Chapter 25

Environmental pollution and their socioeconomic impacts

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25.1 Background

Environmental pollution is the world's largest cause of untimely death and disease (Landrigan et al., 2019). Globally, the term "environmental pollution" has long existed and its impacts have greatly been felt on the whole of humanity and its environment whether knowingly or otherwise ever since the first congregation and groups of people lived for some long time in one particular location of the Earth (Easterbrook, 1995; Botkin, 1995). Archaeologists have discovered several remains of tools, shell mounds, clothing, and rubble heaps of such people (Keller, 1988). During their existence on Earth, pollution was not seen as a serious problem because of the large availability of space for individuals and groups of people to live in. Although some of their activities (if not most) were not pollution-free but human beings were not affected by the menace or nuisance been caused then (Miller, 1997, 2004). However, as the population increased rapidly, resulting in the formation of more permanent colonies by numerous numbers of people, the subject of pollution resulted in becoming a menace to both humanity and its environment, and it has remained a major one ever since (Jackson and Jackson, 1996; Spellman, 2017).

History has it that, in ancient time, both cities and major towns where major civilization emerged from were baneful areas, soiled by debris and the wastes from human. At about 1000 CE the utilization of coal as a source of fuel resulted in considerable air pollution. From the inception of the 17th century all through the commencement of the 19th century, conversion of coal to coke, which was used for iron smelting, further aggravated the problem. Through the 19th century, there was an extension of this menace to water bodies also. Largely, solid waste accretion of congested urban areas was the problem during the 19th century but, due to human population's rapid industrialization and geometrical growth most especially in urban cities, pollution has become a universal problem and a major threat to human's existence (Alina, 2018; Sulaymon et al., 2020). Landrigan et al. (2017) documented that pollution is accountable for the 16% of all deaths worldwide and 9 million deaths yearly three times more deaths than malaria, tuberculosis, and AIDS altogether. Environmental pollution is responsible for greater than one death in four (Landrigan et al., 2019). Moreover, Suk et al. (2016) asserted that children are impeccably responsive to pollution.

25.2 Concept of environmental pollution

The Earth is faced today by numerous negative occurrences and challenges (caused by human beings, animals, organisms, and many more) and each was triggered to the dangerous level as consequence of Industrial Revolution

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(Spellman, 1999). The impacts of this menace increase day by day, causing irreparable damage to the Earth through increasing various anthropogenic activities such as incessant combustion of fossil fuels, which emit both particulate and gaseous pollutants, which are toxic in nature; disposal of toxic effluents by factories into water bodies, rendering them unusable and destroying aquatic life; sprawling urbanization resulting in deforestation and thus causing the quality of air to be poor; damaging the productivity of soil via plastic waste littering, just to mention a few. Despite all these accompanying impacts of environmental pollution, there have been little to none efforts to intentionally and pragmatically address its environmental effects and human health risks.

Defining the term "environmental pollution" can be a bit difficult, as various definitions rendered by various authors in the past have been mainly given, based on their various perspectives of the subject matter. One of such definitions by Spellman and Whiting (2006), which seems to capture this concept entirely is stated as "the contamination of air, water, or soil (food) in such a manner as to cause real or potential harm to human health or well-being, or to damage or harm nonhuman nature without justification." As encompassing as this definition is, a layperson may find it challenging to comprehend, thus resulting in sidelining and neglecting some classes of humanity who also have contributed massively to this long-aged world menace. To avoid the repetitions and catalogs of definitions as used in the past and also to make it all-inclusive, we define environmental pollution in its simplest form as "the pollution of the various aspect of the environment making up our natural resources such as soil, water, air, forests and et cetera." All that surround us make up the environment we inhabit and its pollution is hence termed "environmental pollution."

25.3 Pollution: what does it mean?

Over the years, the state of clearly distinguishing succinctly between the terms "environmental pollution" and "pollution" had often resulted in some mild arguments in the environmental world. Some had termed both concepts to be the same in meaning, while others think otherwise. Even in various colleges and higher institutions of learning around the world, students find it tricky to glaringly differentiate between the two terms, especially as regards the definition of terms. Most of their responses are identical and lie in describing the outright effects of the terms, having witnessed some forms of this scenario firsthand (Spellman, 1999, 2017). As pollution is ubiquitous, seeming to take after one of the characteristics of divinity, giving it a definite meaning is complicated (just like the case of environmental pollution mentioned in Section 25.2). It cannot be easily defined. What pollution clearly represents and vice versa is judgmental. We were even taught by nature, the intimate interconnection of most minute elements with other one, which are ultimately the consequential effects of pollution (Pepper et al., 2006). Let us quickly look at some definitions given by some specialists in matters relating to the environment. They are stated as follows:

Pollution is defined as "the man-made or man-induced alteration of the physical, biological, and radioactive integrity of water" (USEPA, 1989 under the Clean Water Act).

Pollution is explained as the casting off of any substance in the category of solid, liquid, gas or any form of energy (in form of heat, sound, or radioactivity) to the environment at a rapid rate greater than those substances can be dispersed, diluted, decomposed, recycled, or stored in some harmless form. (Jerry A. Nathanson – An environmentalist writer under the auspices of Encyclopedia Britannica Inc.)

Pollution is the state of making every part of the environment including air, land and water dirty and not safe or suitable to use. This is often accomplished via the instauration of contaminants into the natural environment, which may not need to be tangible. Light, temperature and sound as simple as they may look can largely be termed as pollutants when introduced intentionally and artificially into an environment. (Alina Bradford – Live Science Contributor)

Pollution is described as one of the several serious problems facing humanity which occurs at the release of substances into the environment in manners or quantities that forbid the environment from effectively handling it, and thus leading to detrimental effects on the ecosystem. (Harrison, 1996)

Any undesirable change of the environment which can be characterized physically, chemically or biologically, and is harmful to human either directly or indirectly through animals, plants, and other living or non-living organisms or entities is termed pollution. (Titiksha, 2017)

Pollution is the "introduction of harmful materials into the environment" (National Geographic, 2018).

It can be vividly noted from the previous definitions, the various perspectives of authors on pollution with each of their definitions displaying their judgmental manner of approach. This cycle of judgmental inclusion will continue even in thousands of definitions that can be expressed on the subject matter, as it has several manifestations in nature. Fig. 25.1 clearly gives these manifestations. To therefore save ourselves from the stress of giving a universally acceptable and concise definition of pollution, we can state based on its two major classifications, point source and

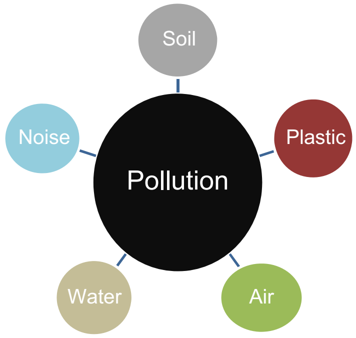

FIGURE 25.1 Environmental pollution and its major types.

nonpoint source, which largely reduce the complexity of defining the term. More discussion will be provided on both in subsequent sections of this chapter.

25.4 Pollutants and their various categories

It is of great importance to look at what pollutants are and how they really affect the environment. The word "pollutant" is closely related to "contaminant" and this may raise some questions if they are not properly defined. Most people use the terms "pollution" and "contamination" interchangeably since they both deal with unwanted elements. According to Mondal (2018), it is simplest to say that the substances that cause pollution are termed "pollutants" while those that lead to contamination are called "contaminants." Citing as an example, a waste material in a body of water may be termed a contaminant or a pollutant. Also, the cleanup processes that occur in remediation, the ones for pollution are similar to that of contamination but they are linked in a way that the introduction of harmful contaminants leads to pollution (Mondal, 2018). There is more negativity attached to pollution due to its more parlous impacts as compared to contamination. Truly, these occurrences are interconnected and comparable, but still have notable differences.

> *A pollutant is any substance which can be chemical or physical in nature, introduced into air, soil or water in a quantity that threatens humanity, its enjoyment and its proper functioning in any aspect of the environment.*
>
> *A contaminant is the availability of grand concentrations of substances which may be chemical, biological, or radiological, present in an environment which is beyond the normal datum level for both the area and the organism in the environment.*

25.4.1 Categories of pollutants

Pollutants can generally be categorized into two major parts. Although, most often, there exist other categories depending on their existence in nature, but when these are critically analyzed, they will fall under one of these two categories. They are *natural* and *artificial* pollutants. They can also be termed *quantitative* and *qualitative pollutants*, respectively.

25.4.1.1 Natural pollutants

These are materials or substances occurring naturally but later attain the position of a pollutant when their amount or concentration in a given sphere of environment escalates as a result of the mindless actions and activities of man. That, they are natural does not mean man is not involved, but his unawareness of contribution is unknown to him. For example, when some gas such as CO_2 (caused by automobiles and industries) is present in greater quantity in the atmosphere than expected, it results in immeasurable effects on animals, plants, and humans.

25.4.1.2 Artificial (man-made) pollutants

These are materials or substances that do not occur naturally in nature but are introduced into the environment via humans and their activities. Depending on the configuration they assume after their discharge into the environment, they can be classified as *primary* and *secondary* pollutants. Furthermore, based on their natural disposal as related to ecosystem, pollutants can be further classified as *biodegradable* and *nondegradable* pollutants. They are all briefly explained as follows:

1. *Primary pollutants*

These are pollutants that are directly emitted into the environment and they persist in the form in which they are released from their various sources. Their emission could be through natural ways or human actions. Gas, ash, smoke, dust, nitric oxide, sulfur(iv) oxide, and hydrocarbons are few examples under this category. The emission of gases and ash from a volcanic reaction are primary pollutants released in a natural way but carbon monoxide (CO) gas emitted from vehicles or generator machines is also a primary pollutant released via human activities. The emission of primary pollutants into the environment or the air is very harmful and can cause serious health and environmental problems such as respiratory diseases, global warming, and acid rains. The major sources of primary pollutants are motor vehicles and industries and, most often, they are precursors for secondary pollutants.

2. *Secondary pollutants*

   These are pollutants not passed off directly into the environment but are formed from primary pollutants. This can be via a chemical interaction between two or more primary pollutants or by reaction with some constituents present in the atmosphere. Examples of these pollutants include ozone, aldehydes, ketones, sulfur(vi) oxide, and nitrogen dioxide.

3. *Biodegradable pollutants*

   These are pollutants broken down by the various actions of microorganism naturally into smaller, nontoxic, substances in due course of time. Domestic garbage, wood, agricultural remains, fecal matter, cattle dung, vegetable remains, and sewage are typical examples of these pollutants.

4. *Nondegradable pollutants*

These are pollutants that cannot be broken down (or they degrade at a very slow rate) in the environment. Polythene bags, plastics, aluminum plates and cans, synthetic fibers, silver foils, mercury, and lead, arsenic are examples of nonbiodegradable pollutants. Some of these nondegradable pollutants conglomerate and are biologically enlarged as they transit along the food chain and the biogeochemical cycle of the ecosystem. Dichlorodiphenyltrichloroethane (DDT), as a distinctive example, moves to the streams and it is taken in by the phytoplanktons that are eaten by the fishes. Therefore the initial ingested dose of DDT by the phytoplankton, which was not harmful, will accumulate over time in the fish and becomes very harmful.

25.4.2 Pollution sources

As mentioned earlier in Section 25.4.1, the two major categories of pollution, point source and nonpoint source will be discussed next.

25.4.2.1 Point source pollution

Point sources represent single and discrete locations or facilities that emit pollution. Examples of these are automobile engine, factory, ditch, tunnel, smokestack, and pipe. This category of pollution makes it easy to monitor and control the discharge of pollutants. Regulatory bodies such as the United States Environmental Protection Agency (EPA) have established standards for emission of some chemicals and compounds in order to control the outflow from any point source and to check and monitor that discharge levels abide by the set regulations.

25.4.2.2 Nonpoint source pollution

Nonpoint sources have no definite origin of concentration and are therefore termed being diffuse and widespread. Discharge of pollutants and contaminants are dispersed into the environment uncontrolled. Wind blows some of these pollutants into the air while others are swept into waterways by rainfall. Some pop up from unrecognized sources, such as oil dripping on roads from faulty vehicles, pesticides used on lawns and fields, livestock and pets droppings, or disturbed soil during excavation. It is difficult to regulate emission of nonpoint sources as the discharge of pollutants cannot be measured at the source but at destination. Samples are collected from any of the sources of pollution in polluted areas and measured. The contribution of various nonpoint sources can only then be estimated. It is difficult for EPA to channel their regulations toward specific individuals or businesses in this case, instead they directed it at municipalities. The federal standards for permissible levels of chemicals in drinking water have been set so that communities are responsible for treating their water until it meets those standards.

25.5 Types of pollution

25.5.1 Water pollution

Water occupies 71% of the Earth out of which 95.6% is held in the oceans, which is not directly available for human consumption such as drinking without arduous desalination process (Jeevanantham et al., 2019). Water is a necessity for both human and industrial growth as it remains one of the vital and defenseless natural resources, which is impossible to survive without its availability (Ajibade et al., 2020; Akosile et al., 2020; Opafola et al., 2020; Ilori et al., 2019; Afroza et al., 2015; Ajibade et al., 2015). The two common types of water are surface and groundwater. Surface water exists in various forms such as ponds, wetlands, streams, rivers, oceans, and lakes. Out of these forms, oceans hold the highest volume of the total water yet are not commonly used directly (unlike the other forms) as a result of high natural salt content (Jeevanantham et al., 2019). The remaining small fraction represents the other forms of water, which we refer to as freshwater on which man mainly depends on. Due to population explosion as well as some anthropogenic activities, which alter the cleanliness of water, the demand for clean water is also increasing highly (Ashraf et al., 2013). Water-related problems are common in developing countries usually due to poor regulatory management, poor design, and inadequate financing (Afroza et al., 2015); however, Juahir et al. (2011) suggested that a joint decision-making process is a sure scheme of action for overcoming these water resource problems.

Water pollution is one of the global environmental problems that threaten both human and industrial development. Though people at present subconsciously associate dirt to disease, the transmission of disease by pathogenic organisms was recognized in the middle of the 19th century (Peirce et al., 1998). Water quality in rivers and other reservoirs is presently threatened by rapid urbanization and industrialization, mining activities, higher level of usage of chemicals in agricultural sectors, poor environmental management (Afroza et al., 2015; Jeevanantham et al., 2019), and indiscriminate disposal of waste (Ajibade et al., 2019a; Adewumi et al., 2019). Pollution of groundwater is commonly by chemical compounds that are harmful to health. Water pollution emanates from two major sources, which are point sources and nonpoint sources. The point sources are recognized as pollution occurring from sources having well-defined point of discharge. Examples of these come from municipal and industrial discharges where the industrial facilities and municipal wastewater treatment plants (WWTPs) are the main sources of water pollution because it contains some toxic heavy chemicals and other pollutants (Adeniran et al., 2016). However, some of these heavy chemicals such as Cu, Cr, Mn, Co, Zn, and Mo, which are heavy metals, are needed in small quantities for plant and animal growth and development but become harmful when supplied in large quantities (Wijayawardena et al., 2016). Nonpoint sources are pollution having their origin of discharge diffused, making it difficult to relate their discharge to a well-defined location. These sources are recognized as dry weather pollutants that enter the waterways via pipes and channels. However, watershed runoff and storm drainages (even though water may be channeled to waterways by pipes) are considered as a nonpoint source (Peirce et al., 1998). Other nonpoint sources include agriculture, silviculture, abandoned mines drainage, solid waste, and leaching from land disposal.

25.5.1.1 Sources of water pollution

When water is polluted, it poses serious threat to the entirety of the environment and, most importantly, the lives of humans (Inyinbor et al., 2018). There are several sources through which water can be polluted, most of which are largely from group of substances that are organic and inorganic in nature such as oxygen-demanding wastes, pathogens, nutrients, suspended solids, salts, heavy metals, pesticides, volatile organic compounds (VOCs), and persistent organic pollutants (POPs). Heavy metals (inorganic) and organic pollutants formed a large part of these sources and they are briefly expatiated next.

1. *Heavy metal*

   Heavy metals find their routes into the environment via various activities of industries, agricultural, mining, and so on (Ugya et al., 2018; Cao et al., 2017) and humans and animals are exposed to the toxicity of this metals through inhalation, food chain, and direct consumption of water having metal (Popa and Petrus, 2017). The effects of these metals' toxicity mostly on human include severe headache (which result in mild eye, nose, and sometimes skin irritations); dizziness to organ dysfunction; vomiting; stomach ache; hematemesis; and diarrhea (Dada et al., 2015). Even some heavy metals considered as essential elements (cobalt, copper, iron, manganese, vanadium, and zinc) are required in small quantity in the body for various biochemical processes while metals such as arsenic, lead, mercury, and cadmium are greatly considered threat or danger in the body (Inyinbor et al., 2018). Water polluted with arsenic when ingested can stimulate lungs, liver, and bladder cancer while the one with cadmium can result in kidney and lung damage (Rana et al., 2017). Brain damage, memory loss, and hampering of learning can result from exposure to lead (Verma and Schneider, 2017; Sun et al., 2017) while mercury (although unique amidst other heavy metals) can travel a wide range of distance in the body of humans and animals, it goes into the bloodstream and can only be flushed through urine or feces. It has the potential of existing in the urinal system for 2 months or less causing renal dysfunction. It is thus classified a global pollutant (Li et al., 2015).

2. *Organic pollutants*

Organic pollutants have several varieties accompanied with huge range of toxicity. Aquatic organisms, humans, and plants have greatly been affected by some of these pollutants such as personal care products wastes, petroleum and its waste, dyes, plant and animal pharmaceuticals, a member of endocrine disruptive chemicals (EDCs) (Kar and Roy, 2010; Aguirre-Martínez et al., 2016). As pharmaceuticals are used universally and unavoidably, they have polluted the environment by the indiscriminate disposal of hospital and household wastes via landfill leaching, drainage water, and sewage (Archer et al., 2017). Dyes are water-soluble giant chemical that is greatly used in many industries to impact color on products but its presence in water has greatly affected aquatic organisms, plants, and humans (Adelodun et al., 2020). Humans are exposed to dye toxicity via consumption of vegetables and fish, which bioaccumulate dyes (Oplatowska et al., 2011). Dyes are considered as carcinogenic and mutagenic; thus their removal from wastewater before disposal is ultimately important (Inyinbor et al., 2018). In human, EDCs increase cancer risk via abnormal endocrine activities while on aquatic lives, their effects range from endocrine system disruption through the reduction in eggs and sperm cells production to feminization of female aquatics (Jung et al., 2015; Akanyeti et al., 2017; Ng et al., 2017).

25.5.2 Air pollution

Air pollution is increasingly becoming an issue globally with a large number of concerns arising from developing cities. It occurs when the atmospheric air is contaminated in such a mode or way that poses potential or real threat to human health, his natural surrounding, and his well-being (Sonibare and Jimoda, 2009). "Unless we clean up the air, by the middle of the century one person will die prematurely every 5 seconds from outdoor air pollution" (OECD, 2016). The use of various modes of sophisticated motorized transports, machineries, and industrial works is expected to increase, thus potentially deteriorating air quality. Also, increase in the concentration of harmful gases and particles being released into the atmosphere causes human and environmental health problems (Sulaymon et al., 2020). The effects of air pollution from natural sources especially volcanic eruption are more severe and significantly last longer than those from anthropogenic sources. For instance, pollutants from volcanic eruption can get to high altitude of the atmosphere and reflect sunlight with consequent decrease in atmospheric temperature for few years or more (Spellman, 2017). Generally, air pollutants can be classified in several ways as follows:

1. *Primary air pollutants*
   These pollutants are released right from the source contributor; an example of primary air pollutant is factory chimney. Moreover, primary air pollutants can also be classified into sources of stationary air pollutants (e.g., power plants) or mobile air pollutants (e.g., automobiles).
2. *Secondary air pollutants*
   These are pollutants that originate from their source contributors and subsequently combine chemically (usually involving sunlight) with other substances to form toxic compounds. An example of secondary air pollutant is the conversion of nonmethane VOCs to ozone (O_3).
3. *Indoor and outdoor (or ambient) air pollutants*

Other classification of air pollutants is indoor and outdoor pollutants, which can be further classified into criteria and hazardous air pollutants. The National Ambient Air Quality Standards (NAAQS) declared under the Clean Air Act (CAA) that the following are the six criteria of air pollutants: carbon(ii) oxide (CO), VOCs or ozone (O_3) particulates, nitrogen oxides (NO_x), sulfur(iv) oxide (SO_2), and particulate lead (Pb) (Spellman, 2017). Table 25.1 depicts several kinds of standards depending on the receptors and severity of the impacts.

25.5.2.1 Sources of air pollution

These are referred to as the various locations, activities, or factors that are responsible for the release of air pollutants into the atmosphere. There are two classes, the natural and artificial sources.

TABLE 25.1 Air quality guidelines for WHO and Europe Union (EU).

Pollutant	Air quality guidelines	EU Air Quality Standards EU Directive 2008/50/EC
PM2.5	10 μg/m^3 annual mean 25 μg/m^3 24-h mean	25 μg/m^3 annual mean (labeled target value as of 2010, and as limit value as of 2015)
PM10	20 μg/m^3 annual mean 50 μg/m^3 24-h mean	50 μg/m^3 24-h mean (not to be exceeded more than 35 times a calendar year) 40 μg/m^3 annual mean
O_3	100 μg/m^3 8-h mean	240 μg/m^3 1-h mean
NO_2	40 μg/m^3 annual mean 200 μg/m^3 1-h mean	40 μg/m^3 annual mean 200 μg/m^3 1-h mean (not to be exceeded more than 18 times a calendar year)
SO_2	20 μg/m^3 24-h mean 500 μg/m^3 10-min mean	125 μg/m^3 24-h mean (not to be exceeded more than 3 times a calendar year) 350 μg/m^3 1-h mean (not to be exceeded more than 24 times a calendar year)

Source: Data from WHO (World Health Organisation), 2006. Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Available from: <http://www.euro.who.int/en/health-topics/environment and-health/Housing-and-health/publications/pre-2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogendioxide-and-sulfur-dioxide>; EEA (European Environmental Agency), 2017. Air quality in Europe—2017 report. In: EEA Report No 13-2017. Available from: <https://www.eea.europa.eu/publications/air-quality-ineurope-2017>.

1. *Natural sources*
   These occur due to numerous natural phenomena that include dust and noble gas from radioactive decay (EIA, 2008). Smoke and carbon (ii) oxide from wildfires react with anthropogenic pollutants (such as NO_x, SO_2, and organic carbon compounds) to produce a seasonal haze of secondary pollutants (Goldstein et al., 2009).
2. *Artificial sources*
   These are due to various human activities and are predominantly related to the burning of different kinds of fuel and materials, which release significant high concentration of pollutants into the atmosphere. The various forms of artificial sources are discussed next.
   a. Mobile sources: Several motorized vehicles numbered up to millions ply the Nigerian highways on daily basis as it is found in many other countries of the world and this leads to vehicles consuming millions of liters of petrol (Ndoke and Jimoh, 2000). Hence, vehicular emission remains a threat to environmental health problem, which is expected to increase reasonably as vehicle ownership increases in the world (Abam and Unachukwu, 2009). Over 600 million people globally are exposed to hazardous level of traffic generated pollutants [WHO (World Health Organisation), 2006]. These pollutants are as a result of incomplete combustion of fuels such as natural gas, coal, or wood. Though it should be realized that O_2 used in internal combustion process is a component of air, which contains 78.08% nitrogen and as combustion takes place, oxides of nitrogen are equally formed. Hence, traffic emissions contribute about 50%−80 % of NO_2 and CO concentration in developing countries (Fu, 2001). Furthermore, the increase of this traffic-related pollution is not only based on the aforementioned factors only, but also on low-quality fuel, poor traffic regulation, and lack of air quality implementation force (Abam and Unachukwu, 2009).
   b. Stationary sources: The most significant stationary combustion sources include energy production facilities such as municipal power plants, waste incineration, and residential combustion. Several industrial processes, such as iron and steel production, also involve combustion of fossil fuels or biomass for generating power and heat needed for the process (Sonibare, 2010). Most of these sources are considered point sources, although smaller and more widespread sources such as residential combustion could also be considered as an area source. Physical and chemical characteristics of the particles emitted from these source categories depend on the combustion process itself, and the type of fuel burnt (solid, liquid, or gas). Combustion processes and properties of particulate matter emitted from these sources have been comprehensively reviewed by Holmes and Morawska (2006). These include smokestacks of power plants (Sonibare, 2010), manufacturing facilities, and waste incinerators, as well as furnaces and other types of fuel-burning heating devices (Anf and Emad, 2014). The emissions from these facilities are majorly products of combustion processes. The industries emit various gases of different magnitude into the atmosphere on daily basis (Anf and Emad, 2014).

25.5.3 Soil or land pollution

Soil is a universal sink originating from living organisms and materials of inorganic substances, which bears the greatest burden of environmental pollution (Ajibade et al., 2019b). Spellman (2017) defines soil as the upmost stratum of weathered rocks and decomposed organic matters, which can support life as it primarily comprises air, moisture, nutrients. Soil is also vital as it supports biogeochemical nutrients cycling. From the global land mass of 13.07 × 109 ha, arable land takes 11.3% only; pasture land takes 24.6%; timberland takes 34.1%; and residences, municipals, industries, and roads take the remaining fraction of 31% (Alloway, 2001). Soil pollution among other degrading phenomena such as erosion, flood, and urbanization is not just a great threat to the sustainability of soil resources only but also to human health as potential toxic substances move through the food chain and groundwater, which are in turn used and consumed by man (Akinbile et al., 2016a,b; Adewumi and Ajibade, 2015). Okrent (1999) defines soil pollution as the presence of toxic compounds, chemicals, salts, radioactive materials, or disease-causing agents built up in soil, which have adverse effects on plant, human, and animal health. Some sources of soil and subsurface contaminants include graveyards, landfills, septic tanks, sump and dry wells, underground storage tanks, and pipelines. Moreover, soil contamination could also occur below the water table as a result of mining operations, test holes, agricultural drainage pits, and canals (Spellman, 2017). Most technologically advanced regions of the world experience more land pollution than undeveloped areas (Alloway, 2001). Through biogeochemical cycles, nutrients contaminate the soil and these contaminants contribute to air pollution. Some of these pollutants include sulfur(iv) oxide, nitrogen gases (NO, NO_2, NH_3), hydrogen sulfide, hydrocarbons, carbon(ii) oxide, and ozone. However, due to the negligible changes that happen in the soil, their effects toward air pollution are usually neglected when analyzing air pollution. Two typical aerial particulate soil pollutions include the accumulation of heavy metals within smelters, and soils within municipalities where exhaust fumes connected with vehicle and industrial machinery emissions (Spellman, 2017).

25.5.3.1 Sources of soil/land pollution

The sources of soil pollution can be categorized under two major types, (1) soil pollution from agricultural sources and (2) soil pollution from nonagricultural sources, for example, industrial effluents, solid wastes, and other urban activities. All these affect the surface soil, underground soil, and soil profile (Ashraf et al., 2014).

1. *Agricultural sources*

   This type of pollution emanates from different agricultural practices such as use of fertilizers, pesticides, insecticides, and herbicides. Animal wastes in large quantities also result in soil pollution.
2. *Nonagricultural sources*

This type usually emanates from urbanization caused by rapidly increasing population, which in turn caused an increase in the per capita output of waste. These wastes are dumped indiscriminately on the soil and with time find their entry into the soil system (Oluwatuyi et al., 2020). Their long persistence and accumulation result in toxic concentration and thus become sources of pollution. Some of those most important soil pollutants are inorganic toxic compounds (Ashraf et al., 2014).

25.5.4 The interface of air, water, and land pollution

There exists a relationship between air, water, and land pollution, as the pollutants contaminating these three resources are interrelated (Nathanson, 2007). The phenomenon of studying these three major types of pollution—air, water, and land and their combined interactions with the environment is termed *pollution Interfacial system*. Fig. 25.2 gives a representation of the interrelationship of environmental pollution problems pertaining to air, water, and soil quality. This interrelationship was duly explained as follows by Spellman (2017).

Number "1" represents *acid rain* caused by air pollution but destroyed both aquatic and terrestrial ecosystem. Number "2" represents *incineration* that indicates burning of waste products to preserve land resources but causes air

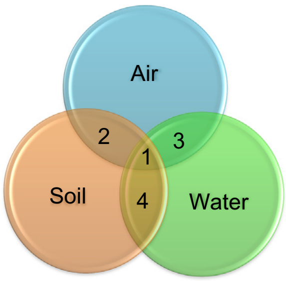

FIGURE 25.2 Environmental pollution issues relating to water, soil, and air quality interrelationship. *Source: Adapted from Nathanson, J.A., 2007. Basic Environmental Technology, fifth ed. Prentice Hall, Upper Saddle River, NJ.*

pollution problems. Number "3" represents *air control system pollution* connoting some certain air pollution control systems such as "scrubbers" but produces a cycle of dirty water, which can cause water pollution, and Number "4" represents *leachate production* indicating that leachate seeping through landfills has high tendency of contaminating both the surface water and groundwater.

25.5.5 Noise pollution

Detection and making of sound are important attributes, which help humans in communicating with one another and in receiving valuable information such as sound signal from a whistling tea kettle, warning as from a fire alarms, and entertainment as in music. Besides these beneficial and enjoyable sounds, there is noise that is an unwanted and irregular sound that commonly comes from such products of development as trucks, industrial machinery, airplanes, trains, air conditioners, and the likes. This phenomenon is termed noise pollution. Noise pollution has been recognized as an urban environmental issue in the world specifically in developing nations. It is well established that noise pollution has been affecting the global population increasingly, mainly in large cities (de Souza et al., 2020) and the intensification of noise pollution has been aggravated since the Industrial Revolution in the 18th and 19th centuries, as a result of the growing use of machinery (Murgel, 2007). Recently, it was reported by the World Health Organization (WHO) (2018) that about 100 million people are affected by road noise in the European Union (EU) and no less than 1.6 million years of healthy life are lost annually. Rinkesh (2019) defines noise pollution as a phenomenon that takes place when there is either an excessive amount of noise or an unpleasant sound that causes a temporary disruption in the natural balance. Psychological health problems such as anxiety, depression, stress, and fatigue can be generated when exposed to high levels of sound pressure (Brazilian Association of Technical Standards, 2019), as well as cardiac, auditory, or cognitive problems, affecting from fetuses to the adults [World Health Organization (WHO), 2018]. In overall, teaching and learning, mental activities, verbal communication, and sleep are frequently the most affected (Brazilian Association of Technical Standards, 2017). Also, it has developed to cognitive impairment in children and tinnitus and can be a risk factor for diabetes (Dzhambov, 2015). Environmental noise is an ancient sensation that has been of great concern. For instance, owing to distraction during sleep, it is said that Julius Caesar prohibited the driving of chariots at night on the cobblestone streets of Rome (Peirce et al., 1998). Urban noise is a gradual and harmful pollutant that has some negative physiological and psychological impacts (sometimes leading to permanent damages) on man. Besides these effects on humans, noise pollution also contributes negatively to the distribution of terrestrial wildlife (Sarikavak and Boxall, 2019). Table 25.2 gives a detail summary of all the types of pollution enumerated in Sections 25.5.1−25.5.5.

25.5.5.1 Sources of noise pollution

The main significant sources of noise pollution are road traffic, industry, railways, and airports. According to European Commission (2017), 69,000 hospital admissions and 15,900 instances of early death are traceable to noise pollution in the EU every year and nearly 6 million suffered highly disrupted sleep as an aftereffect.

25.5.6 Plastic and microplastic pollution

The proliferation and accumulation of plastic materials in the natural environment causing undesirable impacts on living organisms and their habitats are referred to as plastic pollution. Plastic pollution occurs in different forms in the environment, such as plastic litter, marine debris, and plastic particles. For many years, plastic pollution has been recognized as a threat to the ecosystem and has become an issue of global concern (Wagner and Reemtsma, 2019). A large percentage of plastics produced are single-use and are released into the natural environment due to poor management, lack of effective recovery methods, as well as limited success in recycling technology. Since the majority of these materials are resistant to biodegradation, they can remain in the environment for decades, resulting in the massive presence of mismanaged plastics in the environment (Fadare et al., 2019). In effect, about 79% of plastic wastes ended up in landfills (Nature Communications, 2018) while the oceans have become a reservoir for mismanaged plastics through different water channels such as rivers, lakes, and freshwater. It is estimated that by 2050, with the present unabated rate of plastic production, the quantity (in weight) of plastics in the oceans will be more than that of fish (World Economic Forum, 2016). So far, about 700 marine species have been reported to interact with marine debris (Gall and Thompson, 2015), due to the accumulation of plastic waste in oceans, sandy beaches, and seabed. As a result, mismanaged plastics have become a major challenge raising concerns about sanitation, environmental, and human health issues.

Recently, Thompson observed the degradation of mismanaged plastics via natural processes in the environment, which he termed "microplastics" (Thompson et al., 2004). Since then, awareness about the impacts of plastic particles

TABLE 25.2 Environmental pollution.

	Environmental pollution			
Types of pollution	**Water pollution**	**Air pollution**	**Soil/land pollution**	**Noise pollution**
Source contributors	Industries, solid and liquid waste disposal, hydrocarbons, USTs, septic tanks, eutrophication, acidification, biosolids, agriculture, landfills, combustion, oil and gas brine pits, abandoned well sites, saltwater intrusion, surface impoundments	Industries, transportation, solid waste disposal, combustion, miscellaneous, nuclear operations, geothermal operations	Industrial practices, solid and liquid waste disposal, stockpiles, tailing and spoils, salt spreading on roads, animal feedlots, compost of organic wastes, oil spillage, seepage from landfills and illegal dumps, miscellaneous, mining, geothermal operations, agrochemicals, agriculture, hydrocarbons, radionuclides	Railway, airport, industries
Common pollutants	Industrial wastes, WWTPs, breweries, milk processing plants, paper mills, nutrients (e.g., O_2, N, and P), suspended solids, BOD, pH, pathogenic microorganisms, FOG, PPCPs, POPs, toxic (e.g., Zn, Pb, Cd, Ni, and Cu) and nontoxic substances (e.g., Cl, Fe, NH_3, and phenols), pathogenic parasites, Bioconcentrated metals, agricultural wastes, acid rain and acid washed in from watershed and vegetation, pH, fertilizers, fungicides, herbicides, and pesticides, PPCPs, plastics, shipwrecks, heavy metals	Industrial wastes, methane, CFCs, particulate matter, sulfur dioxide, VOCs, CO_2, hydrogen oxides, solid wastes, nitrogen oxides, hydrocarbons, miscellaneous	Heavy metals, leachates, FOG, hydrocarbons, fertilizers, fungicides, herbicides, and pesticides, industrial chemicals, animal feeds, pharmaceutical wastes, biosolids, livestock manures, radioactive substances, pathogenic organisms, plastics	Trucks, industrial machinery, airplanes, trains, air conditioners, generators, dynamites
Effects	Cholera, typhoid, heart and kidney problems, poor blood circulation, vomiting, skin lesions, nervous system problems, damage to aquatic ecosystem, death, diarrhea, loss of occupation	Damage to vegetation, building materials, respiratory system, eyes, nervous system; visibility reduction, death, climate change, low temperature, chronic obstructive pulmonary disease	Underground water pollution, toxicological problems in ecosystems and humans, damage to structures and services	Death, diseases (insomnia, cardiovascular), blood pressure imbalance (hypertension), blood clotting issues, stress, deafness, annoyance, heart attack, stroke, dementia, discomfort
Control/ remediation	Prevention at source, control of nutrients, disinfection, water/ wastewater treatment, thermal treatment, bioremediation, phytoremediation, proper	Pollution prevention, air emission reduction, clearing the air, selection and use of sustainable air pollution control methods, equipment and systems, removal of dry	Adoption of land treatment, thermal treatment, asphalt incorporation, solidification/ stabilization, chemical extraction, excavation,	Modification of the sound producers (e.g., muffling), interrupting the path of the sound, protecting the recipient (e.g., by well, vegetation), effective implementation of

(*Continued*)

TABLE 25.2 (Continued)

	Environmental pollution			
Types of pollution	Water pollution	Air pollution	Soil/land pollution	Noise pollution
	siting, designing, construction and management of potential point source, use of sewerage and proper septic tank designs, proper siting and design of landfills, effective implementation of government policies on sustainable water quality and environment	particulate matters using effective equipment (e.g., gravity settler, cyclone collectors, electrostatic precipitators, wet or venturi scrubbers, baghouse, or fabric filters); absorption, adsorption, condensation, effective combustion, control of crankcase and evaporative emissions, use of catalytic converters, effective implementation of government policies on sustainable environment and land development	manure treatment, waste control technology, waste minimization, input substitutions, process modification, good operating practices, recycling of waste materials, biological treatment, effective implementation of government policies on sustainable air quality and environment	government policies on sustainable environment

BOD, Biochemical oxygen demand; *CFCs*, chlorofluorocarbons; *FOG*, fat, oil, and grease; *pH*, potential of hydrogen; *POPs*, persistent organic pollutants; *PPCPs*, pharmaceuticals and personal care products; *USTs*, underground storage tanks; *VOCs*, volatile organic compounds; *WWTPs*, wastewater treatment plants.

has significantly increased. Micro-/nanoplastics (NPs) are products of mismanaged plastics via degradation or intentionally produced plastic particles that are used in consumer care products or for industrial applications, released into the environment. Plastic debris breaks down over time into smaller particles of various sizes and shapes to form macroplastics (> 25 mm), mesoplastics (5−25 mm), microplastics MPs (0.1−5 mm), and NPs (< 100 nm) (Alimi et al., 2018), under natural processes such as UV radiation and mechanical abrasion (Fig. 25.3). These are known as secondary microplastics (Mattsson et al., 2015). On the other hand, plastic particles that are produced intentionally for industrial applications (plastic pellets), pharmaceuticals or microbeads used to enhance consumer care products are called primary microplastics. Nevertheless, other sources are yet to be classified, for instance, plastic debris from newly manufactured plastic products, which are not as a result of natural degradation processes or plastic particles produced intentionally.

25.5.6.1 *Sources of plastic and microplastic pollution*

Plastics and microplastics can cause pollution in the environment at any stage of product manufacturing, consumption, and disposal. However, the primary source of plastic pollution is mismanaged plastic materials from anthropogenic activities in the environment with terrestrial and freshwater ecosystems as emission pathways (Wagner and Reemtsma,

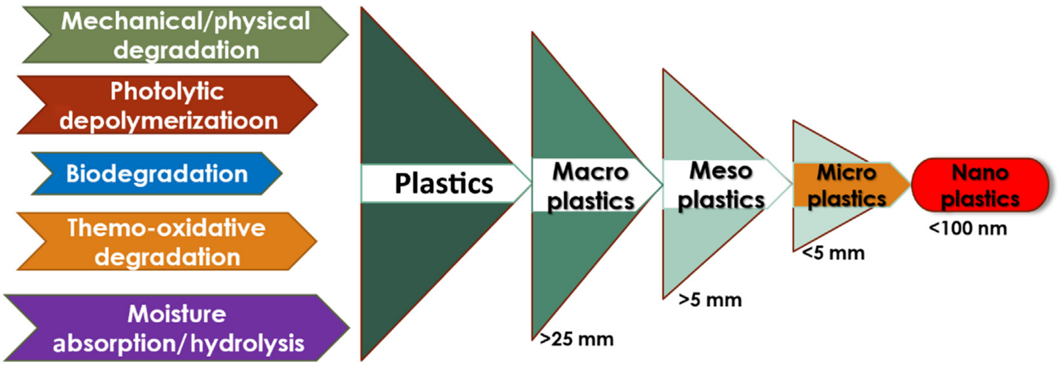

FIGURE 25.3 Plastics degradation processes in the natural environment.

2019). For instance, in the terrestrial system, single-use plastics are found in landfills, and along water channels due to indiscriminate disposal of used plastics into the environment as well as weak recycling system, causing environmental nuisance and unpleasant effects. Also, accidental loss/discharge of nurdles used in plastic production during transportation and illegal discharge of plastic wastes are some of the activities contributing to plastic pollution in the environment (Clunies-ross, 2019).

On the other hand, the presence of mismanaged plastics in the aquatic medium is mainly from land- and ocean-based sources (Li et al., 2016). Plastics that are improperly disposed of are transported from their sources through various water channels and WWTPs into the aquatic ecosystem (Browne, 2015). Land-based sources of plastic litter contribute about 80% of the mismanaged plastics found in the aquatic environment. This usually comes from the industrialized locality with high human presence and activities, which include recreation, tourism, WWTPs effluents, surface water drains, and refuse dumpsites (Lattin et al., 2004; van Wezel et al., 2016). For instance, a recent study identified coastal recreational activities as a significant source of mismanaged plastic wastes in the beach (Clunies-ross, 2019). Ocean-based plastic pollution comes from direct human activities in the oceans; this includes abandoned/lost/discarded fishing nets (Andrady, 2011), shipwreck/accidental discharge, recreational/tourist activities, as well as the illegal discharge of plastic waste in the oceans.

Furthermore, a more significant percentage of plastic particles in the environment emanated from degrading mismanaged plastic materials from landfills. Other sources include wash off microbeads in consumer care products, such as exfoliants, hand cleaners, facial cleaners, toothpaste, airblast cleaning media, and microplastics introduced into fertilizer/herbicides formulation. Also, synthetic clothing is believed to be the primary source of airborne plastic particles (Dris et al., 2016). Other sources are plastic particles from house furniture, building materials, erosion of car tires, industrial emissions, synthetic particles used in garden soils, and plastic incineration (Dris et al., 2016; Dris et al., 2017; Liebezeit and Liebezeit, 2015).

25.6 Socioeconomic impacts of pollution

To better understand the socioeconomic impacts of pollution generally, it is pertinent to know what the term "socioeconomic" means. In brief, it is the study on how both social and economic activities affect the totality of the environment. The socioeconomic standing of a given society is commonly evaluated by defining the state of education, income, health, occupation, and sometimes a combination of these aspects within the populace and their economic growth. There are numerous ways this can be explained when relating it to pollution. It makes no sense to further emphasize that environmental pollution has demean and stretched its poisonous grasping hands into the very basic human needs, which include water, air, and soil via numerous activities. All these activities in the long run tend to have several negative impacts on the environment in which humans are most important. Several studies reveal that pollution has enormous negative impacts on the total environment and people living therein. That is to say that, environmental pollution does not pose threat to human alone but also to nonhuman nature. This section explains the socioeconomic impacts of pollution on:

1. human health,
2. the environment, and
3. economic growth and development.

It could be seen that the previous three categories are a composition of the determining factors (education, income, health, occupation, and economic growth) of the socioeconomic status of a society. These three categories are elaborated one after the other next.

25.6.1 On human health

Environment has a great influence on health, hence, the need to encourage good and healthy environment as the basis of reliable health security. Health is wealth is a common adage because health is very vital for the development and viable growth. The World Health Organization (WHO) estimates that 8.9 million deaths are caused by pollution (Landrigan and Fuller, 2016). Environmental impacts of pollution on health are dependent upon concentration of pollutants, exposure response coefficients, and other related attributes (Feng et al., 2019). It is evident that the severity of most human respiratory diseases such as asthma, bronchitis, sputum, lung cancer, and coughing due to cold increases with prolonged exposure to air pollutants at some degrees of concentrations and nearness (Srinivasan, 2013; Feng et al., 2019); however, the health effects of air pollution vary significantly among individuals with highly susceptible and high-risk groups as adults, infants, and pregnant women with children at the highest risk level because they are prominently active outdoors and their lungs are still developing (Srinivasan, 2013). The WHO appraises that the maximum amount of suspended particulate matter (SPM), which cannot upset human health is 90 $\mu g/m^3$ (Srinivasan, 2013). It is estimated that about 2 million premature deaths in developing countries result from indoor air pollution (Srinivasan, 2013), and from drinking contaminated water mainly in developing countries (Afroza et al., 2015) where almost half of these deaths are due to pneumonia in children below 5 years of age, whereas about 1.3 million deaths globally result from outdoor air pollution; and people living in middle-income countries unevenly suffer this problem [World Health Organization (WHO), 2011]. USEPA (US Environmental Protection Agency) (2013) equally affirms that air pollution is also responsible for some acute and chronic lung diseases and other airborne diseases. It is important to note that air pollution also affect crop plants and animals and, hence, indirectly impair human health when consumed. Air pollution affects not only local environment but also the adjacent areas (Ma et al., 2014; Feng et al., 2019).

Besides air pollution, water pollution is also another vital aspect that greatly affects human health (Ashraf et al., 2013; Afroza et al., 2015) because water resources are very germane for socioeconomic development (Ugya et al., 2018). Increase in the level of water pollution could be attributed to higher development of many fields and anthropogenic activities (Jeevanantham et al., 2019). Agriculture is known to consume water at high level globally and in some cases, polluted water is used. However, polluted water has both advantages and disadvantages and partially treated polluted water is used to irrigate about 20 million hectares of agricultural land in over 50 countries (Ashraf et al., 2010). Polluted water contains toxic and nontoxic metals and microorganisms and when animals (including avian and aquatic lives) drink and/or inhale it or plants absorb it, it gets into them with the pollutant and these plants and animals are in turn consumed by man; hence, health is endangered (Afroza et al., 2015; Jeevanantham et al., 2019). However, assimilating contaminants from water through the consumption of crops by man is less pronounced owing to the fact that plants have power of detoxifying heavy metals and this is achieved through different mechanisms such as mycorrhizae, organic acids, phytochelatins, metallothioneins, root reductases, and heat shock proteins (Kumar et al., 2016; Jeevanantham et al., 2019), though traces of contaminants can be received through this consumption. These heavy metals commonly affect areas like heart (carcinogenic and teratogenic impacts), kidneys, nervous system, liver, pancreas, skin, and reproductive system of man (Jeevanantham et al., 2019). Diseases that can spread as a result of consuming polluted water include typhoid, cholera, poor blood circulation, vomiting, skin leissons, and nervous system problems (Afroza et al., 2015). Ghafoor et al. (1994) affirm that water pollution is the major cause of human death (Ghafoor et al., 1994). About 10% of diseases worldwide are caused by water pollution, hygiene, and sanitation (Pruss-Ustun et al., 2008). It was estimated that half a million population die of malaria as well as 1.4 million deaths recorded for diarrhea among children (Pruss-Ustun et al., 2008; Afroza et al., 2015). UNICEF (2008) concluded that about 900 million people lack access to safe water, whereas 2.5 million people lack proper sanitation systems (Afroza et al., 2015). Water stress is experienced by one-third of the population globally (IWMI, 2007). Health impacts resulting from water pollution have been highly negative that in 2002 alone; more than 3.5 million people died as a result of water pollution, sanitation, and hygiene (Pruss-Ustun et al., 2008); and approximate cases of diarrhea of 4 million reported yearly (Afroza et al., 2015).

Noise pollution is also another subject of interest due to its negative impacts. Studies showed that noise instigates displeasure at levels above 55 and 85 dB in office and in industry, respectively; 55−116 dB causes hypertension, 75 dB causes loss in hearing; and a noise level above 81 dB leads to permanent deafness [World Health Organization (WHO), 2004; Sarikavak and Boxall, 2019]. All these burdens boil down to high medical costs and death in most cases.

25.6.2 On the environment

The frequent penetration of pollutants into the soil affects the organisms living therein. Nevertheless, the effect caused by the presence of pollutants in soil or the lithosphere (on both terrestrial animals and ecosystems) is much more appreciable as these substances cumulate in food chains. The roving component of the soil environment such as water or, more precisely, the underground water can diffuse the contaminants through the soil and soil-forming rocks somewhat rapidly. Ipingbemi (2009) reports that about 5%−10% of the Nigerian mangrove ecosystems have been eradicated by oil spillage and other adverse impacts of pollution on the environment are death and loss of aquatic resources, eutrophication of water bodies, and ecological destruction. Landrigan et al. (2010) revealed that at every level of income in most countries, polluting industries and hazardous waste sites are disproportionately located in poor, minority, and marginalized communities, a phenomenon termed "environmental injustice" (Landrigan and Fuller, 2016). Similarly, some US-owned companies in developing nations make use openly, industrial practices not allowed in the United States, thus creating some significant levels of pollution in these countries due to their lack of knowledge on the impending dangers, the economic ability, or the political structure to protect their environment (Spellman, 2017). A problem long unnoticed, soil pollution generated by industrial contamination, management of superfund sites, exploration and production, mining, and nuclear industrial practices (among others) has affected soil quality at levels we have only recently begun to understand. It is difficult to determine the degree of soil damage in many areas, because assessment itself is debatable; however, based on strong evidences, staggeringly large amounts of polluted soils have been generated (Testa, 1997). Spellman (2017) reported that in Oklahoma, for example, contaminated soil accounts for about 90% of the waste generated as a one-time occurrence.

25.6.3 On the economic growth and development

When it comes to economic growth and development, environmental pollution has tremendous adverse effects on the livelihoods, businesses, education, and occupation of the populace in general. Moreover, other hostile effects of pollution on the environment and economic growth include loss of biodiversity and diminished food and agricultural production levels. In some cases, for instance, the Niger Delta region (where the livelihoods of people come mainly from land and water) of Nigeria that are commonly faced with oil spillage, many residents lose their occupation such as fishing, canoe carving, and forestry, which account for about 70% of the total employment in the region; this often leads to dropping out of school by children of most families who can no longer pay their wards' school fees (Ipingbemi, 2009). It is evident that this menace leads to reduced family income level and, hence, perpetuating poverty. Therefore pollution could be said to have a close relationship with poverty. Some disease like arsenicosis is very dangerous as its patients most likely do not feel or look ill at the early stage but still are treated as "dangerous people" and stripped of their social status (Rahmana et al., 2018), and, hence, face many economic difficulties such as reduction in work efficiency, financial losses, sequestration, and failure to get suitable jobs as a result of judgment (Ahmad et al., 2007; Rahmana et al., 2018). This problem of ostracism of arsenicosis patients has been reported in Bangladesh (Ahmad et al., 2007). These patients of school-age are most times discouraged from appearing in public, attending schools and social event, as well as have been abandoned by their friends and classmates (Alam et al., 2002; Rahmana et al., 2018). In some cases, arsenicosis has led to marriage failure where either husband or wife left each other or remarried in the fear of contracting the disease (Chowdhury et al., 2006). Generally, the diseases initiated by pollution inflict pronounced economic costs globally as well as direct medical costs, opportunity costs resulting in reduced productivity of populace impaired by pollution and cost to health-care systems (Landrigan and Fuller, 2015). Specifically, Trasande and Liu (2011) reported that the United States spends about US$ 76.6 billion yearly on diseases in children as a result of environmental pollution, while the cost of occupational diseases and injuries is US$ 250 billion (Leigh, 2011; Landrigan and Fuller, 2016).

25.6.4 Environmental effects of plastic/microplastic pollution

Plastic wastes can cause adverse environmental impacts, which can affect every organ of the ecosystem (Fig. 25.4). The environmental effects of plastic debris include physical damage to animals, disruption of different habitats, alteration of biodiversity, propagation and transmission of disease-causing organisms, and reduction in aesthetic and recreational worth. Also, the presence of plastics in the environment has been reported as contributing significantly to climate change due to carbon emission and a threat to the global food chain (Reid et al., 2019; Shen et al., 2019). Plastics in landfills have been identified as causing significant changes in the geochemistry and biophysical properties of soils, in addition to its deleterious effects on microbial and plant community, invertebrate, and vertebrate animals (Abel et al., 2018). More so, plastic litters can serve as habitats for disease-causing/transmitting organisms in the environment, such as mosquitoes or reptiles.

In the aquatic environment, plastic debris has been reported to cause physical damage in aquatic animals. For instance, fishes are entangled in plastic materials such as abandoned/lost fishing net that often affects animal's mobility and ability to escape predators or procreate (Clunies-ross, 2019). Ingestion of nylon bags and suffocation (Vince and Hardesty, 2016) are also some of the detrimental effects of plastic litter. The presence of plastics on beaches has resulted in damage to the intrinsic beauty and recreational value of the environment (Andrady, 2011). In some cases, the beaches no longer enjoy human patronage, which can affect social behavior and societal well-being.

Furthermore, plastic pollution can aid or significantly increase the process of rafting, which is the wide mobility of invasive species and the spreading of diseases across diverse aquatic space due to colonization of new favorable environments. Plastics can also enter the food chain when organisms ingest plastic wastes, which can lead to biomagnification and a potential threat to higher organisms, including humans. Plastic-associated chemicals have been detected in wildlife and marine animals as well as in the human blood, urine, and serum (Talsness et al., 2009).

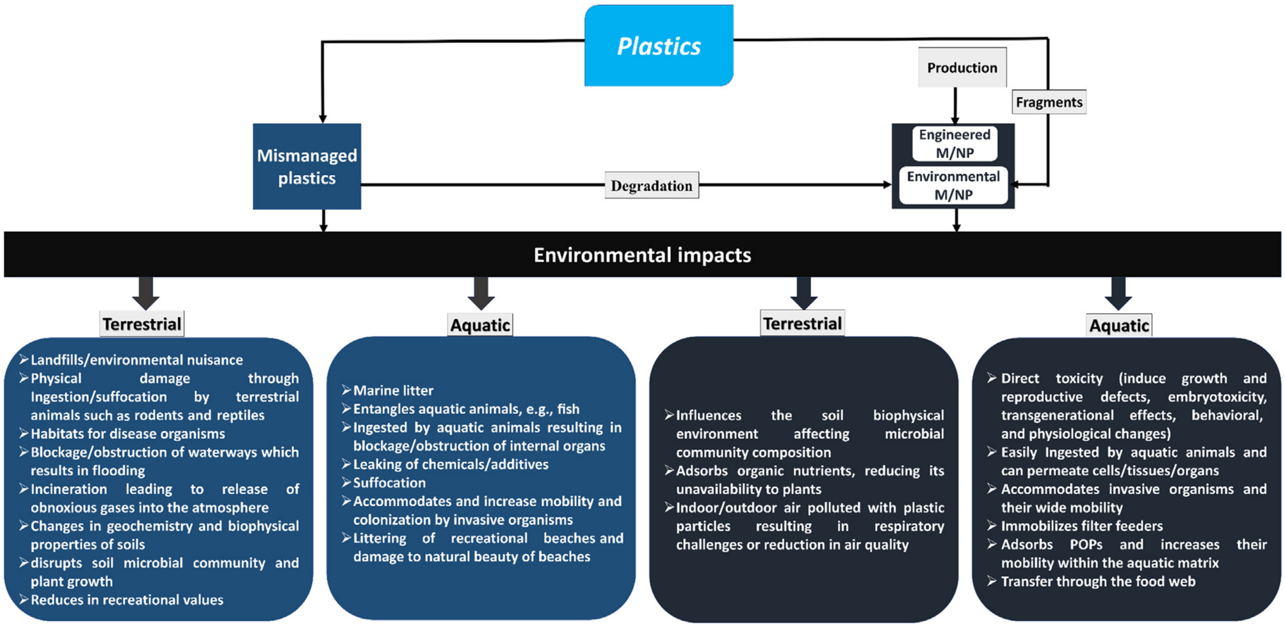

FIGURE 25.4 Plastic and microplastic pollution in the environment with their environmental effects.

In the same vein, several studies have reiterated that microplastic particles have polluted the world's oceans, and various sizes of plastics have been isolated from both freshwaters and marine systems (Dris et al., 2015; Willis et al., 2017; Halle et al., 2017). The presence of plastic particles in bottled water (Eerkes-Medrano et al., 2018) and seafoods (Li et al., 2015; Santillo et al., 2017; Karami et al., 2018) have also been reported. Likewise, microplastics have been reported in urban indoor and outdoor air (Liu et al., 2019). Pets' and human feces have also been demonstrated to contain microplastics (Schwabl et al., 2019; Zhang et al., 2007).

To date, little is known about the detrimental effects of microplastics on living organisms and the environment. However, laboratory studies have demonstrated various possible impacts of plastic particles both in the terrestrial and aquatic environments. Inhalation of polluted air with microplastics (plastic fibers and particles) can induce respiratory discomfort caused by airway and interstitial inflammatory responses in exposed workers (Prata, 2018). Plastic particles can act as vectors for the transport of xenobiotic contaminants, such as POPs and heavy metal. Similarly, the accumulation of plastic particles in soils has been observed to result in a change in soil structure and an adverse effect on soil microbes and plant growth (Awet et al., 2018; Qi et al., 2018; Boots et al., 2019). It has also been shown that microplastics can move through the food chain when, for instance, humans consumed seafood such as bivalves, fish, and shrimps that have previously ingested plastic particles (Li et al., 2015). Besides, several studies have isolated plastic particles from different sea products supporting the transfer of microplastics through the food web (Van Cauwenberghe and Janssen, 2014; Santillo et al., 2017). Plastic particles can penetrate and be retained in the gut wall for a long time and are likely to induce abrasion and internal tissue/organ damage to animals (Wright et al., 2013; Rochman et al., 2013).

Moreover, in smaller aquatic invertebrates, microplastics have been reported to induce growth and reproductive defects, immobility, embryotoxicity, transgenerational effects, and behavioral and physiological changes (Klaper, 2007; Besseling et al., 2013; Browne et al., 2013; Della Torre et al., 2014).

25.7 Remedial measures to control environmental pollution

To promote a sustainable environment, we need to embrace the "green engineering." Green professionals are those environment-friendly and concerned experts such as engineers, scientists, planners, or decision makers who try to incorporate the significance of sustainability while delivering their services. Green engineering, therefore, is a systematic engineering for effectiveness, efficiency, and sustainability. To control or prevent most environmental problems faced today, we need to think and embrace the green engineering by adopting better means of using materials and energy. Pollution as a great threat to the environment and public health has gained enough concern globally. Waste products or pollutants enter the environment in various forms and means and endanger the quality of water, air, and land, which in turn, endangers the public health through the flow of these pollutants within the food chain and, in some cases, direct consumption. The need to prevent pollution has led to the adoption of four types of control, which include legal, social, economic, and technological measures. These measures however help to control environmental pollution by various techniques or methods of operations. These techniques are further applied according to the environment and characteristics of the pollutants and their source contributors. The control actions available for preventing water, air, noise, and land pollution are enumerated as follows.

25.7.1 Corrective actions to control water pollution

Water pollution is a great threat to health as the accumulation and concentration of the pollutants in food chain by absorption is quickly enhanced by biochemical processes, which often lead to high level of toxicity. Hence, it is greatly important to study the methods of treating waste products and eliminating them from aqueous environment. In water pollution control, it would be helpful to consider the various sources of water pollution as whether point sources or nonpoint sources. To control water pollution from nonpoint sources, the following can be used:

1. Judicious use of agrochemicals such as pesticides, and fertilizers, which will reduce their surface runoff and leaching. However, this option is not effective on sloping lands.
2. Use of nitrogen-fixing plants to supplement the use of fertilizers.
3. Adopting integrated pest management to reduce greater use of pesticides.
4. Diversion of manure runoff to basin for settlement instead of flow of manure to water bodies. The manure in the basin can later be used as fertilizer in the fields.
5. Planting trees does not only reduce soil erosion but can also help in trapping sediments, which would have polluted water bodies.
6. Separate drainage of sewage and rain water should be provided to prevent overflow of sewage with rain water.

It should be recalled that point sources of water pollution are municipal and industrial WWTPs. In consequence of the associated health, discomfort problems and environmental degradation from wastewater pollution, the wastewater should be properly treated before being discharged to the environment. While the treatment of wastewater can be costly especially when chemicals and advanced processes such as electrodialysis and ion exchange are used, the natural biomass materials can provide cost-effective, efficient, and sustainable alternative wastewater treatment within the permissible environmental limit (Adelodun et al., 2019). For the control of water pollution from point sources, the following treatment technologies are usually employed.

1. *Adsorption*

   This is a technique that involves the accumulation of the pollutants on the surfaces of specially made chemical, physical, and biological materials known as adsorbents for the removal of pollutants. Adsorption is an economical and effective technique. Examples of commonly used adsorbents include metal organic frameworks, carbon materials, aluminosilicates, zeolites, and mesoporous materials. Biosorbents are biomass-based natural or engineered adsorbents. Other materials used as adsorbents are organic soils, organic carbon framework, activated carbon, activated hydrochars, biochars, carbon nanotubes, graphenes, and clay (Jeevanantham et al., 2019).
2. *Nanotechnology*

   This is a special technology that uses good adsorbent materials called nano-adsorbents for removal of pollutants from water environments. Removal of pollutants is done by of nanotubes, carbon- and carbon-based nanomaterials, nanofiltration, nanoparticles, nanofibers, nanoclusters, and nanocomposites. Common nano-adsorbents used for removal of nitrate from water environment include Fe_3O_4 nanoparticles, magnetic nanomaterials (those with magnetic properties), chitosan and aluminum oxide nanofibers, oxidized carbon nanotubes, polystyrene and zinc, nanocomposites of carbon, silicon, chitosan, polyvinyl acetate, and polyethylene glycol.
3. *Electrochemical treatment*

   This technology removes heavy metals from water environment by the application of electric current. Electrochemical treatments include (1) electrochemical precipitation method that removes metals by forming precipitation as a result of direct current supply, (2) electrodialysis method that removes pollutants by the use of membranes, (3) electrochemical oxidation method, and (4) membrane electrolysis.
4. *Biological treatments*

   This involves removal of heavy metals and other pollutants by using biological substances such as bacteria and microorganisms. Biological treatment methods include (1) biosorption, (2) using bacteria and microorganisms, (3) activated sludge process, (4) biofilter, (5) anaerobic digestion, (6) stabilization ponds, and (7) biofilms.

5. *Phytoremediation*

This is a comparatively contemporary method in pollution control especially in constructed wetlands (Omotade et al., 2019; Ajibade and Adewumi, 2017; Akinbile et al., 2015; Vymazal, 2007). It involves the use of plants that have great ability to store metals or diminish accessible metals in the polluted environment. As these plants grow, they take up the heavy metals and nutrients present in the environment (soil or water) and by some mechanisms convert the toxic contaminants to nontoxic forms. Phytoremediation treatments include phytostabilization, rhizodegradation, rhizofiltration, phytoextraction, phytoaccumulation, and phytovolatilization. According to Jeevanantham et al. (2019), phytoremediation procedure taken by phytoremediators in the removal of contaminants can be shown in the following order:

Upgraded take-up by transporters → Bioactivation of metals → Detoxification by dispersion → Vacuole sequestration.

25.7.2 Corrective actions to control air pollution

Emissions into the air are basically random and indefinitely numerous. Precipitation is the commonly known air cleaner though, not quite efficient and its seasonal occurrence. Sustainable air quality is dependent upon effective prevention of pollution and possible emission of pollutants. It is technically difficult and costly to prevent or control air pollution. However, some methods or techniques have been employed and confirmed efficient for the control of air pollution. These air pollution control techniques are discussed as follows:

1. *Source correction (including raw materials substitution, process/equipment modification)*: Prevention is generally affirmed to be better than cure. Hence, it is better to change or eliminate the practice that causes emission of pollutants into air than striving to confine the pollutants when already released. For instance, the further refining of gasoline for proper removal of lead and, hence, eliminating lead emission to air. In the same way the removal of sulfur from coal, and oil also helps in the elimination of SO_2 during fuel combustion. Some processes such as the control of odors from municipal incinerators by incinerating at high temperature capable of completely oxidizing the odorants. The 1990 CAA in an effort to improve air quality by reducing CO emissions from automobiles decrees that oxygenated fuels should be used in urban areas (Peirce et al., 1998). On the other hand, the substitution of raw materials, and modification of process and/or equipment are all resourceful in the control of air pollution.
2. *Pollutants collection*: There is a great challenge often experienced in the collection of pollutants, which often makes it often almost impossible especially for preventing mobile air pollutants sources, for example, that from automobile exhaust. Recycling of exhaust gases is confirmed a good control process. Though automobiles cannot meet 1990 exhaust emission standards through recycling exhaust and blowby gases, the method is still proven to be a promising control technique for controlling emission from automobiles (Peirce et al., 1998). However, recycling better employed in stationary industrial machines and satisfactory results are obtained. Carbon monoxide (CO) and VOCs are the usually recycled. CO serves as fuel as it releases heat when burnt to CO_2 (Peirce et al., 1998). Channeled exhaust gases through one or more stacks are easier to be collected, but emissions through windows, doors, some cracks in walls, and dust particles raised during on-site transportation of materials offer great hitches to collection; hence, there is need for industries to renovate the entire airflow arrangement for efficient control.
3. *Cooling*: By cooling the temperatures of some pollutants drop below their condensation points hence, making it easier to collect them as liquids. Some common techniques often employed in carrying out this are dilution, quenching, and heat exchange among which quenching relatively higher advantage of cleaning of some gases and particulates, nonetheless, its drawback is that it yields dirty, hot liquid that equally needs to disposed of. For heat conservation, use of cooling coils method is preferred.
4. *Treatment:* What is important in this regard is the selection of the most efficient device for each or a particular set of pollutants since pollutants even though they may come from the same stack vary in size, characteristics, and magnitude. Considering the basic nature of air pollutants, the control or treatment devices are divided into:
   a. Particulate matter control devices: They are cyclones, fabric (baghouse) filters, wet (venture) collectors, electrostatic precipitators, and gravity settlers.
   b. Gaseous pollutants control devices: These can be classified according to classification of the mobility of the source contributors. Hence, treatment processes for controlling pollutants (and other gaseous emissions) from stationary sources include absorption, adsorption, condensation, and incineration (which could be any of: direct flame combustion or flaring, thermal combustion or afterburners, catalytic combustion). While treatment processes for controlling pollutants (and other gaseous emissions) from mobile sources often involve the modification of the devices or their components. Common technologies used include (1) positive crankcase ventilation;

(2) catalytic converters (types include oxidizing catalytic converters, reducing catalytic converters, and three-way catalytic converters); (3) hydrocarbon adsorbers; (4) ceramic wall-flow particulate filters or traps; (5) De-NO_x technologies (selective catalytic reduction, and NO_x adsorber); and (6) installation of a canister (under fuel tank) filled with activated charcoal to adsorb hydrocarbon emissions, hence, controlling evaporative emissions.

25.7.3 Corrective actions to control soil/land pollution

It is necessary to perform some sorts of remediation or cleanup a contaminated soil where the degree of contamination is high enough beyond the recommended standard. Common options employed include excavating the polluted soil and either disposing of it safely in an approved landfill (also known as "dig and dump") or taking it out of site (also called ex situ remediation) (Alloway, 2001). Nevertheless, due to high cost associated with haulage and landfilling, the adoption of in situ remediation techniques has been commonly used. Concise definitions of common soil/land pollution control methods are as follows:

1. *Containment*
   This is the restriction of contaminants by making of physical barriers such as trenches and reinforcing them with impermeable clay, for example, bentonite; or use of hydraulic barriers in order to maintain fluid pressure differentials by the removal or introduction of water for the confinement of the contaminant column in aquifers.
2. *Pump and treat*
   This is a system employed in treating polluted groundwater. In this technique the groundwater is pumped to the surface from custom-built drilled wells and subsequently remedial treatment is employed to remove the contaminants and afterward, the cleaned water is returned to the aquifer.
3. *Air sparging*
   This technique is used when dealing with VOCs, for example, chlorinated solvents. It involves the aeration of extracted water, hence, enhancing the volatilization of the organic pollutants in the water.
4. *In situ soil washing*
   This technique involves the injection of water through contaminated soil for the dissolution and extraction of the contaminants. Alloway (2001) affirms that this technique can be applied in extracting several contaminants even those that are not water-soluble, and including sulfate salts.
5. *Soil vapor extraction*
   This is an enhanced in situ recovery technique that is carried out by aerating the soil of enough macropores to provide enough air penetrability and then collected from special extraction wells where the volatile contaminating compounds can either be burnt in situ or adsorbed into activated carbon. It should be noted, however, that soil pollutants that are adsorbed into the soil solids are highly difficult to treat (Alloway, 2001).
6. *Bioremediation*
   This is typically used in treating soils contaminated with organic compounds. It involves improvement of encouraging conditions for microbial decomposition of the contaminating chemicals.
7. *Phytoremediation*
   Ajibade et al. (2013) defines phytoremediation as a promising cleanup technology for contaminated soils, groundwater, and wastewater that requires both low tech and low cost. Although numerous decontaminating plants with great capacities have been proven, most of them do not yield adequate biomass to excellently extract substantial quantity of metals out of polluted soil. Hence, it is better used to treat soils of low contamination level and in treating severely contaminated soil, further treatment may be recommended.
8. *Natural attenuation*

This is a natural decomposition and adsorption of organic pollutants. Common soil/land pollution control techniques can be summarized as shown in Table 25.3.

25.7.4 Corrective actions to control noise pollution

Noise polluted has been identified as another problem of concern when dealing with environmental pollution as it has various significant psychological and health hazards. Transmission of sound involves three stages, production, transmission pathway (or medium), and receiver. To control noise pollution (in industries, communities, and homes) effectively, various techniques have to be employed across these three stages of its transmission. Generally, it should

TABLE 25.3 Common soil/land pollution control methods.

S/N	method	Pollution problem
Civil engineering–based techniques		
1	Excavation and landfill	"Trouble spot" pollution at concentrations too high for safe in situ treatment, especially inorganic chemicals such as heavy metals
2	Physical containment	Organic NAPLs, landfill leachates
3	Hydraulic control	Supporting containment and/or for treatment of polluted surface or groundwater
Process-based techniques		
1	Thermal treatment	Incineration of soils polluted with POPs, such as polycyclic aromatic hydrocarbons (PAHs), PCBs, PCDDs
2	Physical treatment to separate contaminants from soils or different fractions of contaminated media (commonly ex situ)	Soil washing to remove sulfates, PAHs metals, and other contaminants adsorbed in silt and clay particles
3	Chemical treatment (may be in situ or ex situ): this could be for removal, destruction, or modification of pollutants	Dechlorination of PCB-polluted soils, acid leaching of metal-polluted soils
4	Biological treatment (may be in situ or ex situ): using microorganisms for removal, destruction, or modification of pollutants	Organic pollutants, hydrocarbons, pesticides, solvents, tars, PAHs
5	Stabilization/solidification (may be in situ or ex situ)	Heavy metals, POPs

NAPLs, Non-aqueous phase liquids; PCBs, Polychlorinated biphenyl; *PCDDs*, polychlorinated dibenzodioxins; *POPs*, persistent organic pollutants.
Source: Courtesy Harris, M., Herbert, S. 1994. 'Contaminated Land', Institution of Civil Engineers, Thomas Telford Publishers, London (Harris and Herbert, 1994).

be noted that noise pollution is commonly associated with industry, community, and home. Noise pollution is generally controlled by:

1. reducing the sound production,
2. interposing the sound path, and
3. defending the sound receiver.

It should also be noted that noise pollution control involves money and private enterprises tend to avoid incurring such expenditure; hence, government or the public comes into noise pollution by making and enforcing some sustainable policies that would help regulate noise in the environment.

1. *Industrial noise control*

   In general, industrial noise control primarily has to do with the substitution of noisy machinery with quieter substitutes. Examples of such technique is the reduction of noise from air fan by increasing its number of blades and decreasing its rotational speed, while gaining the same airflow efficiency. By interposing the sound path, industrial noise can be controlled, for instance, the use of insulating material for covering some necessary parts of a noisy motor. By trying to defend the receivers (workers) in an industry, protective hearing devices should be provided to the workers however; such devices should be effective enough not to cause impairment on workers from hearing normal human communication and cautionary signals in the workstation.
2. *Community noise control*

   Community noise comes mainly from aircraft, highway traffic, construction (Peirce et al., 1998), and railway. Peirce et al. (1998) suggests that noise from construction sites should be regulated by local ordinances (unless federal funds are involved). The control techniques usually involve use of mufflers in air compressors, jack hammers, hand compactors, and other similar equipment. In aircraft noise regulation the US Federal Aviation Administration provides major laws on aircraft-associated noise. These are as follows:
   a. A certain limit of aircraft engine noise is allowed in airports, hence, compelling industrialists to develop a quieter engine that would still yield desired thrust.

b. Diversion of flight pathways away from populated areas, and, whenever necessary, mandates pilots to use less than maximum power when the takeoff transports them above a noise-restricted area.

c. Another regulation is the banning of the use of supersonic commercial aircraft. This is as a result of great noise produced by the engines and damage to property due to high sonic boom.

Traffic is another major source of community noise. The components of cars, trucks, and trains such as the exhaust system, tires, engine, gears, wheels, and transmission are the major contributors of traffic noise. Moreover, this noise is often increased when vehicles move over raised highways and bridges owing to the resonation of the bridge and the raised highway with the motion. Generally, the worst contributors of traffic noise are trucks and high-speed trains.

Nevertheless, there are three basic useful choices that can be adopted in the control of traffic noise. They are basically noise from the source, which can be regulated by producing quieter vehicles; second, highways should be distantly directed from populous zones; and third, noise can also be controlled by walling or planting vegetation (as in boulevards) along the highways. However, these options have their imperfections: there is possibility of noise bouncing off the walls and creating little or no noise reduction, walling also creates poor ventilation along the highway, hence, increasing the concentration of CO- and traffic-related pollutants. Design noise levels for various land uses as set up by the US Department of Transportation are as given in Table 25.4.

Similarly, in an effort to regulate noise problem across Europe, the EU adopted some regulations, which are based on interoperability directives specified in the technical specification for interoperability (TSI). They are classified into two, conventional railways and high-speed railways. These EU directives and TSIs are listed in Table 25.5.

Furthermore, the Ministry of Environment and Urban Planning of the Turkish Republic stated their regulations on environmental noise criteria and pollution (mainly in urban centers) in their Official Gazette published June 4, 2004 in issue number 27601. The threshold values for railway systems are stated in Section 4, Article 19, thus in the daytime (7 a.m.−7 p.m.), it should be less than 65 dB (A); in the evening (7 p.m.−11 p.m.), less than 60 dB (A); and at night (11 p.m.−7 a.m.), less than 50 dB (A) (Sarikavak and Boxall, 2019).

3. *Noise in the home*

Individual dwellings are becoming noisier due to internally produced sound and also sound from the external environment. This is also becoming more pronounced as modern homes buy and use more noise-making gadgets (e.g., the New Year's Eve noisemakers). To curb noise from simple appliances in the homes, it is imperative to ask during

TABLE 25.4 Design noise levels for various land uses set up by the Federal Highway Administration.

Land category	Design noise levels (L_{10})	Description of land use
A	60 dB (A) exterior	Activities requiring special qualities of serenity and quietness, such as amphitheaters
B	70 dB (A) exterior 55 dB (A) exterior	Residences, motels, hospitals, schools, parks, libraries Residences, motels, hospitals, schools, parks, libraries
C	75 dB (A) exterior	Developed lands not included in categories A and B
D	No limit	Undeveloped land

Source: Courtesy Peirce, J.J., Weiner, R.F., Vesilind, P.A., 1998. Environmental pollution and control, fourth ed. Butterworth-Heinemann.

TABLE 25.5 Interoperability and European Union (EU) derivatives in terms of noise.

Type	EU directive	Technical specifications for interoperability
High-speed traffic	Directive 96/48/EC; Interoperability of the trans-European high-speed rail system	Commission Decision 2002/735/EC—TSI relating to high-speed rolling stock Commission Decision 2002/732/EC—TSI relating to high-speed railway infrastructures Commission Decision 2008/232/EC—TSI relating to the rolling stock subsystem of the trans-European high-speed rail system

TSI, Technical specification for interoperability.
Source: Courtesy International Union of Railways (UIC), 2010. UIC high speed rail. www. uic.org/download.php/publication/521E.pdf. (accessed 18.06.15); European Commission, 2015. Existing directives relating to noise sources: http://ec.europa.eu/environment/noise/sources.htm (accessed 25.06.15) (International Union of Railways, 2010; European Commission, 2015).

shopping for how much noise an appliance makes just as one invariably asks for how much an appliance cost. Also, use of dissipative silencers as effective modifications of appliances should be used.

25.7.5 Corrective actions to control plastic/microplastic pollution

The reports on the environmental implications of plastic/microplastic pollution have provoked ideas on how to address this global problem. Plastic pollution is a problem caused as a result of human activities in the environment; therefore human behavioral change is key to solving the problem. From the individual user of plastic materials to plastic products' manufacturers, nongovernmental organizations, government regulatory agencies, government at various levels, and international environmental monitoring organizations (Vince and Hardesty, 2016) must come together to address the plastic pollution and its associated problems. Behavioral change is a major panacea in addressing global plastic waste proliferation and pollution. Individuals must cultivate the habit of proper waste disposal to avoid mismanaged plastics in the environment. The principle of three Rs (reducing, reusing, and recycling) of plastic materials must be adopted and fully incorporated at all levels as one of the control measures in combating the impacts of the accumulated plastics in the natural environment. Plastic product manufacturers must take responsibility for their products, even after use. Likewise, more resources must be invested into the development of low cost, effective and efficient plastic waste evacuation, and recovery and recycling techniques. Researchers must come up with alternative uses for plastic wastes that will help to minimize or eradicate plastic pollution in the environment. For instance, some countries such as India (Laskar and Kumar, 2019) have utilized some of their plastic wastes in road construction. Nongovernmental organizations must step up their campaign, awareness, and sensitization of the public on the impacts of plastic pollution on the environment and human health.

Moreover, advocacy and education on proper usage and disposal of plastic waste must be incorporated to the elementary schools' curriculum. Stringent regulation on production and consumption of single-use plastics and plastic additives, for instance, more tax may be introduced to discourage unnecessary use of disposable plastics. Regulatory agencies must adopt strict procedures in enforcing compliance both by the users and the producers of plastics. New laws must be promulgated to punish any violation of plastic pollution control laws. Global sanction/regulations on plastic wastes must be adopted; illegal discharge of plastic waste in another nation's territory must be met with a strict sanction. Global constant monitoring and assessment of various efforts in combating plastic pollution will also contribute immensely to reducing the effect of plastic waste on the environment and human health.

25.7.6 Bioremediation technique of controlling environmental pollution

The presence of chemical pollutants in freshwater bodies such as lakes, rivers, stream, and pond is referred to as freshwater chemical pollution. Their occurrences alter the freshwater characteristics thereby making freshwater unsafe for drinking, recreational activities, irrigation, and sometimes habitat due to the negative effects that chemical pollutants exert on the organisms inhabiting in freshwater bodies (Malaj et al., 2014; Choudri et al., 2017).

Anthropogenic generated chemical pollutants that contaminate freshwater habitat can be classified in two major groups, organic and inorganic pollutants (Ugya et al., 2019). Table 25.6 shows various organic and inorganic pollutants that have been shown to be responsible for the alteration of physicochemical and nutrient status of different freshwater bodies. Organic pollutants are chemical pollutants containing carbon with the exception of carbonates, cyanides, and oxalates (Schweitzer and Noblet, 2018; Ugya, 2015). These pollutants tend to contain other elements such as oxygen, chlorine, bromine, sulfur, nitrogen, phosphorus, and hydrogen, in addition to carbon atom that is the principal element. These pollutants are produced as a result of the usage and production of synthetic organic compounds such as pesticides, herbicides, fertilizers, and petrochemicals (Carpenter, 2011; Ugya and Imam, 2017). Organic pollutants can be classified into two classes based on polarity, hydrophilic and hydrophobic organic pollutants (Schweitzer and Noblet, 2018). Hydrophilic organic pollutants are polar and soluble in water while hydrophobic organic pollutants are nonpolar and insoluble in water (Nanny and Ratasuk, 2002). Hydrophilic organic pollutants include alcohol and carboxylic acid with relatively small alkyl group (CH_3, C_2H_5, C_3H_7, and C_4H_5). Another vital example of hydrophilic organic pollutants is methyl tertiary butyl ether (MTBE). These pollutants do not exert pressure on freshwater due to their nonpersistent nature and their ability to mix well with water (Qin et al., 2010; Gabrielska et al., 1997). Hydrophobic organic pollutants, on the other hand, include organic pollutants, including DDT; polychlorinated biphenyls (PCBs); polybrominated diphenyl ethers (PBDEs); polychlorinated dibenzodioxins (PCDDs); polychlorinated dibenzofurans (PCDFs); and benzene, toluene, ethylbenzene, and xylene (BTEX) (Jaffe, 1991). These pollutants are problematic due to their persistent

TABLE 25.6 The ecological fate of chemical pollutants in freshwater habitat.

S/N	Pollutant types	Case study examples	Environmental fate of chemical pollutant	References
1	DDT	Amazon River, Brazil, Sayong River Watershed, Malaysia	Accumulate in sediment, water, and organisms of freshwater habitat, is reported to cause reproductive failure in fishes and aquatic birds that prey on fishes.	Torres et al. (2002) and Ghani et al. (2017)
2	PCB	Willamette River Basin, Arkansas River Basin	Accumulate in sediment, water, and organisms of freshwater habitat, is reported to cause reproductive failure in fishes and aquatic birds that prey on fishes.	Hope (2008) and Belden et al. (2000)
3	PBDE	Chaohu Lake China, Asunle Stream, Nigeria	Accumulate in sediment, water, and organisms of freshwater habitat, is reported to cause reproductive failure in fishes and aquatic birds that prey on fishes.	Liu et al. (2018) and Olutona et al. (2017)
4	PCDD	Detroit and Rounge, Saginaw River	Accumulate in sediment, water, and organisms of freshwater habitat, is reported to cause reproductive failure in fishes and aquatic birds that prey on fishes.	Kannan et al. (2001, 2008)
5	PCDF	Jukskei and Klip/Vaal South Africa, Xiangjiang River	Accumulate in sediment, water, and organisms of freshwater habitat, is reported to cause reproductive failure in fishes and aquatic birds that prey on fishes.	Rimayi et al. (2016) and Chen et al. (2012)
6	PAH	Columbia Cauca River, Lower Fox River	PAH is utilized by aquatic organisms, including mollusks, crustaceans, polychaetes, and fish, but at higher concentration PAH tends to be toxic to aquatic organisms leading reproductive and endocrine failure in fish.	Sarria-Villa et al. (2016), Brewster et al. (2018), and Collier et al. (2013)
7	BTEX	Tegas River and Marrecas Stream, Buriganga River	BTEX are moderately toxic to aquatic flora and fauna at higher concentration, which are resulted from spillage but are unlikely to cause any toxicity at normal environmental concentration because they degraded easily.	Fernandes et al. (2014) and Mottaleb et al. (2003)
8	Ammonia	Yellow River, Grand River	Causes eutrophication and algae blooms.	Zhang et al. (2007) and Sonthiphand et al. (2013)
9	Nitrate	Lowa's River	Causes eutrophication and algae blooms.	Li et al. (2013)
10	Phosphate	Poyang Lake	Causes eutrophication and algae blooms.	Wang and Liang (2015)
11	Heavy metals	River Pra	Effect depends on the type of heavy metal but toxicity of all heavy metal in freshwater organisms results when the uptake rate exceeds the combined rates of detoxification.	Duncan et al. (2018) and May et al. (2008)

BTEX, Benzene, toluene, ethylbenzene, and xylene; *DDT*, dichlorodiphenyltrichloroethane; *PBDE*, polybrominated diphenyl ether; *PCB*, polychlorinated biphenyl; *PCDD*, polychlorinated dibenzodioxin; *PCDF*, polychlorinated dibenzofuran.

nature, leading to bioaccumulation in freshwater habitat until they reach an elevated concentration, which is injurious to freshwater flora and fauna (Zhang and Kelly, 2018).

Inorganic pollutants are pollutants, including sulfur and its compounds, ammonia, nitrate, phosphate, and heavy metals, that are released into freshwater bodies from industrial and power plants, from agricultural and urban runoff, and acid mine drainage. These pollutants tend to facilitate the depleting of oxygen in freshwater habitat and also lead to the change of the physical chemistry of freshwater bodies thereby exerting negative impact on the flora and fauna organisms inhabiting freshwater habitat (Camargo and Alonso, 2006; Zhou et al., 2014).

The ecological fates of chemical pollutants in freshwater habitat for some particular chemical pollutants have been summarized in Table 25.6. The most similar effect attributing to almost all the pollutants is eutrophication. Eutrophication has been defined by Walker et al. (2019) to mean the incessant accumulation of organic and inorganic material in the aquatic environment. The continuous accumulation of these nutrients stimulates the increase of algae biomass, which is as a result of the utilization of the accumulated nutrients by the algae species. The increase in algae biomass leads to toxic algae blooms that are associated with the release of toxins, affecting both the flora and fauna of freshwater habitat (Heisler et al., 2008). The blooms also encourage the growth of bacteria which used up the available dissolve oxygen present in freshwater habitat, thereby contributing to the negative effect on the flora and fauna of freshwater habitat (Ramanan et al., 2016; Yarimizu et al., 2018). Persistence organic chemical pollutants such as DDT, PCB, PBDE, PCDF, PAH, and BTEX tend to accumulate and magnify in sediments and across aquatic food chain and web, although scanty literature exist showing acute toxicity to freshwater fauna resulting from these organic pollutants. However, the reproductive failure has been reported to occur in fishes and some aquatic birds (Opopol, 2008). The presence of these persistence organic compounds in freshwater habitat can stimulate the growth of bacteria, which used up the available dissolve oxygen in the freshwater environment, thereby affecting the biodiversity of the habitat in enormous ways (Doolotkeldieva et al., 2018). The environmental fate of heavy metals tends to vary between heavy metals. Mercury, for instance, tend to accumulate and magnify in bottom sediment of freshwater habitat leading to the formation of methylmercury, which is a highly toxic chemical to the flora and fauna of freshwater (Rice et al., 2014), and across the food chain and food web (Tchounwou et al., 2012). The concentration of mercury accumulated in small fishes tends to double as compared to in the planktons that were directly exposed to the heavy metal (Rajeshkumar and Li, 2018). Similarly, the concentration of mercury accumulated in larger fishes was higher than the concentration accumulated in the small fish, with the accumulated concentration getting higher across the food chain and web (Kim et al., 2006). Arsenic and cadmium tend to accumulate in water, sediment, and tissues of freshwater organisms, thereby resulting in deleterious effects on aquatic fauna (Perera et al., 2016). Selenium is another heavy metal that accumulates but does not magnify like mercury. Selenium affects the survival and growth rate of juvenile fishes and has been linked to ill development of offspring of fishes (May et al., 2008).

25.7.6.1 Microbial world and wastewater treatment

Microorganisms are unicellular organisms that are either prokaryotic or eukaryotic microscopic organisms that are classified into major groups such as algae, bacteria, fungi, and protist. They are crucial in wastewater treatment plants for water decontamination to safeguard public and environmental health (Wu et al., 2019). These organisms have shown great importance to man and other organisms in many ways, including fermentation of food, clinical importance, veterinary importance, treatment of sewages, production of biofuel, production of enzymes, production of bioactive compounds, and wastewater treatment. The process by which microorganisms are used for biological treatment of wastewater includes bioremediation (bacteria), mycoremediation (fungi), and phycoremediation (microalgae). Recently, an emerging biological process of treatment of wastewater is the use of algae biofilm, which is a complex assemblage of algae, bacteria, and fungi that multiply by forming thick submerged mats in an aquatic environment and terrestrial surfaces under suitable condition.

25.7.6.2 Bioremediation of wastewater

The potentiality of bacteria in the wastewater remediation is on the rise with different bacteria consortia employed by either converting the pollutants into nontoxic substances or by acting as a catalyst in the degradation of pollutants into nonharmful substances. The mechanism involved in the bioremediation of organic and inorganic pollutants by bacteria is a redox reaction in which an electron must be donated by one substance and accepted by a different substance for degradation to occur. The ability of bacteria to bioremediate inorganic substances such as heavy metals has been proved to be due to the ability of the bacteria to tolerate heavy metals due to their high adsorption potential. The techniques in bioremediation in the treatment of wastewater are categorized into aerobic and anaerobic methods.

1. *Aerobic method*

   Aerobic method of wastewater treatment, which is commonly called activated sludge, involves the degradation of organic and some inorganic compounds present in wastewater in the presence of oxygen. The roles of the activated sludge in the wastewater treatment include oxidation and flocculation. A convectional activated sludge process consists of an aeration tank and a sedimentation tank. The aeration tank is an enclosure where aerobic oxidation of organic pollutants occurs while the sedimentation tank is use for the sedimentation of microbial sludge produce during the process of aerobic oxidation in the aeration tank.
2. *Anaerobic method*

   The anaerobic method of wastewater treatment involves the breakdown of inorganic and organic compound by microbe in the absence of oxygen. The method of wastewater treatment using anaerobic biological method is employed in septic tank, upflow anaerobic sludge blanket, anaerobic filter, anaerobic attached-film expanded-bed and fluidized-bed reactor and rotating biological contactors (RBCs).

a. *Septic tank*

A septic tank is a system consisting of an underground chamber that could be in the form of a tank, concrete, or fiberglass via which wastewater is stored for the biological digestion of organic pollutant in a wastewater under anaerobic condition. The process of sedimentation also occurs in the chamber and the septic tank also contains an absorption field, which is surrounded by some gravel or crushed stones and functions for the treatment and disposal of wastewater after the removal of contaminant and impurities.

b. *Upflow anaerobic sludge blanket*

This is a system that is used for anaerobic wastewater treatment; this system consists of packed sludge forming a bottom layer, a liquid upper layer, and a sludge blanket in between. During wastewater treatment, wastewater tends to flow upward via the sludge bed and the organic pollutants in it are degraded. The organic pollutants are degraded because the sludge bed is covered with flocs of active bacteria in the form of floating blanket. The treated water is separated from the sludge flocs by the settler screen while the methane gas produce is collected at the top of the reactor.

c. *Anaerobic filter*

This system is in the form of bioreactor consisting of many filtration chambers connected in series forming a fixed bed of biological reactors. These filters tend to correlate positively with the anaerobic trickling filter, the support media present in anaerobic filters are in the form of either a rock, gravel, or plastic with empty spaces. The filter media serve as attachment medium for the microorganism although some microorganisms tend to form flocs that are trapped within the filter medium. This system is advantageous due to low sludge production and high efficiency in solids and biological oxygen demand (BOD) reduction.

d. *Anaerobic* attached-*film expanded-bed and fluidized-bed reactor*

This efficiency of this system in the treatment of wastewater depends on the upflow of wastewater, which is greater in expanded beds than the fluidized beds. Wastewater tends to flow upward via the sand bed of diameter of less than 1 mm, which serves as surface for the growth of the biofilm. The high flow rate causes the recirculation of the wastewater via the bed leading to the treatment of organic pollutants present in wastewater.

e. *Anaerobic RBC*

RBC is a system of fixed bed reactor that contains stacks of rotating disk placed on a horizontal shaft. These rotating disks are partially submerged and rotated as wastewater flow via the system. These systems are used in the convectional WWTP as a secondary treatment method after the use of sedimentation for the treatment of domestic gray or brackish water. The microbial community is alternately exposed to the atmosphere and the wastewater allowing both aeration and assimilation of dissolved organic pollutants and nutrients for degradation.

25.7.6.3 Fungi (mycoremediation)

Mycoremediation of wastewater is the form of landfill remediation that involves the remediation of pollutants present in wastewater by fungi. This method is very cheap and has been proved to have high efficiency in the removal of both organic and inorganic pollutants. The ability of fungi to mycoremediate inorganic substances such as heavy metals has been proved to be due to the high hyperaccumulating potentials of these organisms and their the ability to tolerate heavy metals due to their high adsorption potential. Mycoremediation of compounds such as dye (Congo dye, azo dye, malachite dye, nigrosin dye, and trypan blue dye); pesticides (insecticide endosulfan, imazalil, thiophanate methyl, orthophenylphenol, diphenylamine, and chlorpyrifos); organic compounds (BTEX); PAH (polycyclic aromatic hydrocarbon); and MTBE (methyl tert-buthyl ether) has been proved to be due to the ligninolytic enzyme such as laccase, and manganese peroxidase, released by fungi (Chen et al., 2019; Colborne et al., 2019). These enzymes bring about the degradation of these compounds.

25.7.6.4 Microalgae (phycoremediation)

Phycoremediation of wastewater is the process by which both macro- and microalgae bring about the transformation of pollutant present in landfill leachates. The mechanism involved in the phycoremediation of wastewater is based on the fact that algae are autotrophic organism so are able to perform photosynthesis, during the process of photosynthesis, algae produce reactive oxygen species (ROS) such as hydrogen peroxide (H_2O_2), super oxide (O_2^-), and hydroxide (OH^-) radicals. Many researchers have shown the ability of the ROS produced by algae to be the reason why algae bring about the degradation of organic compounds and also reduction of metal oxide, which is in turn used by the algae for biomass production since the process of phycoremediation is also based on the ability of microalgae to use pollutants for biomass production.

25.7.6.5 Biotechnology and wastewater treatment

The biotechnological technologies used in wastewater treatment include bioaugumentation technology, immobilized cell technology, membrane technology, and bioelectrochemical technology.

1. *Bioaugumentation technology in wastewater treatment*
   The advancement in the field of genetic engineering has led to the isolation and production of commercially available microorganism for the degradation of pollutants such as pesticides and other chemicals in wastewater. These process of addition of microbial world and enzymes for rapid degradation of contaminant in wastewater is referred to as bioaugmentation. Wastewater contains microbial world of origin that has the potential of breaking the contaminant present in wastewater at a slow rate with low-reduction efficiency but with bioaugumentation the efficiency is increased. The strain of microbial world used for bioaugumentation is isolated from substrate such as biosolids, compost, soil, and even the wastewater using the convectional enrichment techniques, among the samples isolated from the substrate is enzyme that includes catalase, phosphatase, aminopeptidase, and esterases, which are also added to wastewater to enhance the degradation of pollutants in the wastewater.
2. *Immobilized cell technology*
   Immobilize cell technology is a technology used in the treatment processes such as activated sludge, trickling filter, or RBCs. This technology is of advantageous because it protects the cell from biotic and abiotic stresses, toxic chemicals and increases survival rate and catabolic and anabolic activities. This technology is used in the removal of brown lignin compound from paper mill effluent, biodegradation of phenolic compounds, treatment of cyanide wastewater, dehalogenation of chloroaromatics, methane production, and enhancement of nitrification, denitrification, and the efficiency of activated sludge
3. *Membrane technology*
   Membrane technology is the combination of biological and physical processes to treat wastewater, it is commonly known as membrane bioreactors (MBRs) because it involves microfiltration or ultrafiltration combined with biological wastewater treatment process. MBRs are efficient in the removal of chemical oxygen demand (COD), biochemical oxygen demand (BOD), trace organic compounds, and heavy metals. MBRs can be operated with high concentration of biomass and settling does not depend on the formation of biological flocs in the aeration tank thereby do not lead to bulking problems. MBRs tend to retain planktonic microorganism and particles and are widely used in industrial treatment of wastewater and gray water. The disadvantage of MBRs is the formation of inorganic and organic pore clogging and sludge cake formation known as membrane fouling. Inorganic membrane fouling is resulted due to chemical precipitation mainly as calcium carbonate and to biological precipitation caused as a result of interaction between biopolymer and metal ion. Organic membrane fouling is as a result of microbial biomass, bound extracellular polymeric substance (EPS) colloidal organic matter, adsorbed dissolved organic matter and biofilm formation on the membrane which increases with time.
4. *Bioelectrochemical technology*

This is a technology that is based on the use of electrochemically active microbes as catalysts through the electron transfer inside of a cell to an electrode to interconvert both chemical and electrical energy. The categories of bioelectrochemical systems include microbial fuel cell, microbial electrolysis cell, and phototrophic microbial fuel cells. In a bioelectrochemical system, electromotive force (emf) of the overall reaction can be represented as follows:

$$\mathrm{emf} = \frac{\Delta G}{nF} \tag{25.1}$$

where ΔG is Gibbs free energy (J/mol), n is amount of electron (mol), and F is Faraday's constant (96, 485.3 C/mol). The three categories of bioelectrochemical system are briefly described as follows:

a. Microbial fuel cells: negative ΔG and positive emf leading to electricity production.
b. Microbial electrolysis cell: ΔG is positive and emf is negative, requires energy but produces H_2.
c. Phototrophic microbial fuel cell: involves photoautotrophs such as algae (Croese et al., 2011).

25.8 Ensuring environmental quality and sustainability: preventing pollution

One of the major goals of this chapter is to bring awareness to the general public (including government, social and political groups, environmental, industry, as well as a several body of ordinary people who are marginally concerned), the urgent need of action in combating the threats and menace resulting from environmental pollution. We have discussed about pollution and some of its types, sources, and effects in previous sections of this chapter. It is not enough to point out both potential and current issues on pollution effects on the present environment, it is also imperative to stress the need for pollution reduction via pragmatic approaches thereby providing a sustainable environment for future generations to live in. Ensuring proper environmental quality and sustainability especially in reducing and preventing pollution is the key to securing safe future habitation on the planet Earth.

25.8.1 Environmental quality and sustainability

There exists a strong interaction between quality of life and the environment (Diener and Suh, 1997; UNECE, 2009; Streimikiene, 2015). It is the truth that one of the key factors in people's well-being is *environmental quality* as their lives are greatly affected by the health status of their physical environment (Holman and Coan, 2008; Kahn, 2002; Streimikiene, 2015). Environmental quality is essential because most people value and care about the depletion of its environment natural resources and the health of the environment they live (Brajša-Žganec et al., 2011). Preserving environmental and natural resources is therefore one of the most important factors in ensuring the preservation of well-being overtime (VanLiere and Dunlap, 1980).

Elleuch et al. (2018) defines e*nvironmental sustainability* as the process of meeting our current needs without affecting or jeopardizing future generation's right and ability to meet theirs. The focus of sustainability (and sustainable development) is hinged on balancing the line between our competing need to advance both economically and technologically and also the needs to protect the environments in which we live with others. Kates et al. (2005) established the fact that sustainability is not limited to the environment but also extends to our health as a society in order to ensure that no areas of our life suffer. Sustainability also extends to the state of examining human's actions and their long-term effects and how this can be prevented or improved (United Nations General Assembly, 1987). A key issue for sustainable environment is environmental pollution with its health impacts (United Nations General Assembly, 1987).

25.8.2 Pollution prevention

The rising in both human and animal population has made pollution become a great concern and this scenario will continue because various activities of human will increase more (meaning this is a problem that is inevitable). Therefore, with an all-encompassing program of pollution prevention, most pollution can be majorly be reduced, reused, or prevented (Thiel et al., 2015).

The term *pollution prevention* has generally not been in use as pollution control, but the basic idea of preventing pollution instead of fixing problems is highly pertinent for efficient and economically processes and it also helps to address many environmental problems (Harland, 2012). It is therefore this way; pollution prevention will make an essential component of sustainability. The amount of pollution generated via processes and activities in industries, agriculture, and so on is reduced through the concept of pollution prevention but pollution control strategies generally seek to manage and reduce a pollutant and its impact upon the environment after its emission, which most often is more strenuous and costly especially for nonpoint source pollutants (Elleuch et al., 2018). Pollution prevention approach, however, increases the efficiency of pollution generated processes by reducing the amount of pollution generated at its source (Sherman et al., 2016). Another best approach to this is to prevent the pollution from being created in the first place by finding new efficiencies and ways of doing things astutely.

Jorgenson and Wilcoxen (1990) emphasized the need for people to possess primal ideas of preventing pollution in every sphere with new materials and new approaches, rather than just fixing problems. It holds both economic and environmental benefits to reduce the input of materials and energy, minimize the amount of waste for treatment and disposal, and make sure that the wastes that are produced are reusable or can be disposed of easily without harm to the environment (Harland, 2012). To tidy it up the first watchword within any environmental management hierarchy is prevention. Pollution prevention should therefore be everyone's goal. Individuals across cultures are expected to utilize their knowledge to take actions that are protective of human health and the environment.

25.9 Conclusion

Environment is the primary niche of all living organism and it describes the overall condition of one's immediate surroundings. The degradation of the environment via several activities, caused majorly by man over the years, has made it hard for his convenient living. This chapter has clearly explained the concept of environmental pollution, the widely recognized types of pollution (namely, land/soil, water, air, noise, and plastic/microplastic) and their respective socioeconomic impacts on health, environment, and economic growth and development. Some remedial measures to controlling environmental pollution were provided alongside pragmatic approach toward environmental quality and sustainability, which will largely help to enhance public health and well-being of man and his immediate environment.

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