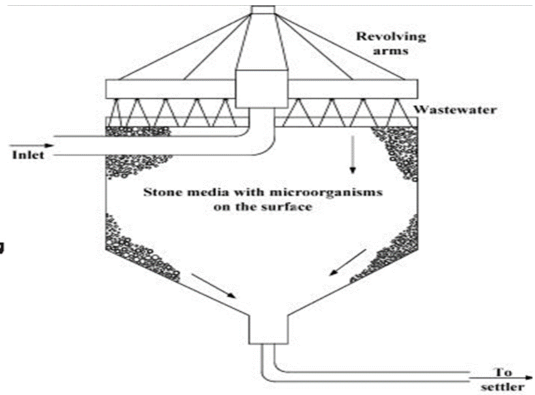
Anaerobic hybrid reactor



Fixed bed reactor (FBR)



Anaerobic sequencing batch reactor (ASBR)



Trickling filter

Figure 3. Various methods and reactors used for the treatment of distillery spent wash.

2. Aerobic treatment

After the treatment with anaerobic process, the treated water still contains the undesirable concentration of pollutants. The most important pollutant remains after the anaerobic treatment is colourant compound. After anaerobic treatment, aerobic treatment of distillery spent wash is performed for the decolourization of the major colourant compounds and for the reduction of the COD and BOD (Mohana *et al.*, 2009).

Activated Sludge Process (ASP)**:** Most common biological method for the treatment of industrial and municipal wastewater. Aeration of incoming wastewater is performed with intermittent supply of micro-organism in an aeration tank. Aeration tank (reactor), clarifier, and recirculation system are the essential steps of ASP. Organic materials are biodegraded by being in contact with micro-organisms within an aerobic environment. Activated sludge treatment is regarded as a suspended growth process due to microbes being suspended in the water.

Trickling Filter (TF)**:** Trickling filters also called attached-growth processes are used to the biological treatment of municipal and industrial wastewater for approximately 100 years. The fixed or rotating arms distribute or spray the wastewater over media or rocks that are covered with a biological layer of slime and provide the oxygenation to the water. Microbes present in slime layer (mainly bacteria and algae and various other organisms such as protozoa and metazoa), break down the organic matter. This system also requires a lot of energy and man power so considered as unsustainable.

Rotating Biological Contactor (RBC)**:** Used for the treatment of carbon-based wastewater. Closely spaced circular plastic disks partly submerged into a tank moved through untreated wastewater. Microbial films developed on the surface of the circular disks degrade the organic material in the presence of air. Although, RBC, activated sludge process and trickling filter treatments are mostly similar to each other but the formation of biofilm on the disk process is the principal feature of RBC. RBC requires less land area, and has high removal rates of BOD. It is also an energy intensive process.

Phytoremediation /constructed wetlands**:** Phytoremediation, an emerging low-cost is the process of treating the effluent with the help of plants. Aquatic plants reduce the level of BOD, toxic metals, and solids from the wastewaters excellently (Kumar and Chandra, 2004). Billore *et al.* (2001) studies the potential of *Typha latipholia* and *Phragmites karka* for the treatment of distillery effluent in constructed wetlands. Kumar and Chandra (2004) successfully treated distillery effluent in a two-stage process using a bacterium *Bacillus thuringienesis* and a macrophytes *Spirodela polyrrhiza*. A similar biphasic treatment was also performed with *B. thuringienesis* and *Typha angustata* by Chandra *et al.* (2008). Similar works were performed by Bama *et al.* (2013) and Bhardwaj and Bhasin (2012). Distillery spent was also treated using nanofiltration (Dave *et al.*, 2013), Electrocoagulation (Wagh and Nemade, 2015; Vijaya *et al.*, 2013), Adsorption (Kulkarni, 2013), and Fungal treatment (Tripathi *et al.*, 2007).

Need of the present study

In highly growing population, industrialization, and energy consumption, coupled with an increasing on fossil fuels, the energy security needs of the world continue to escalate. Till date Indian government was not permitted the alcohol blending in motor fuels, due to which the use of alcohol is less but if the government will permit, there will be drastic increase in the demand of alcohol which results in the production of huge amount of DSW. Treatment and safe disposal of the raw spent wash has been a big challenge for a long time (Balasubramanian and Kannan, 2016). The present study was performed on the water treatment plant of UP Co-operative distillery Jahangirabad, Anoopsahar (UP). The plant is continuously struggling to improve the quality of the effluent. Therefore the plant started both the process (aerobic and anaerobic) but running them separately. Thus the present study was carried out to characterize the raw distillery effluent (DSW) and compare the efficiency of aerobic and anaerobic process for the remediation of selected physicochemical parameters.

For the present study UP Co-operative distillery Jahangirabad, Anoopsahar (UP) was selected. In the plant, the DSW was treated with both aerobic and anaerobic treatment processes. For the present study raw distillery effluent, outlet of aerobic and anaerobic treatment process was collected twice in a month in morning hours (7 am-10 am) from UP Co-operative distillery Jahangirabad, Anoopsahar (UP) for a period of five months (From October 2019 to February 2020). A total of ten sampling were performed and named as sampling number 1 to 10 (SN-1 to SN 10). Grab water samples from all the sites were collected in plastic jerry cans keeping and opening Jerri cans below the water surface. Caps of cans were removed and closed after filling up inside the water and then the water samples were transported to the laboratory directly and analysis were performed for following physicochemical parameters *viz*. Colour, Temperature, Total Suspended Solids (TSS), pH, Acidity, Dissolved Oxygen (Winkler method), Biochemical Oxygen Demand (BOD), chemical oxygen demand (COD), Total Kjeldahl Nitrogen (TKN) and Volatile Fatty Acids (VFA). All the analysis was performed within 24 hour of sampling. Analysis of water was done according to standard methods as prescribed by APHA (2012), Trivedy and Goel (1986) and Khanna and Bhutiani (2008) for the examination of the water and waste water.

Aerobic treatment processes of DSW are those processes which are operated in the presence of oxygen while anaerobic treatment processes are those which are operated in the absence of oxygen. The results of aerobic treatment and anaerobic treatment are presented in Table 1 and Figure 4. The minimum, maximum and average temperature was observed 68.0^{0}C, 76.0^{0}C and 71.3^{0}C±2.6 in RAW-DSW while 28.0^{0}C, 33.0^{0}C and 30.4^{0}C±1.6 with aerobic treatment and 29.0^{0}C, 36.0^{0}C and 32.1^{0}C±2.0 with anaerobic treatment. The minimum, maximum and average temperature removal was observed 54.3%, 60.0% and 57.3% in aerobic treatment while 49.3%, 58.7% and 54.9% in anaerobic treatment.

The minimum, maximum and average TSS was observed 1380mg/L, 1560mg/L and 1496.6mg/L±56.0 in RAW-DSW while 160mg/L, 220mg/L and 186.0mg/L±17.0 with aerobic treatment and 80mg/L, 210mg/L and 143.6mg/L±48.5 with anaerobic treatment. The minimum, maximum and average TSS removal was observed 85.5%, 89.7% and 87.5% in aerobic treatment while 86.1%, 94.9% and 90.4% in anaerobic treatment. The minimum, maximum and average pH was observed 4.2, 4.5 and 4.1±0.1 RAW-DSW while 7.2, 7.8 and 7.5±0.1with aerobic treatment and 7.8, 8.5 and 8.1±0.2 with anaerobic treatment. The minimum, maximum and average pH gain was observed 60.0%, 78.6% and 70.7% respectively in aerobic treatment while 73.3%, 95.2% and 85.2% in anaerobic treatment. In most of the research an increase in the pH was observed (Banu *et al.*, 2007; Mohana *et al.*, 2009; Mise *et al.*, 2013).

BOD removal is indicative of the efficiency of biological treatment processes and is the most widely used parameter to measure wastewater quality. The minimum, maximum and average BOD was observed 31876mg/L, 34145mg/L and 32869.2mg/L±835.5 in RAW-DSW while 20032mg/L, 22012mg/L and 20848.7mg/L±581.8 with aerobic treatment and 8509mg/L, 10000mg/L and 9316.8mg/L±487.9 with anaerobic treatment. The minimum, maximum and average BOD removal was observed 34.2%, 38.7% and 36.6% respectively in aerobic treatment while 68.9%, 74.5% and 71.6% in anaerobic treatment. Results are in accordance with that of Mallick *et al*. (2010). COD is the amount of oxygen required for the breakdown of organic and inorganic matter chemically (Akan *et al.*, 2008). The minimum, maximum and average COD was observed 82000mg/L, 86198mg/L and 85010.2mg/L±1548.1 in RAW-DSW while 48087mg/L, 51134mg/L and 49180.9mg/L±1054.5 with aerobic treatment and 36056mg/L, 37900mg/L and 36871.0mg/L±628.4 with anaerobic treatment. The minimum, maximum and average COD removal was observed 38.9%, 44.2% and 42.1% respectively in aerobic treatment while 54.9%, 58.1% and 56.6% in anaerobic treatment. Our results are in accordance with that of Kumar *et al*. (2006), Kumar *et al.* (2020) and Mise *et al.* (2013)

The Kjeldahl method consisting of three steps *viz.* digestion, distillation and titration is a method of quantification of the nitrogen content in different soil and water samples. The minimum, maximum and average TKN was observed 900mg/L, 1040mg/L and 960.0mg/L±52.5 in RAW-DSW while 240mg/L, 288mg/L and 266.7mg/L±14.6 with aerobic treatment and 231mg/L, 270mg/L and 251.9mg/L±13.2 with anaerobic treatment. The minimum, maximum and average TKN removal was observed 70.4%, 74.5% and 72.2% respectively in aerobic treatment while 71.7%, 75.9% and 73.7% in anaerobic treatment. More or less similar results were obtained by Banu *et al*. (2007) and Kumar *et al*. (2006). The minimum, maximum and average acidity was observed 1650mg/L, 2220mg/L and 2027.0mg/L±165.0 in RAW-DSW while 695mg/L, 867mg/L and 754.4mg/L±52.0 with aerobic treatment and 80mg/L, 760mg/L and 577.0mg/L±121.1 with anaerobic treatment. The minimum, maximum and average acidity removal was observed 55.5%, 65.6% and 62.6% respectively in aerobic treatment while 59.6%, 79.4% and 71.6% in anaerobic treatment. Our results are in accordance with that of Shivayogimath and Ramanujam (1999). The minimum, maximum and average VFA was observed 4856mg/L, 5876mg/L and 5181.2mg/L±311.8 in RAW-DSW while 3102mg/L, 4988mg/L and 4065.7mg/L±626.6 with aerobic treatment and 2474mg/L, 3015mg/L and 2724.8mg/L±158.3 with anaerobic treatment. The minimum, maximum and average VFA

Table 1. Average values of all the parameters and their average removal through aerobic and anaerobic treatment process during the study period.

Parameters/treatment	RAW-DSW	Aerobic	% removal	Anaerobic	% removal
Temperature	71.3	30.4	-57.4	32.1	-55.0
TSS	1496.6	186.0	-87.6	143.6	-90.4
pH	4.38	7.5	+70.5	8.1	+85.2
BOD	32869.2	20848.7	-36.6	9316.8	-71.7
COD	85010.2	49180.9	-42.1	36871.0	-56.6
TKN	960	266.7	-72.2	251.9	-73.8
Acidity	2027	754.4	-62.8	577.0	-71.5
VFA	9681.2	4065.7	-58.0	2724.8	-71.9

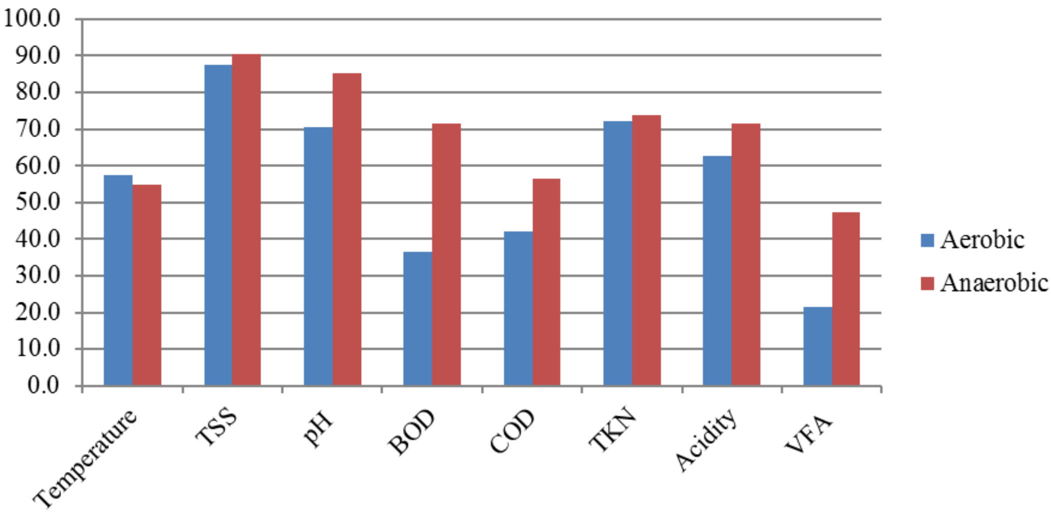


Figure 4. Percent efficiency of aerobic and anaerobic treatment process for all the studied parameters.

removal was observed 0.6%, 39.4% and 21.4% respectively in aerobic treatment while 44.6%, 54.7% and 47.3% in anaerobic treatment. Our results are in accordance with that of Banu *et al.* (2007).

Conclusion

The objective of the present study is the comparative assessment of treatment efficiency of aerobic and anaerobic treatment processes treating the effluent of a distillery plant. The raw effluent of the distillery (RAW-DSW) was found highly polluted during all the samplings. Influent was observed highly acidic in nature. After the treatment aerobic and anaerobic treatment, pH was increased and the effluent becomes near neutral in case aerobic treatment and slightly alkaline in case of anaerobic treatment. When overall efficiency of both the treatment processes was compared, it was observed that anaerobic treatment processes are much effective for the treatment of distillery effluent. The concentration of parameters of outlet from both the treatment processes was found above the standards limits of discharge. Although anaerobic treatment processes improve the quality of outlet, yet the performance is not satisfactory and it requires further attention to improve the quality of effluent to meet the discharge limits. Our recommendation for the distillery industry wastewater treatment is the use of both anaerobic and aerobic treatment process in combination one after the other to achieve the desirable water quality.

Conflict of interest: The author declares that there is no conflict of interest.

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