Chapter 3

Water Pollution: Effects, Prevention, and Climatic Impact

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Additional information is available at the end of the chapter

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Abstract

The stress on our water environment as a result of increased industrialization, which aids urbanization, is becoming very high thus reducing the availability of clean water. Polluted water is of great concern to the aquatic organism, plants, humans, and climate and indeed alters the ecosystem. The preservation of our water environment, which is embedded in sustainable development, must be well driven by all sectors. While effective wastewater treatment has the tendency of salvaging the water environment, integration of environmental policies into the actor firms core objectives coupled with continuous periodical enlightenment on the present and future consequences of environmental/ water pollution will greatly assist in conserving the water environment.

Keywords: pollution, chemical pollutants, microbial pollutants, sustainable development, climate change

1. Introduction

Industrialization, in any society, is a major initiator of development and urbanization. Although the merits of industrialization are innumerable, it has been identified as a major threat to the environment as it releases various toxic chemicals, gases, solid wastes as well as microbes of various kinds into our immediate environment—land, air, and water. Of particular interest is water pollution, which has become a global challenge, developing nations being highly affected due to their drive for development [1, 2].

Pollution of our water bodies poses a great threat to humans and the aquatic ecosystem while marked population increase catalyzes climatic changes [3]. For instance, various human activities as well as the release of greenhouse gases by industries greatly contributes to global warming, planet temperature enhancement, and lowering of atmospheric air quality.

The drive for sustainable development must bring along water pollution prevention techniques. Effective wastewater treatment before their eventual discharge is one way to driving water pollution prevention. Some remediate climate change mitigation measures against water pollution can also be explored.

This chapter is aimed at critically discussing water pollution effects viz-a-viz global challenges, threat, and climatic impacts while also focusing on various possible preventive measures.

2. Water pollution

2.1. Promoting environmental sustainability

Sustainable development in any society is an access to initiate a good standard of living for the populace. It aims at providing solutions to the economic, environmental, and societal challenges without posing a threat to human and environmental future development, that is, we must consider the future as we make present decisions. Also, these include social progress and equality, environmental protection, conservation of natural resources, and stable economic growth [4].

There are numerous instances where urbanization has destroyed the environment and threatened its survival chances. Sustainable development put into consideration how we survive in the natural world protecting it from destruction and damages. One of the major challenges of urbanization is sustainability, as most developed or developing society now revitalizes a lot of natural resources daily. Most of these resources meet the needs of man but they are also limited. Sustainable development tends to balance the competing needs of the society.

In achieving this, many science bodies and institutions have seen the requisite of sustainable development and have set goals and targets to meet it. This also has pushed such institutions to have a role in measuring and monitoring the impact of these goals on the society. However, the contribution of scientist in sustainable development should not only focus on the environment. It should also take into consideration the health of the populace in ensuring that no area of life suffers [5].

While sustainable development may mean different things to different people, environmental sustainability is all encompassing. It is directly concerned with the future of humanity, and it defines how we should protect and handle the sustainability of resources, air quality, water quality, and ecosystems. It also helps to prevent the environment from impending damage from technological advancement. One way to achieving environmental sustainability is via effective wastewater treatment.

Various conventional wastewater treatment methods are available; their characteristics vary from complexities of operations through sludge generations among other things to various inadequacies. Their economic disadvantages are widely related to expensive equipment, complexities of operations and skilful manpower requirement. Many industries avoid the conventional wastewater treatment methods due to their economic disadvantages, hence discharging untreated or fairly treated wastewater into the water bodies. A simple and cheap wastewater treatment method will therefore facilitate effective wastewater treatment and protect the water environment from pollution.

2.2. Effects and challenges

Water is an essential and general need of life with an undeniable effect directly or indirectly. All industrial, environmental, and metabolic processes are water dependent. In living organisms, water plays a number of roles such as solvent, temperature buffer, metabolite, living environment, and lubricants [6]. Water, however, is said to be polluted when some of the water quality parameters have been hampered by unguided and irregularities from several anthropogenic activities, thus rendering water unfit for intended use.

Water pollution may pose serious threat to the environment as well as lives. Pollutant effects may vary depending on their types and source. For instance, while heavy metals, dyes, and some other organic pollutants have been identified as carcinogens, hormones, pharmaceuticals, and cosmetics and personal care product wastes are known as endocrine disruptive chemicals [7]. These pollutants, which enter into the water body through various channel but predominantly anthropogenic, have become a great concern to environmentalists due to various hazard they pose on the environment.

2.2.1. Heavy metal pollution

Heavy metals top the list of inorganic pollutant with wide range of negative effects on aquatic organisms, plants, and human. Heavy metals are released into the environment via different routes such as industries, mining activities, agricultural activities etc. [8]. Bioavailable metals present in the soil may be absorbed by plants resulting in serious plant metabolism dysfunctioning [9]. High heavy metal ion concentrations are also known to damage the cell membrane, affect enzyme involved in chlorophyll production, thus reducing photosynthetic rate as well as affect plant reproduction via decrease in pollen and seed viability [10].

Humans and animals can be exposed to heavy metal toxicity through the food web, direct consumption of water containing metal or via inhalation [11]. Heavy metals readily bioaccumulates in vegetables and enters into man and animal through food chain. Effects of heavy metal toxicity on human ranges from mild eye, nose and skin irritations through severe headache, stomach ache, diarrhea, hematemesis, vomiting, dizziness to organ dysfunctioning such as cirrhosis, necrosis, low blood pressure, hypertension, and gastrointestinal distress [12]. While some heavy metals also called essential elements (cobalt, copper, iron, manganese, vanadium, and zinc) are required in minute amount in the body for various biochemical processes; others such as lead, cadmium, arsenic, and mercury are of serious threat and considered foreign in the body. Looking at specifics, human ingestion of water polluted with arsenic can cause cancer of the lungs, liver, and bladder. Kidney and lungs damage as well as bone fragility may result when cadmium containing water is ingested. Exposure to lead can severely damage the brain and kidneys. In children, lead exposure even at very low concentration may hamper learning, cause memory loss, affect attention and response functions, and generally make children aggressive [13, 14]. In pregnant women, high levels of exposure to lead may cause miscarriage, whereas in men, it can damage the organs responsible for sperm production. Mercury is unique amidst other heavy metals; it has the capacity to travel a wide range of distance, thus have been classified as a global pollutants. The chemical form of mercury in the environment is also important in analyzing their toxicity. The organic form of mercury, that is, methyl mercury (MeHg) and dimethyl mercury (DMeHg), is known to be more toxic than inorganic mercury [15, 16]. While inhaled mercury goes into the blood stream, their elimination from the body is either through the urine or faeces. Mercury has the ability to exist in the urine for about 2 months, hence their renal dysfunctioning characteristic [16].

Many physiological disorders may accompany crustaceans' exposure to metals, and instant metabolic activities' alterations. Exposure of crustaceans to heavy metals may also result in loss of appetite for food and subsequently body weight loss. Continuous exposure may reduce reproduction in adults as well as hamper the growth larvae [17].

2.2.2. Organic pollutants

Organic pollutants are very wide in variety with a huge range of toxicity. Among the list of organic pollutants that has been of great threat to aquatic organisms, plants, and humans are dyes, plant and animal pharmaceuticals, personal care products wastes as well as petroleum organic pollutants. A group of chemicals referred to as endocrine disruptive chemicals (EDCs) also belongs to the organic pollutants group, which are classed as emerging contaminants. EDCs are described as external agents that interfere with hormonal activities, thus affecting the normal homeostatic reproduction, development or behavior [18].

Dyes are water soluble giant chemical that is greatly used in many industries viz; textile, leather and tanning, food, paper, etc. to impact color on products. Aquatic organisms, plants, and humans are greatly affected by dyes' presence in water. They impede sunlight penetration into water bodies and reduce dissolved oxygen, thus leading to death of photosynthetic organism and other lives within the aquatic environment [1]. Humans may be exposed to dye toxicity via consumption of vegetables and fish which bioaccumulate dyes. The use of colored paper towels used in drying hands and in food preparation is another route of exposure to human [19]. Dyes are considered as carcinogenic and mutagenic, thus their removal from wastewater before disposal is ultimately important.

Human and veterinary pharmaceuticals, which are members of EDCs, are chemicals used as curative or preventive of various diseases. Veterinary pharmaceutical may also serve the purpose of increasing efficiency of food production. Pharmaceuticals are used widely and unavoidably, thus they enter into the environment through one of these routes indiscriminate disposal

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of hospital and household waste, landfill leaching, drainage water and sewage. Although pharmaceuticals have been found to exist in various environmental samples at the ng/l to μg/l levels, it is considered a great threat to both aquatic lives and humans [20]. The presence of pharmaceuticals in water is known to pose both acute and chronic toxicity on aquatic organisms [21, 22]. EDCs as their name implies causes abnormal endocrine activities and increase cancer risk in human. Their effects on aquatic lives may range from endocrine system disruption through the reduction in eggs and sperm cells production to feminization of female aquatics [23–25].

2.3. Salvaging the aquatic environment: demands and expectations

Water is one important part of our day to day activities and their preservation can never be overemphasized. Three quarter of the fluid in man is made of water and it forms the essential medium in which the biochemical reactions take place in human body. Water moves blood from one place to the other in the body and helps in digestion; electrically charged ions, which generate nerve signals that make the human brain possible, are also held and transported by water. Water is a good solvent and it is usually referred to as universal solvent; all the major components in cells, that is, protein, deoxyribonucleic acid (DNA) and polysaccharides are all soluble in water. Pure water is tasteless, odorless, and transparent and thus provides a habitat for aquatic plants and organisms because sunlight can reach them within the water. Though clean water is a vital commodity for the well-being of human but unfortunately, the availability of fresh water is unevenly distributed and greatly threatened where available due to problems associated with climate change, inefficient water management and pollution. Recent report says very high percentage of the world population still lacks water for human well-being and ecosystem conservation [26]. The world is faced with the dilemma of achieving balance between economic development and sustainable natural environment.

Effective wastewater treatment has been earlier identified a way of protecting the water environment with detailed discussion on effective, cheap, and accessible method of wastewater treatment [27]. Various other methods of water purification such as forward and/or reverse osmosis [28–31], precipitations [32, 33], coagulation [34–36], filtrations [37–39] modular anaerobic system [40], microbial fuel cell [41], and advanced oxidation process [42] with their attendant challenges have been reported in literature.

Various environmental policies stipulating discharge protocols exists. These policies are however not effectively executed as the industries consider them as damaging to business. The ability of industries to run with the various environmental discharge policies will sustain our natural environment.

Policy integration, that is, factoring environmental issues of concern into the core of economic development, is highly important to facilitate policy performance. The main actors in environmental issues, that is, the industries, agro firms, and populace, show very little understanding of the impact of their activities on the present and future environment. While organized periodical training concerning environmental sustainability should form part of environmental policy objectives, ensuring that these objectives are integrated into sectors plains and policies is important.

3. Microbial perspective of water pollution and remediation

Drinking water supplied to our communities is usually sourced from rivers, springs, and underground sources. Usually, some form of treatment is carried out to ensure the water is fit for drinking although some sources are somewhat free from contaminating microorganism and can be clean, for example deep well. In many developing countries, one source of water can serve many uses such as drinking, washing, swimming, bathing, etc. In the same vein, sewage can be channeled into water bodies. Sewage can be defined as used water draining out of homes and industries that contain a wide range of debris, chemicals, and microorganisms. Such water is regarded as potential health hazard to consumers or the users of other sort. A major kind of hazard is the presence of pathogenic organisms in such water. This is why water is usually treated in three phases [43, 44].

The first is to separate large matter in the water source and the second stage focuses on removing more toxic substances and other matter. The tertiary phase involves total purification of water commonly by chemical disinfection. More recently, membrane bioreactors are being used and have been found to be very efficient in removing contaminants. These are combinations of communities and high-efficiency membranes that are much more effective at removing contaminants. The role of microbes is obvious in the second stage where microorganisms actively carry out biodegradation of organic matter in the aqueous portion produced after the first stage. Biodegradation of materials, such as paper and petroleum, are by bacteria, algae, and protozoa. When water is exposed to air, soil as well as effluents, it gains saprobic microorganisms; it can also pick up pathogens such as *Cryptosporidium*, *Campylobacter*, *Salmonella*, *Shigella*, etc.

To monitor water for each of these pathogens may not be possible but detection of fecal contamination is an easier way of spotting contamination. In such case, when the fecal contamination is high, pathogens are believed to be present and the water is unsafe for drinking. Hence, indicator organisms are used as tools to detect fecal contamination of water. They usually inhabit the intestine of mammals and birds and can be easily identified using common laboratory procedures. To achieve water protection, it will be almost impossible to search for the pathogens themselves. Hence, certain organisms with specified criteria are used as ‘indicators’ of the presence of enteric pathogens in a water sample. An indicator bacterium should be applicable for analysis of all types of water; it should be found anytime enteric pathogens are present and it should thrive in the wastewater longer than the toughest enteric pathogen. In addition, such organism should not reproduce in the contaminated water because this will give exaggerated values and it should not be harmful to human begins. Other criteria are that the level of contamination should be directly proportional to the level of fecal contamination; assay procedure for the indicator organism should be highly specific and the test procedure should be easily performed.

The following are commonly used as indicators of fecal contamination in water: total coliforms, *Escherichia coli*, fecal coliforms, fecal streptococci/enterococci, coliphage, and *Clostridium perfringens*. Coliforms are members of the family Enterobacteriaceae (they include *E. coli*). They are facultative anaerobic, Gram-negative, nonsporing, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C [45].

Microbial contamination of water can be detected by checking for certain organisms including heterotrophic bacteria, coliforms, and *Escherichia coli* in such samples. The work by Kora *et al*. [46] showed that heterotrophic bacteria were in abundance in the lake water sampled. They also reported that contamination by *E. coli* and coliforms were beyond the allowable limit; indiscriminate disposal of sewage into water as well as release of human excreta was implicated in the high level of indicator organisms.

Control of pathogens in water is important to prevent waterborne diseases; this can be effectively done using multiple barrier approach. Microbial treatment methods goes further than traditional municipal wastewater treatment, because it takes into consideration the removal of nutrients (e.g., nitrate and phosphate) and easily degradable organic compounds as well as the possible presence of toxic compounds and variations in pH of the wastewater. A more advanced design is required in the bioreactor to be used. Some parameters to be considered in designing a treatment system are biomass yield, nutrient addition, the supply of oxygen or other electron donor, pH control as well as kinetics, that is, biological reaction rates (biotransformation). It is important to note at high concentration many compounds of interest are toxic to bacteria being used for treatment. Also some dissolved organic and inorganic compounds may constitute inhibitors to biodegradation by the organism. Biological treatment processes may not consist of the following—lagoon treatment, activated sludge as well as fixed film bioreactors.

The lagoon treatment is long-detention time basins; but unlike activated sludge processes, they do not use solid recycle. Such treatment scheme may be in three categories: anaerobic lagoon treatment, which makes use of highly loaded lakes creating anaerobic conditions. It has been used successfully for the pretreatment of meat and poultry processing wastewater reducing the biochemical oxygen demand considerably [47].

In the case of facultative ponds, there is an aerobic surface and an anaerobic bottom. The top aerobic layer facilitates treatment of dissolved organic compounds as well as odourous compounds. This has found application in pulp and paper industries. With regards to aerated lagoons, oxygen is provided by mechanical means or diffused aeration and the solids are continuously mixed and in suspension. Biological oxygen demand (BOD_5) removal may range up to 95% [48].

Another biological treatment process of interest is the activated sludge. It is made up of an aeration basin where aeration equipment provides both oxygen and adequate mixing of wastewater to maintain a uniformly mixed liquor suspended solids (MLSS). The aeration basin is followed by a liquid–solid separation usually in a clarifier by gravity and finally the settled biomass is returned again to the activated sludge basin. Examples of aeration basin configurations are – plug-flow systems, single completely mixed basins, and basins in series. The solid retention time (SRT) is important in this treatment process. The solid retention time is the average time biomass is maintained in a biological treatment process reaction. Generally, SRT control is temperature dependent and for a warmer climate (15–25°C), SRT should be between 4 and 9 days [49]. The clarifier is very important in the performance of activated sludge processes. It ensures that efficient clarification and thickening of mixed liquor occurs. When the readily degradable soluble biochemical oxygen demand is high in wastewaters, growth of filamentous bacteria is encouraged leading to poor sludge settlement. The use of powdered activated carbon (PAC) has been discovered to enhance the efficiency of activated sludge processes. The PAC functions by adsorbing inhibitory chemicals or adsorbing chemicals that buffer variable loads. The application between 10 and 50 mg/liter of wastewater has been proven to remove organic inhibitors of the process as well as improve nitrification since it absorbs organic compounds that can prevent this process (ammonia-nitrite/nitrate conversion) in autotrophic bacteria [50].

Apart from the aforementioned, anaerobic bioreactors are also beneficial for the industrial wastewater treatment. This is because it is cost effective and can be used for industrial wastewater with high strength. The processes in the anaerobic bioreactor lead to the production of mainly methane as well as other gases. However, there is a need to strike a balance between fermentation bacterial activity and methanogenic bacteria activity as the latter is slow growing. Advantages of anaerobic treatment include low sludge formation, production of useful product, low nutrient requirement, and more importantly less energy requirements since aeration is not necessary. In addition to the energy production, advantages of anaerobic wastewater treatment, high organic matter removal efficiency, low excess sludge production, and stable operation are characteristics of this wastewater treatment technique [51].

A most recent advancement in the biological treatment of wastewater is the use of membranes in bioreactors. In such cases, the membrane can serve three major purposes. Firstly, membranes can be used as a surface for the attachment for growth of organisms and to permit oxygen to permeate into the biofilm. An example of this is the hollow-fiber gas-permeable membranes in wastewater treatment. Such membrane is produced from microporous, hydrophobic polypropylene and allows almost 100% oxygen transfer while ensuring high biomass density within the space. The second way membranes can be used as selective barriers. Such membranes permit organic compounds in wastewater to permeate but do not transport ions into the bioreactor. Thus, it allows for the selection of biodegradable organic compounds. An example of a material used for such membrane is silicone rubber. Finally, membranes can be for biomass separation. This third category requires that the membrane be used instead of a clarifier after activated sludge treatment. When such membranes are used, the effluent produced is of high quality and less sludge. In addition, automated processing can be easily employed. The disadvantage however is the financial enormity of the investment for initial start-up as well as maintenance [50, 52, 53].

3.1. Monitoring water distribution systems

Since coliform bacteria are often detected in drinking water and often, the source of contamination is not known, it is important to put in place control measures. The water distribution systems must be considered because water quality deterioration (i.e., negative quality changes that occur from the point of distribution to the point of detection) may occur. This can be as a result of reduced maintenance of the distribution system or from insufficient treatment and may lead to undue microbial growth, which the consumer may not notice. Water distribution systems should be periodically flushed to remove sediments, deposits as well as the growth of microorganisms within the pipe. For areas where the flow rate is low and possibly of the water becoming stale is high, a secondary disinfection using monochloramine and proper maintenance should be carried out in such as to prevent nitrification. Another point is to avoid a break in the distribution system especially during construction, repairs or installations, and cross connections. The officers should also ensure that the level of treatment a water sample is given is in conformity with the quality of the source of water. Also, the sampling for laboratory analysis must also be taken into consideration and monitored thoroughly when aseptic techniques are compromised, detection of coliforms may occur.

Even though reports of water diseases have been low and less serious in most developed countries, it is still a major concern in some underdeveloped countries especially war-ravaged countries. It is however important to operate a multibarrier approach, which will ensure protection of the water source, and also certify adequate treatment and distribution of water. It is however important that every occurrence of coliforms in drinking water be properly investigated so that if the contamination is as a result of operational deficiency, this can be addressed and future occurrence is prevented, thus safe guarding the health of the public [54].

3.2. Herbal disinfection of water

Several modern methods of water purification have been well embraced in our society today. However, some rural dwellers who may not be able to afford these modern treatment methods still have water pollution as a major challenge [55]. Furthermore, the disinfection by-products which remain after treatment is another reason why herbal attempts in water treatment should be encouraged.

It is important to note that not many researchers apply their antimicrobial extract or fractions directly in water treatment. Many groups stop at establishing the antimicrobial potential of their study plant, whereas others go further to apply the extracts in water treatment. For instance, a reported work used alcoholic, aqueous, and fresh juice extracts of *Ocimum sanctum* (tulsi) and *Azadirachta indica* (neem) and applied them in vitro against salmonella, which was chosen as an indicator organism. The alcoholic extract gave the best result for well water, whereas the aqueous extract was best for lake water [56]. Similarly, inspired by the fact that tulsi, neem, and amla are used to treat microbial infection without any side effect, another researcher compared the effectiveness of these three herbs in water purification, using percentage of *E. coli* removal to measure the effectiveness of each herb. A notable observation is the fact that a mixture of 1% concentration of each herb is not as efficient as the synergistic combination of the three [57].

An indirect application of herbs in water purification is their use in the synthesis of nanoparticles, which are afterwards applied to remove contaminants from water [58]. These extracts influence the surface properties of the nanoparticles, thus dictating their unique properties Owing to the obvious advantages of natural disinfection, there is a need for more research into natural products for water purification. This will in no small way help rural dwellers to cheaply assess cheap clean water and so live a healthier lifestyle.

4. Water pollution and impact on climate

All organisms, including man need water for their survival. Water resource managers had strongly depended on wastewater treatment in ensuring that the quality of water is sustained, preserved, and maintained for optimal use. By 2025, an estimated around 5 billion people out of a total population of around 8 billion will be living in areas of water stress [59]. One of the major environmental issues affecting humanity is the increasing worldwide contamination of freshwater systems as a consequence of industrial and chemical compound materials being emptied into their pathways/runways, majorly in form of micro-pollutants. According to Schwarzenbach et al. [60], most of these pollutants are present at low concentrations, many of them however can raise significant toxicological concerns, more importantly when such compounds are present as constituents of composite blends. Numerous micro-pollutants had been identified in literatures [61–64], which are not vulnerable to current treatment and are subsequently transported to the aquatic environment. Some of these include steroid hormones, pesticides, industrial chemicals, pharmaceuticals, and many other emerging materials. This consequently endangers both the aquatic and human life. It is therefore not surprising that freshwater pollution is a strong public menace, which requires global concern. The next quotation properly situates the environmental risk humans are exposed to:

> *"It is in the interest of all the world that climatic changes are understood and that the risks of irreversible damage to natural systems, and the threats to the very survival of man, be evaluated and allayed with the greatest urgency"[65]*

The above quotation were the statements of the President of the Republic of the Maldives, His Excellency Maumoon Abdul, Gayoom, during the United Nations General Assembly held in 1987 in the United States of America, as adapted from the (World Health Organization Geneva Report) [66]. The meeting was centered on Issues of Environment and Development. Due to climate change effect, both the thermal and hydrological phases of rivers are expected to vary. Owning to these, it is necessary to briefly discuss what climate change is as climate change has the potential of imposing additional pressures in some regions of the world.

4.1. What climate change is

In other to get a good grasp of what climate change is, it may be better to first define climate. Climate is usually narrowly defined as the average weather, or broadly, as the statistical description in terms of the average and variability of relevant parameters or quantities of interest over a period of time, ranging from days to millions of years. Most often, the parameters often used are temperature, precipitation, wind, etc. Climate can therefore be generally described as a state, including statistical description, of the climate system.

Climate change, on the other hand, often referred to as global warming, is the rise in the average temperature on the Earth's surface. It is well believed that the climate change event is as a consequence of human use of fossil fuels, which consequently releases carbon dioxide (CO_2) and other greenhouse gases into the air. These gases trap heat within the earth's atmosphere and can have a variety of effects ranging from rising sea levels to severe weather events. Green et al. [67] had submitted that global climate change can include natural and anthropogenic influences on terrestrial climate and the hydrologic cycle. Most notable international scientific community had actualized the reality of climate change. Some of these include the National Aeronautics and Space Administration (*NASA*), the National Oceanic and Atmospheric Administration (*NOAA*), and the Environmental Protection Agency (*EPA*) of the United States, to mention a few. These agencies further reiterated that climate change is a menace created from human activity to affect human. **Figure 1** adapted from World Health Organization Geneva Report [66] revealed that all the major activities of global climatic changes eventually bore its consequence on human in general and on human health in particular.

However, pressures and anxiety on the Earth's climatic system are having impacts on the surface of the Earth. Apart from the rising surface temperatures, the activities of increasing and frequent flooding and droughts and the changes in our natural water ecosystem are other areas of great concern in the continuous existence of man on Earth. According to WHO Geneva Report [66], climatic situation and activities affect human well-being both directly and indirectly. The direct influence is through the physical effects of climatic extremes, whereas the indirect means include the influence on the intensities or level of pollution in the air, on the marine and freshwater systems that provide food and water, as well as the pathogens that cause infectious diseases. For the purpose of this section, we concentrate on the climatic activities with respect to water pollution. This will lead us to the next sub-section.

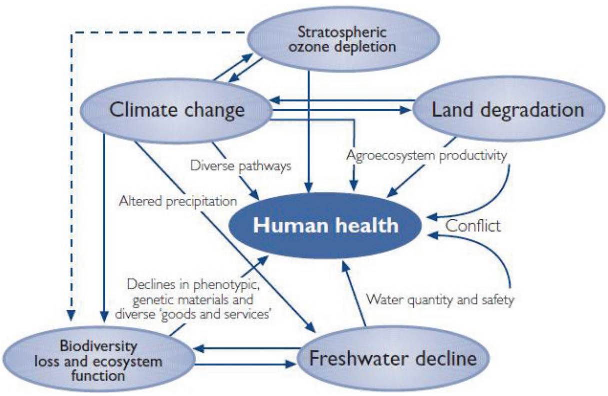

Figure 1. Inter-relationship between various kinds of environmental change. Adapted from WHO Geneva Report [66].

4.2. Probable link between water pollution and climatic impact

> *"Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems"*

- Excerpt from the executive summary of the technical paper of the IPCC edited by Bates et al. [68]

Human activity affects weather, climate, and the environment. While some of human activities are harmless, others damage the environment. While the environment can absorb some abuse without long-term effects, much harmful human activity exceeds the environment's capacity to recover. Water pollution is one of the inevitable human-induced climate change issues that called for urgent remedial measures. Water pollution will in no small measure affect or alter the basic water quality parameters comprising the micro-pollutants, physiochemical, and biological parameters [69]. Probable and incessant changes in both rainfall and air temperature has the capacity to affect river flow thereby inducing chemical reaction kinetics as well as drop in the freshwater ecological quality. Associated with such process are dilution of contaminants and water sediment loads, which when ran into lakes will alter its natural features and affect its inhabitants. This form of water pollution or through man-made toxic chemical or/and by-products addition may therefore generate some toxic and greenhouse gases, which may subsequently contribute to global warming activities or more severe environmental threats.

The greenhouse gases are the gaseous constituents of the atmosphere (both natural and anthropogenic), which can absorb and emit radiation at certain wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, the atmosphere itself, and the clouds. The primary greenhouse gases in the Earth's atmosphere include carbon dioxide (CO_2), nitrous oxide (N_2O), water vapor (H_2O), methane (CH_4), and ozone (O_3). The other ones identified from the Kyoto Protocol include hydrofluorocarbons (*HFCs*), perfluorocarbons (*PFCs*), and sulfur hexafluoride (SF_6). Some of these environmental threats include earth's temperature enhancement (as earlier stated), lowering of atmospheric air quality, and killing of aquatic animals. Consequently, given the legacy of historic greenhouse gas emissions and the prospect of inevitable climate change, one cannot but commit significant financial and technical resources to remediating the effect through rigorous research efforts and sensitization activities [70], more importantly to water pollution and water-related issues. Thus, water resources managers are continuously and increasingly looking for information on the possible changes in hydrological regimes, which may arise in the next few decades for likeable adaptation measure plan [68].

An interesting challenge is that while incessant water pollution may bring about a change in climatic conditions through greenhouse effect and activities, the climate too will in turn take its toll effect on the water system and environment (hydrological cycles). This is because the higher temperature generated from the greenhouse effect will eventually turn some part of the snowfall into rainfall, causing an earlier snowmelt season [71]. These effects will consequently alter the timing and volume of spring flood appreciably. The rise in sea level during this time will then cause saline water intrusion into groundwater aquifers close to the coast thereby reducing the available groundwater resources. This process will in no small measure affect humans as almost about 50% of the world population depends on groundwater for their various activities [72]. Mitchelle et al. [73] using physically hydrological and water temperature modeling framework had reported an increase in the seasonality of river discharge for about 35% of the global (consisting of all continents) land coverage for the projected and modeled data for years 2071–2100 when compared with the years spanning 1971–2000. They also projected a rise in temperature—revealing a projected global change into the future. Other effects of climate change on the hydrological cycle include increasing atmospheric water vapor content, changes in soil moisture and runoff, and changing precipitation patterns [74]. Furthermore, higher temperatures of freshwater and changes in extremes, including floods and droughts can also intensify many forms of water pollution. The authors also showed that water fluctuation in quantity and quality has the potential of affecting food stability and availability—leading to a reduction in food security to vulnerable poor farmers.

4.3. Water pollution remediates measures against climate change

Almost 20% of the entire population of the Earth do not have adequate access to safe water, while about 40% suffer the effects of deplorable sanitary situations [75]. Schwarzenbach et al. [60] had submitted that the increase in surface/groundwater pollution will go a long way in affecting both the human and aquatic life systems. According to Schwarzenbach et al. [60], about 35% of the Earth's available and renewable freshwater are used for industrial, domestic, and agricultural purposes. However, if this activities are not well managed, water pollution may be inevitable with different kinds of pollutants. Some of the water pollutants according to the authors include industrial chemicals (e.g., solvents and petrochemicals), biocides (e.g., pesticides and nonagricultural biocides), natural chemicals (e.g., heavy metals and cyanotoxins), industrial products (e.g., additives and lubricants), as well as consumer products (e.g., detergents and personal care products). Industrial manufactured nanomaterials had also been found to be a major water pollutant whose effects is on the increase in affecting aquatic ecosystem [76]. According to Lapworth et al. [77], groundwater pollution mainly results from landfill leachate, infiltration of contaminated water from agricultural land, groundwater-surface water reaction, as well as seepage of sewer systems. While some of these pollutants, like heavy metals, are not degraded at all, some others disintegrated very slowly and can be transported to hundreds of kilometers away from the source. The effects of their waterborne pollution however ranges from contamination of drinking water causing drinking water quality problems to emission of greenhouse gases, resulting in climatic change challenges.

Some remediate climate change mitigation measures against water pollution can however be taken. Some of these include carbon dioxide capture and storage, planting of bio-energy crops, proper solid waste disposition, afforestation or reforestation, cropland management–both for water and reduced tillage [74] among other measures. Scientific researches involving water pollution should be geared more toward ascertaining the physical underlying molecular mechanisms and factors rather than just the usual empirical comparison approach that is commonly used. The mechanisms involved if well understood will go a long way in properly situating ways of combating the water pollution challenges. This according to Metz and Ingold [62] may be achieved by developing a structure that addresses both the problem dimension (causes and effects) and sustainability dimension (long term and cross-sectoral) of assessing best instruments that regulate water pollution. A sustainable working policy on water pollution should not only be designed and enacted but also rigorously followed, more importantly in the developing and underdeveloped countries where the menace of water pollution has not been effectively managed. Bemelmans-Videc [78] had presented a classification for effectively managing water pollution. These are (i) regulation (i.e., substance ban and authorization restriction) (ii) economic instruments (i.e., product or substance charge—in which case a charge is levied on substances that contains hazardous compounds with the aim of reducing its use), and (iii) information (e.g., disposal requirements and information campaign). These Bemelmans-Videc [78] classifications according to Metz [63] would help in differentiating source-directed measures from end-of-pipe measures in water quality regulation. While the source-directed measures help in avoiding pollution before toxic and injurious chemical materials enter into waters, the end-of-pipe measures concentrate on filtering pollution after its input into wastewater.

Furthermore, usage and disposal approaches should be in place with the aim of minimizing the addition of critical pollutants into aquatic environment. In addition, such system-specific properties and reactivities (like adsorption to solid phases and abiotic/biological transformations) should be well understood and quantified. This kind of processes will yield a significant framework for reliable coverage and evaluation of chemical compounds in complex macroscopic ecosystems [66]. Other alternative methods for removing pollutants from waters include ozonation and advanced oxidation process (AOPs), coagulation-flocculation, membrane bioreactor, *PAC*, and attached growth treatment processes. Refer to the work of [61] for comprehensive reading on the methodology and activity of each process. It can therefore be concluded that whatever form of measure taken in inhibiting both surface and groundwater will not only advance our aquatic ecosystem, but will also help man from further endangering his environment from the menace of climate change.

5. Conclusion

Since water forms a core of the existence of human and other living things, its preservation and sustainable availability cannot be overemphasized. The availability of clean water is greatly threatened by various human activities and of interest is pollution which in turn affects the ecosystem and causes various climatic changes. While various wastewater treatment methods are being explored by industries and various treatment plants, untreated wastewater is still being discharged into the water bodies by some industries. Thus, effective environmental protection policies compliance drive will be of immense benefit to the environment and by extension to human. Factoring these environmental protection policies into the goals and objectives of various actors involved in environmental deterioration will help policies performance. This will serve as a step forward in the direction of ameliorating water pollution.

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