Environmental Contamination and Remediation

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Edited by

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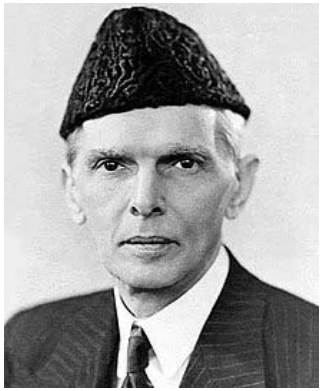
This book is dedicated to



Muhammad Ali Jinnah
(1876-1948)
Founder of Pakistan

Allama Muhammad Iqbal
(1877-1938)
Poet of the East

And to my dear father Anwar ul haq (Late)
who guided me throughout my life

"Remembering you is easy, I do it every day. Missing you is
the heartache that will never go away"

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PREFACE

Environmental pollution is one of the biggest challenges of the modern world. Various gaseous and chemical pollutants as either the by-products of industrial processing, the military activities ranging from manufacturing, transportation, the usage of explosives and weapons or the chemicals used as pharmaceutical and agricultural augments, are increasingly contaminating all the components of our environment. This indiscriminate increase in the pollution rate is now becoming a major threat to all organisms including human beings.

Though various remediation methods are in practice to decontaminate the pollutants from the environment, all these traditional methods are either costly, small-scale operations, short-term applicable or non-ecofriendly. Because of these challenges, the focus has been shifted to develop and adopt low-cost, environmentally-safe and sustainable technologies for the remediation of environmental issues. The natural way of environmental remediation commonly known as Bioremediation is a sustainable solution against environmental contamination. As of now, tremendous research work being carried out is well established using the beneficial bacteria and plants for the remediation of surface soils polluted and contaminated with toxic heavy metals. The plant-based technologies are applicable to inorganic and organic contaminants and pollutants. A wide variety of technologies using plants and microbes to remediate or decontaminate soils, ground waters, surface waters, or sediments, including the air, are currently researched in various laboratories all over the world. These technologies have become attractive alternatives to conventional clean-up technologies due to relative cost effectiveness and their inherently aesthetic nature.

The current book, ***Environmental Contamination and Remediation*****,** is an attempt to provide a detailed account of various environmental pollutants including the polycyclic hydrocarbons as well as the pharmaceutical pollutants, their influence on biological systems and how to use bioremediation procedures to mitigate them from the environment. This book also discusses the role of microorganisms including the symbiotic ones and poultry composts in decontaminating the environment.

This is our opportunity to thank the contributors/authors, who have given their time unselfishly to meet the deadlines for each chapter. We

greatly appreciate their efforts and commitment. We would also like to thank Cambridge Scholars Publishing (CSP) for their generous cooperation at every stage of the book's production. We hope this volume will be useful to all researchers as well as others concerned with agriculture and our environment.

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CHAPTER ONE

EMERGING ENVIRONMENTAL POLLUTANTS

SAMIA QADEER, MUZAMMIL ANJUM
AND AZEEM KHALID

Introduction

The continuous struggle to improve lifestyles has led to the continuous development of the human race over the past decades. However, the cost of this development is paid for by the adverse effects on the surrounding environment (Gavrilescu, 2010). Various human activities like transportation, industrialization, urbanization, and agriculture are casting severe effects on its surroundings (Gavrilescu et al., 2015). Though industrialization is pivotal for the economic stability of developing nations, the fact is that it also has negative impacts on the economy due to the increasing depletion of natural resources and environmental pollution (Antoci et al., 2017). The extent of increasing natural disasters due to environmental and mainly climatic anomalies burdened the developing economies. Similarly, the provision of a safe environment in terms of water and air for the well-being of inhabitants also becomes difficult due to the addition of different contaminants and pollutants to these media. Using unsafe water or breathing in the polluted air puts pressure on an economy by increasing the health and well-being cost.

The term environmental pollution is used to describe the condition of "any discharge of unwanted substances in the form of both materials and energy". These, added to any of the earth's media like soil, water or air may produce an acute or chronic disturbance to the earth's ecological systems resulting in loss of service provision. Such types of damage can be divided into primary or secondary pollution (Levy, 2013; Juodis et al., 2016), for instance, if the effect is direct and noticeable at the spot then the damage is primary and a pollutant causing such damage will be termed as a primary pollutant, whereas, in a case where the pollution is minor leading to the damage of other entities or affecting a delicate balance of the ecosystem, becoming evident after a period of time, it will be

secondary damage and a pollutant will be termed as a secondary pollutant. Secondary pollutants are also those entities, which do not directly pose any harm to the environment, but they enter into the medium along with other entities or pollutants and produce toxic substances that could potentially damage the environment (Gheorghe and Ion, 2011).

Over the period, tackling environmental pollution is becoming more difficult. There is a continuous addition of new substances to the environment and their impacts differ greatly from region to region. Another challenge in dealing with environmental pollution is that the impacts usually appear distant from the source. Therefore, a global consensus is required to resolve the issue of environmental pollution. Environmental pollution is usually described in three of the earth's media i.e. water, air and soil (Gavrilescu, 2010). Recently, food toxicity pollutants have also become a major field of environmental pollution study.

a) Water Contamination: The addition of toxic substances to water bodies has become a serious concern worldwide. Water is continuously polluted by industrial discharge, agricultural runoff, and municipal supplies (Gavrilescu, 2010). Though various treatment plants are available for the treatment of wastewater, the extent of the problem is far greater than the capacity of these treatment plants. Around two million tons of waste from sewage and industries are discharged daily into open water channels (UN WWAP, 2003); similarly, annual wastewater production is 1500 km^3, which is six times greater than all the world's river water collectively. The fact that freshwater resources are not distrusted equally worldwide makes the access to fresh water a challenge to the deprived communities. Therefore, people often use unhealthy and unsafe water. Water is also a universal solvent; therefore, apparently clear water could be a home to a large number of toxic contaminants or pathogens. Access to water and sanitation is a challenge worldwide, however, the situation is more critical in developing and underdeveloped nations where around 80% of people lack the facility of safe drinking water (Geissen et al., 2015). Not only surface water, but groundwater is also being contaminated due to the addition of pollutants from the leachate of surface pollutants such as municipal solid waste (Anjum et al., 2012), food processing waste (Anjum et al., 2017; Qadeer, Mahmood, et al., 2017), and wastewater (Anjum et al., 2016) containing toxic materials, etc. The pollution load also affects the water ecosystem. In a few regions of the world, one-third of the amphibians and half of the freshwater fishes are on the verge of extinction due to pollution (Vie et al., 2009).

b) Air Contamination: Similarly, the addition of particulate matter, chemicals, gases, biological agents or energy to the atmosphere that either is new to the atmosphere or increases the existing background concentrations, creating a threat to human health and other living organisms or causing damage to the ecosystem, the natural environment or the built environment, is recognized as air pollution. Smoke from industries, automobiles, and burning waste is a continuous source of air pollution where the other sources include aerosols, molds, etc. Approximately 3000 new substances have been identified in the atmosphere that were not previously part of the atmosphere (Gheorghe and Ion, 2011). Air pollution not only poses a serious threat to human health but also affects natural vegetation by blocking their light penetration and stomata. These pollutants could produce local effects (near to the source) like smog, PM or ground level ozone or could be carried long distances through the currents of air. The global distribution of air pollutants is more convenient than water pollutants as air circulations are continuous and cover the entire globe so the distribution of pollutants becomes easy.

c) Soil Contamination: Soil is usually considered as a dump for all types of materials, but in past decades, it has been identified as an exhaustible natural resource which, if not used properly, can be lost over time (de Souza et al., 2013). The soil is polluted by widespread hazardous waste disposal, oil spillages, pesticides, chemicals and the addition of non-biodegradable materials (Gavrilescu, 2010). Recently, studies showed that the addition of biochar to agricultural soil is also a source of toxic pollutants such as PAHs and heavy metals (Qadeer and Anjum et al., 2017). Another important factor is to consider the carrying capacity of any soil so it may not be exhausted of its vital nutrients and functions. It is estimated that around 3 million sites in Europe are polluted. Soil pollution is also connected to other forms of pollution such as for the medium of plant growth, pollutants and contaminants from the soil can enter our food, few chemicals experience breakdown or are dissolved in rainwater polluting groundwater through leaching or surface water through agricultural runoff, where the continuous activity of the soil's flora and fauna results in various gaseous emissions to the atmosphere.

d) Food Toxicity: Another form of pollution that is addressed nowadays is food pollution. The food is polluted by long-term, low-level contamination that increases with time through exposure e.g. the diffusion of persistent chemicals through the surrounding environment or sprayed pesticides, where food is naturally contaminated by biological agents including pathogens and toxins (OTA, 1979).

Environmental Excellence and Public Health Challenges

In modern management, the key aspect of sustainable development is human resources (Buono 1998). Various approaches have been taken into consideration for achieving sustainable development in the developing industrial world, but human resources remained unfocused. Thus, human health is adversely affected due to environmental pollution (Mohammadfam et al., 2013). A conceptual model of the relationship between sustainable development and human resources is illustrated in Fig. 1. It shows that environmental health is directly linked to the two factors of human resources i.e. public health and the economy.

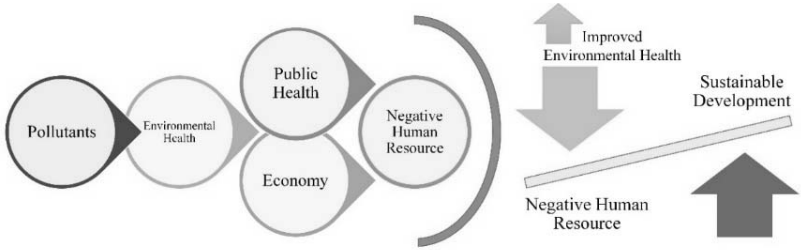

Fig. 1. Relationship between human resources and sustainable development

Research on the impacts of environmental degradation on public health has been followed by various scientists for a long time. Lu et al. (2017) have described the detailed historical background of various theories linked to the environment and human health. The pioneering work that started in 1972 developed the health production function model (Grossman, 1972) which was modified and improved in 1986 (Gerking and Stanley, 1986). This theory described, in the relationship between the output and input health functions, that lifestyle, healthcare, heredity, and environment are the main aspects affecting the status of health. In continuation research (Alberini et al., 1997), they revealed that inhabitants in areas with serious environmental pollution experience high impacts of accelerated depreciation.

The effect of environmental pollution on human health is contingent on the likelihood of exposure to contamination risk; therefore, the focus of attention is towards the categorization of the hazard due to different types of pollution (WHO, 2007). According to Pope et al. (1995), in cities, the greater the level of pollution, the higher will be the mortality level. The reliability of various research findings has remained highly controversial

because of the uncertainty in the environmental indicators, for example, the level of exposure, and individual exposure time may be unknown at a certain level of pollution.

The assessment of impacts of environmental health is also applied by many economists to estimate the environmental value, which offers empirical evidence for the design of the environment, economic policy and health (Pautrel, 2008; Pautrel, 2009; Matus et al., 2012). Recently, Beatty and Shimshack (2014) concluded that exposure to atmospheric pollution might significantly affect the respiratory health of non-infant children. More recently, Arceo et al. (2016) observed the negative relationship between infant mortality and pollution in Mexico, which is typically a developing country. In Greece, according to a study, there exists a dynamic interdependence among economic performance, environmental quality and health conditions (Katrakilidis et al., 2016).

Public health is a vital channel linking the environment to economics i.e. poverty and income, however, it has not received the attention it deserves. In fact, the negative impacts of pollutants in the environment on public health will mostly affect the economy and public welfare including labor, education, income and its distribution. Keeping in view the above context, the conservation of human health and safety should be the basic focus of the modern management approach and an essential part of organizations' policy (Mohammad et al., 2013).

Pollutant Categories and Environmental Impacts

An environmental pollutant is produced from a variety of sources and broadly classified as chemical pollutants, physical pollutants and biological pollutants (Fig. 2). Each type of pollutant has its own specific detrimental impact on the environment that results in an overall loss of environmental services and products. Various environmental and associated health challenges have been identified below:

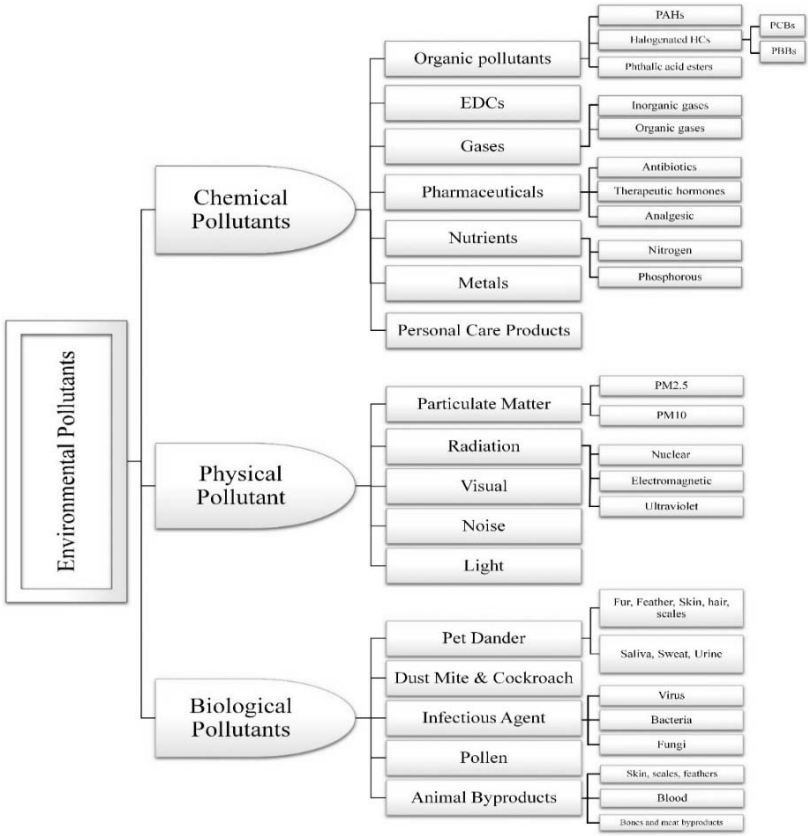

Fig. 2. Broad categories of environmental pollutants (Chemical, physical and biological)

Chemical Pollutants

Chemical compounds, either organic or inorganic chemicals that enter the environment via multiple fates are called chemical pollutants. The most common chemical pollutants include persistent organics (POPs), pharmaceuticals, nutrients (N and P), gases (VOC, CO2) and heavy metals. The most hazardous are those used in large areas and called persistent, meaning they do not degrade easily in nature. For example, pesticides, insecticides, and herbicides used in agriculture and gardening, as well as chlorinated solvents are released from many industrial processes.

Chemical pollutants are released from a variety of sources and can cause various health effects from simple digestive issues to chemical intoxication and in some cases can lead to sudden death due to poisoning. Generally, chemical pollution leads to serious diseases due to the consumption of poisonous food and contaminated water for drinking purposes and breathing in highly contaminated air. Table 1 summarizes the various environmental and health challenges due to chemical pollution. Various classes of chemical contaminants and their challenges to health are described in detail in the coming sections.

Tab. 1. Environmental and health challenges due to chemical pollutants

Types of Pollutant	Environment	Health
POPs	• Persistent and Long term • Biomagnification • Bioaccumulation	• Carcinogenic • Mutagenic • Teratogenic
PAHs	• May be absorbed by food crops from soil such as *lentils,* rye, and wheat	• Seven priority PAHs cause cancer e.g. BaA and BbF • Mutagenic • Teratogenic • Cataracts • Skin inflammation
PCBs	• Accumulate in sediments • Pesticides' contamination of food	• Damage the reproductive system • Affect the immune system
EDS	• Bioaccumulation Biomagnification • Steroidogenesis in fishes	• Disrupt the endocrine system in aquatic animals and humans • Abnormalities
Gaseous pollutants: Ethylene, methane, VOCs, etc.	• Affect the quality of ambient air quality • Difficult to assess exact the contribution in environmental contamination • Contamination levels widely vary with source	• Irritation of eyes, nose and throat • Headaches • Loss of coordination • Nausea • Damage to liver, kidney, CNS • Some organics can cause cancer in animals
BTEX	• Potent and persistent	• Leukaemia

	environmental damage • Contamination of agricultural land • Contamination of ground water due to leaching	• Gastrointestinal diseases • Nervous system problems • Damage to kidney, liver and eyes
Nutrients (N and P)	• Eutrophication • Hypoxia in aquatic environments • Secondary source of air pollution and ground level ozone	• Respiratory problems • Stomach/Liver illness • Blue baby syndrome
Heavy Metals	• Toxic to soil biota • Inhibit physiological metabolism of plants • Bioaccumulation in aquatic organism • Non-degradable	• Metallosis (metal poisoning) • Body burden (nausea, vomiting, headache) • **Hg:** Minimata disease, caustic gastroenteritis • **Cd:** Effects the kidneys, proteinuria, cardiovascular diseases, hypertension osteomalacia • **As:** Hypopigmentation, encephalopathy, carcinogenic • Effects to lungs, bladder and skin • **Pb:** Nausea, vomiting, encephalopathy, anaemia, brain damage in foetus

Organic Pollutants

Organic pollutants are the most diverse class of chemical pollution. The global occurrence and adverse health effects of organic contamination are leading to increasing public concern. Several organic contaminants, such as polychlorinated biphenyls (PCBs), organochlorine pesticides, polyaromatic hydrocarbons (PAHs) and phthalate esters (PAEs) are characterized by high persistence, toxicity and their bioaccumulation potential in the environment (Sun et al., 2018). The halogenated derivatives of phenols are one of the classes of organic pollutant that is also resistant to removal, released from a variety of industrial effluents (Anjum et al., 2017). Another large class of organic pollutants is

petroleum-based products obtained from industries. The leakage and spillage of petroleum hydrocarbons occur during exploration, refining, production, storage and transportation (Varjani, 2017), leading to adverse environmental impacts (Waigi et al., 2015). Hydrocarbons are also released due to natural crude oil seepage, which is reported as up to 600,000 metric tons per year. Among all petroleum products, monoaromatic hydrocarbons, such as toluene, benzene, ethylbenzene and xylene also known as BTEX are highly potent and persistent in the environment (Meckenstock et al., 2016; Varjani et al., 2017).

Organic pollutants in general enter through agriculture soil where it is difficult for these to degrade biologically under normal conditions. The residues of organic compounds in agricultural soils can pass into food chains and ultimately cause a potential risk to humans through successive trophic transfers (Fantke and Jolliet, 2016).

Persistent Organic Pollutants (POPs)

POPs are toxic chemicals that adversely affect human health and the environment around the world. They can easily be transported by water and wind throughout the trans-boundaries, thus can affect people and wildlife far away from where they are produced. POPs have a special property of persistence; they can remain in the environment for long periods and can bioaccumulate and be transferred through the food chain from one species to the next. POPs are known as one of the serious global concerns. In this scenario, the USA joined forces with ninety other countries to sign a groundbreaking treaty of the United Nations in 2001 in Stockholm, Sweden. Under this treaty, countries decided either to reduce or eliminate the production, release and use of 12 key POPs (Fig. 3) (EPA, 2017c).

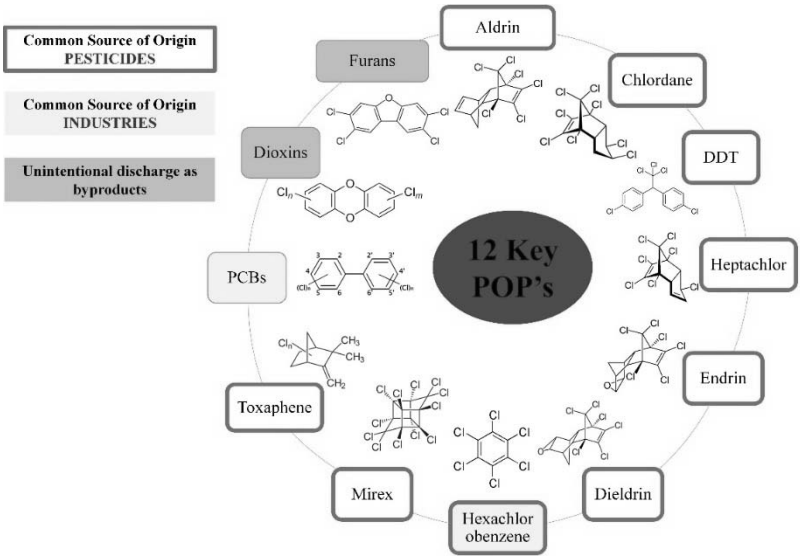

Fig. 3. Key persistence of organic pollutants and their prime source of origin

POPs are ubiquitous in the environment. Our bodies are exposed to pollutants mainly through three routes (a) inhalation through respiration; (b) dermal by skin; and (c) ingestion by eating food (Yang et al., 2015). Among various POPs, monoaromatic hydrocarbons and PAHs are highly lipophilic. Due to this property, these pollutants can cause serious damage to internal organs, mainly adipose tissues. Human beings can be exposed to these pollutants by outdoor and indoor activities. Similarly, the exposure routes through both occupational and non-occupational activities include adverse hazards to health (Varjani et al., 2017).

There are different classes of persistent organic pollutants reported which are polyaromatic hydrocarbons (PAHs), halogenated hydrocarbons such as PCBs and pesticides, petroleum products and phthalic acid esters, etc.

Polyaromatic Hydrocarbons (PAHs)

For many decades, PAHs have been extensively studied as they are found in every type of environment (soil, water, and air) and have high toxicity (Blanchard et al., 2004). PAHs were also included in the USEPA list of priority pollutants of 1976 (Deblonde et al., 2011). PAHs are formed primarily during the pyrolysis and incomplete combustion of organic matter (Sun et al., 2018). Most of the PAHs are released from the

combustion of automotive fuel, industrial production, residential combustion (coal and wood), energy production (in power plants utilizing oil and coal) and incinerators (Deblonde et al., 2011). In the priority control list of USEPA, sixteen PAHs were identified (Box 1), out of which seven PAHs, i.e. BaA, BbF, BkF, Chr DahA, BaP, InP, and BghiP are confirmed as carcinogenic compounds (Sun et al., 2018).

Box 1: List of sixteen PAHs

1. Naphthalene
2. Acenaphthalene
3. Acenaphthene
4. Flourene
5. Phenanthrene
6. Anthracene
7. Pyrene
8. Fluoranthene
9. Benzo[a]anthracene
10. Chrysene
11. Benzo[b]fluoranthene
12. Benzo[k]fluoranthene
13. Benzo[a]pyrene
14. Dibenzo[a,b]anthracene
15. Indeno[1,2,3-cd]pyrene
16. Benzo[ghi]perylene

US EPA Priority control list of PAHs

The PAHs are a serious concern for the environment having mutagenic, teratogenic and immunotoxic properties (Zhang et al., 2010). They are lipophilic in nature and thus less soluble in water (Beškoski et al., 2011). When irrigated PAHs contaminate water to agriculture, some crops such as lentils, rye, and wheat have the potential to absorb PAHs from the soil and enter the food chain (Veyrand et al., 2013). The recalcitrant nature of PAHs causes biomagnification in successive trophic levels (Varjani, 2017). Numerous remediation technologies of PAHs have been established and implemented up until now but are still insufficient and facing serious challenges due to continuous increasing concerns of human development and modern industrialization.

Halogenated Hydrocarbons

Halogenated hydrocarbons are a group of manufactured organic chemicals comprised of carbon (C), hydrogen (H) and halogen (X) atoms. PCBs were recognized as a major class of POPs by the Stockholm Convention in 2001. The most important halogenated hydrocarbons are polychlorinated biphenyl commonly known as PCBs that include about 209 types of chemicals. A few PCB congeners, for example, PCB-77, 81, 105, 114, 118, 126, 156-157, 167-169, and 189, were recognized as dioxin-like PCBs because of their highly toxic nature (Sun et al., 2016). Despite the fact that PCBs are banned in various countries, they still represent a significant class of pollutants that poses high human and ecological risks (Su et al., 2012).

PCBs were used in hundreds of commercial and industrial areas such as: (a) heat transfer, electricals, and hydraulic equipment, and (b) plasticizers in paints, rubber and plastic products, dyes, pigments, and carbonless copy paper. They are often released into the environment and usually accumulate in sediments (Sánchez-Avila et al., 2009; Deblonde et al., 2011) and thereafter become part of bioaccumulative pollutants found in some fatty tissue in humans, even in human milk (Faroon et al., 2003). A variety of adverse health effects are associated with PCBs. They have been reported as a reason for cancer as well as a number of serious non-cancer health hazards in animals, which include effects on the reproductive system, immune system, endocrine system, nervous system and other health effects.

Pesticide is a special subclass of PCBs, which are those substances that are applied to destroy, repel, prevent or mitigate any pest ranging from animals to small insects, and from weeds to microorganisms (Grube et al., 2011). Besides this, inadvertent exposure to pesticide chemicals has adverse effects on human health (Bonner and Alavanja, 2017). Pesticides are the only agricultural chemicals which are recognized as environmental contaminants of food. Poultry, livestock, and fish can be contaminated when the manufacturing or the application of pesticides takes place in the vicinity of the other way including the transportation of chemicals through the environment. The transportation and storage of human food in fumigated trucks, railroad cars, ships, and storage buildings are also sources of environmental contamination. The food materials are sprayed and fumigated with specific pesticides, and if managed improperly, contamination of the food likely occurs (OTA, 1979).

There are only a few reliable epidemiologic studies available relating to chronic cancer due to pesticide exposure, which allow us to estimate the health risks from dietary (food) exposure to pesticides and from

contaminated drinking water. Health effects which are caused by high dose exposure to pesticide contaminated food, are better documented and are not necessarily relevant to understand the toxicological mechanisms involved in chronic exposure at a low dose (Fenner-Crisp, 2001; Bonner and Alavanja, 2017).

Phthalic Acid Esters (PAEs)

PAEs are a class of chemicals that are extensively used as plasticizers in polyvinyl chloride, polyvinyl acetates, and polyurethanes. Due to their hazardous impacts on the environment and human health, six PAEs are classified as priority pollutants by USEPA and the China State Environmental Protection Administration. These include bis(2-ethylhexyl) phthalate (DEHP), di-n-butyl phthalate (DnBP), butyl benzyl phthalate (BBP), di-n-octyl phthalate (DnOP), dimethyl phthalate (DMP) and diethyl phthalate (DEP). It is estimated that 6.0 million tons of PAEs are consumed and produced worldwide on an annual basis according to the estimation by Arbeitsgemeinschaft PVC and UMWELT e.V (AgPU). In the context of the large and widespread application and production of PAE-containing products, their residues have been detected in various environmental matrices such as plants, soils, water, air, sediments, and humans. PAEs are reported to act as endocrine disrupting compounds in humans and animals, thus they may induce irregular functions and become the cause of carcinogenic, mutagenic and teratogenic effects.

Endocrine Disrupters (EDCs)

The organic pollutants are differentiated in a special class called endocrine disrupters. Endocrine disrupters are defined by the Endocrine Society as:

> *EDR is an exogenous man made chemical, or mixture of chemicals, that interferes with any aspect of hormone action within a body*

Hormones are chemicals naturally produced in the cells of endocrine glands and released into the blood for transportation in the blood (Gore et al., 2014). As the endocrine system has a critical role in various physiological and biological functions, thus little impairments to even a part of the endocrine system may lead to serious impact or even death. By

interfering with the body's endocrine systems, EDC exposure can, therefore, perturb many functions.

Most of the known EDCs are synthetic organic chemicals, e.g., bisphenol which was introduced into the environment due to anthropogenic activities, yet they can also be produced naturally such as estrone and 17b-estradiol, etc. (Jiang et al., 2013). Various sources of EDCs production include personal care products, pharmaceuticals, surfactants, and industrial additives and many other chemicals are reported to be endocrine disrupters which remain un-metabolized and are released into sewers. A few examples of EDCs include pesticides especially DDT, bisphenol, and phthalates used in children's products, food containers, and as flame-retardants in furniture and floor coverings.

About 1000 compounds have been identified as EDCs, where in addition there are countless suspected EDCs that have not been tested (Gore et al., 2014). With increasing knowledge about EDCs, the list of these chemicals exhibiting endocrine disrupting properties will increase. Thus, a unique challenge will arise regarding the identification and evaluation of new compounds in the environmental matrixes. This made the detection and measurement of EDCs difficult. Moreover, the precision of the determination methods is also still disputed and progressively under research.

Gaseous Contaminants

Organic gases

Organic gases such as ethylene and methane, volatile organic compounds (VOCs) are known as the most common organic gaseous pollutants. Ethylene is continuously released from various sources including combustion, the processing of petroleum and its products and the burning of agriculture residues, e.g. straw, husk, etc. Other organic gases are also produced in various chemical industrial processes. Ethylene is also known as a natural plant growth hormone, so its addition may cause abnormal growth symptoms.

In the case of methane, there are both anthropogenic and natural sources of methane emissions. The human sources include livestock, livestock farming, landfills, and industries. The natural sources include termites, wetlands, oceans, etc., that account for 36% of methane emissions. The industrial release poses a significant hazard to fuelling climate change, public health, and the wastage of energy resources. Methane is recognized as a potent greenhouse gas thus having a significant role in climate change after CO2.

Volatile organic compounds commonly recognized as VOCs are released as gases from certain liquid and solid

media. VOCs comprise a variety of chemicals, some having short- and long-term adverse effects on health. Concentrations of various VOCs are consistently ten times higher in indoor than outdoor environments. VOCs are emitted by a wide array of products numbering in the thousands (EPA, 2017b). The main health impacts of VOCs include; (1) eye, nose and throat irritation, (2) loss of coordination, headaches and nausea, and (3) damage to the kidneys, liver and central nervous system. Some organics are known to cause cancer in animals, while a few are suspected of causing cancer in humans.

Inorganic Gases

Inorganic gases enter the atmosphere from different routes and act as serious pollutants. The increasing concentration of gases such as carbon dioxide (CO2), nitrogen dioxide (NO2), carbon monoxide (CO), chlorine (Cl2), ozone (O3), ammonia (NH3) and sulfur dioxide (SO2) represents an expensive impact on environmental quality (Gheorghe and Ion, 2011). However, the effects of high concentrations of these gases cannot be detectable easily. Several epidemiological studies are performed in the literature, which has shown considerable evidence of a relationship between various respiratory and cardiovascular diseases with air pollutants (Araujo et al., 2017). The impacts of various inorganic gaseous pollutants are briefly described as follows (Gheorghe and Ion, 2011):

1. SO2 is the most important air pollutant produced because of the combustion of fuels especially coal for domestic use. It is also produced during the smelting process of the sulfide ores. SO2 is known as stinging gas and causes serious breathing problems in humans. Moreover, SO2 in the air also causes acid rain and winter smog.
2. CO is usually produced during the incomplete combustion of fuels in industries. Carbon monoxide is a greenhouse gas and a cause of the greenhouse effect, smog, and acidification. In humans, when it enters the lungs it can bind to hemoglobin in blood, and prevent oxygen transport in the body resulting in oxygen depletion of the heart, blood vessels and brain eventually causing death.
3. NO2 is released from automobiles into the air and reacts with other air pollutants. NO2 plays a crucial role in the formation of the ground level ozone atmosphere, soil acidification and

eutrophication of lakes. In humans, it deeply penetrates the lungs and damages lung function.

4. CO2 is the most important greenhouse gas released from the burning of fuel and natural gas. The main impact of CO2 is global warming which causes heat to be trapped in the atmosphere leading the planet to become warmer than it would be naturally. There is no direct impact of CO2 on human health until the atmospheric concentration reaches 15,000 ppm, which is 40 times the natural concentration. This high level of CO2 can cause hypercapnia (an excess of CO2 in the blood), which results in acidosis characterized by nausea, headache, and visual disturbances.
5. Cl_2 concentrations change very rapidly in the air; however light rain can remove Cl_2 from the air in a very short time. Cl_2 can cause injury to plants near the point of the pollution source.
6. Fluoride pollutants are released from aluminium factories, brickworks, glassworks, ceramic factories, steelworks, uranium smelters and phosphate fertilizer plants. The most injurious fluoride pollutant is gaseous hydrogen fluoride. The fluoride gases are absorbed by vegetation and if these are forage crops, they may be fed to cattle, horses, and sheep causing serious problems. Common fluoride pollutants include: (1) gases (HF, CF4, SiF6 and F2); (2) particulates (Cryolite, NH3F, CaF2, AlF6, NaF, CaSiF and Na2SiF6); and (3) aerosols (NaF AlF6 and NaAlF6)
7. NH3 released in the air from various sources is not sufficient to cause acute injury but occasionally high release and spillage may cause a serious pollution problem. NH3 plays an important role in acid deposition and eutrophication. Subsequently, acid deposition causes effects on aquatic ecosystems in lakes and rivers and damage to crops and forests. Whereas, eutrophication may lead to poor water quality including the impacts of decreased biodiversity, changes in species dominance and composition.

Pharmaceutical Contaminants

Pharmaceutical compounds are classified into different classes: hormones, antiepileptic, anti-inflammatory, antidepressants, statins, beta-blockers, antibiotics and products of contrasts (Deblonde et al., 2011). These molecules are used in domestic, hospital and veterinary areas. After the utilization of a human drug, residues are excreted as metabolized or metabolized. Human drugs have been detected in urban wastewater, surface water and sewage from hospitals (Deblonde et al., 2011). A few classes of pharmaceutical pollutants are described below:

Antibiotics

During the last decade, the global consumption of antibiotics increased by more than 30%, i.e., about 50 to 70 billion standard units (Gelband et al., 2015). Antibiotics are usually known as pseudo-persistent molecules because of their continued existence in the environment. Antibiotics are designed to inhibit and kill the microorganism related to the disease thus, when present in wastewater, they hinder the activity of beneficial microbes in the wastewater treatment operation. Antibiotics such as sulfonamides, fluoroquinolone and macrolide are commonly present in both wastewater and surface water. Other antibiotics including chloramphenicol and tetracycline may be present in surface water in the range of 0.05–23.5 ng/L (Tiwari et al., 2017).

Therapeutic Hormones

Therapeutic hormones are known as a synthetic analog of plant and animal natural hormones. The most common hormone found in the environment is estrogen and its metabolite that have become the abundant group of emerging pharmaceutical pollutant. Synthetic estrogenic steroids are used as the agent of birth control and in estrogen substitution therapies. Therapeutic hormones affect the endocrine system and cause impacts on animals and human health. 17b ethinylestradiol, in a metabolite of estrone (E1), is a powerful EDC and causes an adverse developmental and reproductive effect in non-targeted organisms (Gross-Sorokin et al., 2006). About 70 different types of therapeutic hormones have been reported in environmental water in some countries, e.g. b-blockers, antidepressants, non-steroidal anti-inflammatory drugs and antiepileptic carbamazepine (Tiwari et al., 2017).

Analgesics

Analgesics are the widely used drug for inflammation and pain relief. Common examples including ibuprofen, naproxen acetaminophen, meprobamate and diclofenac are regarded as important contaminants due to their persistence in ground and surface water (Radjenovic et al., 2009). About 15% of original ibuprofen as the original and 26% as its metabolite are excreted after medication. The metabolite of ibuprofen is highly toxic to aquatic organisms compared to its parental compound (Evgenidou et al., 2015). Analgesics such as gemfibrozil, hydrochlorothiazide, and frusemide (furosemide) have been found in rivers in a range of 2-18 ng/L (Tiwari et al., 2017).

Nutrients

The term "nutrient" technically refers to a source of nourishment to support organism growth. In the context of pollution, nutrients mainly refer to nitrogen (N) and phosphorus (P) which aquatic plants use to grow and proliferate. The main source of nutrient pollution is agriculture where excess fertilizer and animal manure are applied to fields and crops. When precipitation happens, it runs across agricultural land and carries N and P into local waterways. Another source is the improper treatment of septic wastewater, which cannot remove enough nitrogen and phosphorus before discharging into environments. The burning of fossil fuel in electric power generation, transportation, and industries has increased the amount of N in the air. N and P that can contribute to nutrient pollution in domestic areas, the yard and pet waste, detergents and certain soaps.

Excessive N and P often causes direct impacts on human activities. Human health is affected directly by nitrate toxicity when drinking especially for infants (Beaudry, 2017). Excess nitrates and phosphorus in water bodies encourages the growth of aquatic algae. Nutrient-enhanced algae growth leads to enormous algae blooms, which are visible as bright green and have a foul smell. These blooms produce toxins that are dangerous to aquatic organisms, wildlife, and humans. The blooms eventually die, and their decomposition product consumes the available dissolved oxygen from the water. Fish and invertebrates are killed when oxygen levels die. Due to nutrient pollution, some areas are called dead zones, because they become empty of most life (Beaudry, 2017).

Heavy Metals

Heavy metals are referred to as metallic elements and some metalloids with the assumption that heaviness (density) and toxicity are inter-related (Duffus, 2002). Although there is no recognized definition of heavy metals available, their density in most cases is taken as a defining factor, according to which in pollution terms "heavy metals are those having a specific density greater than 5 g/cm3."

Global and public health concerns are continuously increasing associated with the contamination of the environment by heavy metals. Their use in agricultural, industrial, mining and domestic applications has increased human exposure to an exponential level (Tchounwou et al., 2012). Similarly, the weathering of rocks is another source of heavy metals that increases their load in both surface and groundwater (He and Charlet, 2013). Groundwater polluted with heavy metals is the main source of drinking water in most of the regions of the world (Ab Razak et

al., 2015), thus, action and the possible risk to human health have been studied widely (Demir et al., 2015).

Certain heavy metals are required for normal functioning of the human body, but exposure to excess concentration of heavy metals may lead to health risks.

The World Health Organization cites four heavy metals (lead, cadmium, mercury, and arsenic) in its list of ten chemicals having major public health concerns (Elumalai et al., 2017). The main challenge due to heavy metals in humans is the impairment of the immune system.

In the case of lead, acute poisoning leads to the symptoms of abdominal pain, irritability, headaches and various symptoms related to the nervous system (Jarup, 2003). The immune system appears to be most sensitive to contamination due to lead (Forrest, 2014). Lead has been the most extensively studied heavy metal for understanding how heavy metals damage the human immune function. If the dosage and exposure of lead are high, it results in lowering the total antibody levels. In effect, lead switches the B-lymphocytes in blood from producing IgG and IgM antibody isotopes which are critical in conferring protection from infectious agents to IgE linked to allergic and hypersensitivity responses (Forrest, 2014). Children are particularly more susceptible to exposure to lead due to the permeable blood-brain barrier and high gastrointestinal uptake.

Cadmium is classified as a group I human carcinogen by the International Agency for Research on Cancer (IARC) on the basis of sufficient evidence of its existence in both humans and animals. In most cases cadmium is associated with cancer of the prostate. Another important heavy metal is mercury, which is used in barometers, thermometers, and instruments of blood pressure measurement. Acute exposure to mercury is likely to cause cancer of the lungs whereas chronic exposure is characterized by psychological and neurological symptoms, such as changes in personality, tremor, anxiety, restlessness, depression and sleep disturbance. The fourth important heavy metal in the environment is arsenic which causes acute toxicity. Intake in large quantities leads to severe disturbances of the cardiovascular and central nervous systems, gastrointestinal symptoms and ultimately death. In some cases, the symptoms of bone marrow depression, hepatomegaly, hemolysis, melanosis, encephalopathy, and polyneuropathy may be observed (Järup, 2003).

Personal Care Products

Personal care products (PCPs) cover a large group of chemical compounds that are used to improve the quality of life. These include both prescribed and non-prescribed products. A large number of these products include analgesics, synthetic hormones, steroids, fragrances, cosmetics, shampoos, sunscreens, body care products, steroids and lipid regulators. These PCPs enter the wastewater stream and can reach the wastewater treatment plant where they are either mineralized to simpler compounds or become part of sludge or biosolids. Therefore, the possibility of the release of these compounds untreated into the treated water stream is very high (Jiang et al., 2013).

These compounds are diverse in structure and form and therefore, there are different effects. Thus, the EA of England and Wales has produced a ranking system for these PCPs depending upon their level of toxicity, persistence, bioaugmentation, and biomagnification in aquatic life. Ten of the most toxic compounds cited on the basis of these characteristics are listed in Box 2 (Ebele, Abdallah, and Harrad, 2017).

The major challenge in addressing PCP pollution is due to their characteristics, and most of these are highly persistent in the environment like POPs and PCBs. Other implications that make them biologically active compounds are perfluoroalkyl (PFAS) and PBDE that are specifically designed to work even at low doses. Impairments arise when such chemicals affect the non-target organs in the body (medicinal allergy) and thus affect the well-being of a human. When such compounds are released in aquatic systems they affect the aquatic life (Fabbri and Franzellitti, 2016). In some cases, a very low concentration of discharge of these chemicals may not produce instant toxic effects but have the potential to bioaccumulate and can enter the food chain and end up in non-specified end time users. Many PCPs are known to produce different health issues including hormonal misbalance, obesity, skin problems and even cancer in some cases.

Physical Pollutants

Physical pollution can be referred to as the addition of physical elements that are usually noticeable in terms of their mass and energy. Nature has a self-sustaining system that produces no waste however, the intrusion of human activities disturbs the natural balance of nature and results in pollution. The recognizable physical pollutants like trash particulate matter, visual contaminants and unrecognizable pollutants like