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THE MENACE AND MITIGATION OF AIR POLLUTION IN THE BUILT ENVIRONMENT:A REVIEW

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Abstract
Air pollution has become one of the leading causes of death globally. This paper investigates the causes as well as sources of air pollution in the indoor and outdoor environment. It identifies anthropogenic activities related such as transportation and other activities involving the combustion of fossil fuel as the major causes of air pollution. The several and diverse health implications of air pollution were highlighted. The dangerous nature of carbon monoxide was x-rayed and the common indoor and outdoor sources were discussed. The risks of carbon monoxide poisoning from generator fumes and vehicle exhaust were clearly enumerated. Particulate matter (PM_{10}, $PM_{2.5}$ and ultra fine PM) were clearly shown to be the major casue of chronic and fatal respiratory and cardiovascular diseases. Indoor air quality, which is usually overlooked was brought to the fore and shown to be worse than outdoor air quaility in some cases, especially where ventilation is poor. The inextricable link between air pollution and climate change was also established. Mitigative measure such as policies/acts, replacement of fossil fuel with solar PVs, replacement of conventional vehicles with electric vehicles and establishment of urban forests were discussed. Frequent and evenly distributed air quality monitoring, especially using android-enabled portable devices was broached. Besides, policies and other global approaches, individuals must adopt personal protective measures to protect themselves from the menace of air pollution.

Keywords: Air, Health, Fossil fuels, Emissions

1.0 INTRODUCTION

Air forms a critical component of man's existence and continued survival on the planet. It is the most important but the most neglected aspect of our daily lives. Naturally, humans drink in ten of thousands of litres of oxygen daily without as a matter of reflex. Most people are hardly ever aware that they are breathing until they begin to have difficulty doing so. The average person takes in 7 to eigth litres of air per minute and a total of about 11,000 litres of air per day [1]. Air is basically a mixture of three main gases namely: Nitrogen (78%), Oxygen (21%) and 1% of others – Ar, CO_2, etc (Figure 1) [2][3]. The uniqueness of the earth as a the only planet that can support life is partly based on its atmosphere which has the perfect combination of gases for life support. Oxygen supports life through the process of respiration, CO_2 supports plant life through photosynthesis (Figure 2) while Nitrogen regulates combustion. Besides, the gases in the atmosphere shield the earth from the dangerous effects of solar radiation. Human beings breathe in the entire spectrum of air mixture and exhale 78% Nitrogen, 16% Oxygen, 4.4% CO_2 and traces of thousands of other gases [3][4][5]. An average person can go without food for about three weeks and without water for about 3 days, but if a person is deprived of air for about six minutes, the brain would suffer irrepairable damage and death will set in [1][6]. This shows that the life of humans is intricately tied to oxygen. The average cost of oxygen in Nigerian hospitals is about #4,500 per hour, which translates to #108,000 per day, #3.24 million per month and approximately #2 billion for a period of 50 years.

2.0 AIR POLLUTION

As a result of natural and mostly anthropogenic factors, significant changes in air composition can occur either momentarily or over a prolonged period. Air pollution is therefore:

(i) the emission of alien substances into the atmosphere

(ii) emission of atmospheric gases into the atmosphere thereby causing a distortion in baseline air composition

(iii) Emission of gaseous substance into the atmosphere causing a build-up in their concentration beyond natural or guideline concentrations.

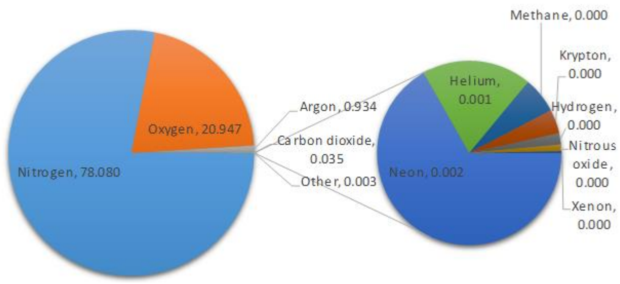

Figure 1: Composition of air, showing only the major constituents [2][3]

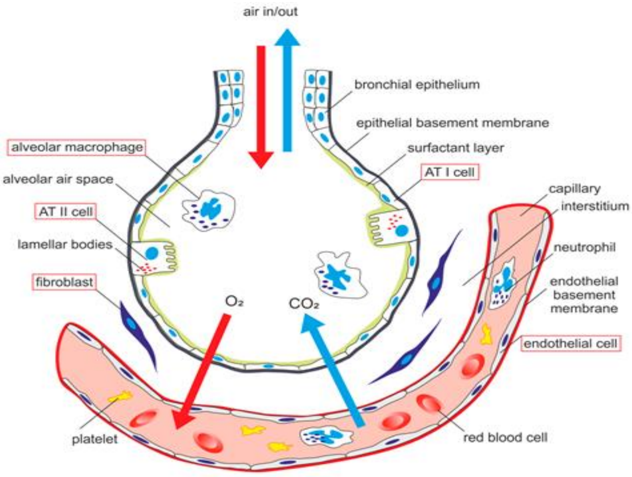

Figure 2: Gas exchange in the alveoli [7]

Air pollution is a global phenomenon which has gradually assumed a cataclysmic dimension. Though air pollution takes place on a local scale, its effect is usually felt on a global scale. No country of the earth is free from air pollution. However, the burden of air pollution has exerted the greatest toll on the poorest countries of the world most of which are in sub-Saharan Africa. New data from World Health organization (WHO) [8]; Four of the twenty most polluted cities are in Nigeria, Pakistan, India and Saudi Arabia have three each, while Afghanistan and Bahrain have two each (Figure 3). Onitsha Nigeria is the most polluted city in the world with PM_{10} concentration which is about 30 times the recommended ambient concentration. Air pollution is so dangerous because most people are either ignorant or unaware of it. This is partly because some of the most toxic air pollutants are odourless and colourless. And even, when they have characteristic colour and smell, most people will not be able to associate the smell or colour to these poisons. In some other cases, the odor threshold may be too high to detect at low concentrations. One of the deadliest air pollutants is carbon monoxide – a colourless and odorless gas emitted from vehicle and electric generator exhaust – which can kill within a few minutes.

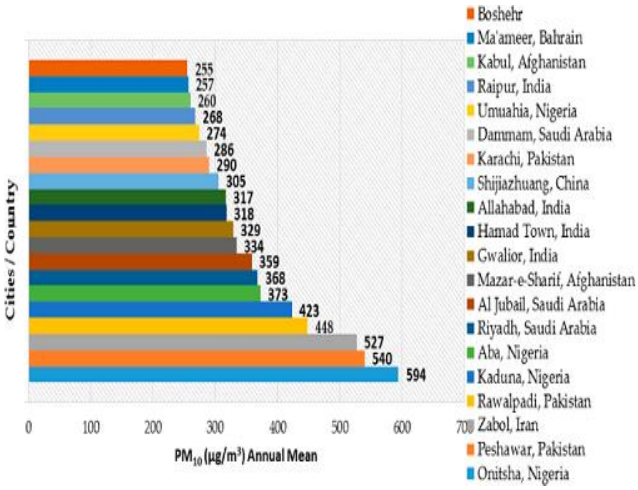

Figure 3: Twenty most polluted cities in the world as ranked by WHO [8]

2.1 Types of Air Pollutants and Causes of Air Pollution

Air pollution has been attributed to rapid population growth, urbanization, industrialization, increase in energy demand, deforestation and increase in automobile. It has been established beyond reasonable doubt that industrialization/urbanization is the root cause of the twin and intricately linked tragedy of ***air pollution*** and ***climate change***. Rapid urbanization means that we are now exposed to unhealthy concentrations and more diverse variety of ambient air pollutants [9]. Urbanization automatically triggers a change in lifestyle that exerts a negative toll on the environment and the entire ecosystem. Hence, the cumulative effect of aggressive urbanization and development of megacities worldwide has caused an irreversible paradigm shift in the environment whose repercussion will last for decades to come. Specific activities that cause or aggravate air pollution include emission from automobiles (especially old and poorly-maintained ones) coal-powered plants, construction activities, foundries, smelting, tobacco use, mining, use of agricultural chemicals, etc. The range of specific causes of air pollution is so wide that the list is almost inexhaustible. Table 1 shows a summary of the different types of air pollutants, its chemical composition, its sources and the threshold it must not exceeded according to the WHO guideline.

Air pollution is classified as follows:

Primary/Secondary

Primary pollutants are those pollutants that are directly released in to the atmosphere, such as CO, SO_2, NO_x, PM (Figure 4).

Secondary pollutants are those that are formed in the air as a result of chemical reactions with other gases, such as O_3, NO_x.

Indoor/Outdoor

Indoor pollutants are those gases which are generated within the home by *cooking, particle resuspension, building materials, air conditioning, consumer products, smoking, heating, biological agents.* The specific pollutants resulting from these are CO, CO_2, PM, VOC, organic dust, radon, microbial agents.

Outdoor pollutants are those gases which are in industries, commercial premises, agriculture, transportation, etc(Figure 4). The specific pollutants resulting from these are CO, CO_2, NO_x, O_3 PM, VOC, organic dust, radon, microbial agents

Gaseous/Particulate

Gaseous pollutants are gaseous products of all activities giving rise to air pollution. Such gases are SO_2, CO_2, CO, VOC and O_3.

Particulate pollutants are small particles emitted into the air. They are in three categories: PM_{10} (<10 μm), $PM_{2.5}$ (< 1.5 μm) and ultrafine PM (< 0.1 μm)

2.1.1 Natural causes

Air pollution is not entirely caused by anthropogenic activities. Localized and sporadic air pollution episodes can be attributed to natural sources such as dust from earth surface (PM), sea salt (PM), pollen (PM), spores (PM), plants or animal debris (PM), volcanic eruption (PM), thunderbolt (NO_x), algae (H_2S), wind erosion (PM). Air pollution generated by natural processes are nearly insignificant and short-lived compared to air pollution triggered by anthropogenic causes [10]. The earth has the inbuilt capacity to accommodate minor levels of air pollution caused by natural process. On the contrary, there is sufficient evidence that the earth has been struggling to cope with the myriads of fumes spewed up by man in an ever-increasing quest for the easy life [10]. For instance, the CO_2 exhaled by living things is taken up by photosynthetic plants, thereby maintaining the atmospheric CO_2 at its natural level. However, CO_2 resulting from anthropogenic activities, especially burning of fossil fuel, has resulted in over 25% increase in atmospheric CO_2 concentration since 1960, giving rise to global warming [10][11].

2.1.2 Combustion as the primary anthropogenic culprit

Several domestic, commercial and industrial activities involve the burning of one form of fuel or another, giving rise to CO_2, NO_2, CO, SO_2, particulate matter (PM) and soot. Major activities involving combustion are: transportation, powering of industrial machines, incineration/burning of waste, burning of biomass for cooking, use of electric generators in homes, forest fires, power plants, cooking, etc. Transportation emission is the largest singular cause of air pollution (Figure 4). Children who are living within 100 m of a freeway experience significantly more wheezing, coughing, running nose and asthma [12]. The picture looks grimmer considering that there are over sixty million electric generators in private homes [13] and about twelve million automobiles on Nigerian roads pumping hundreds of air pollutants into the atmosphere [14].

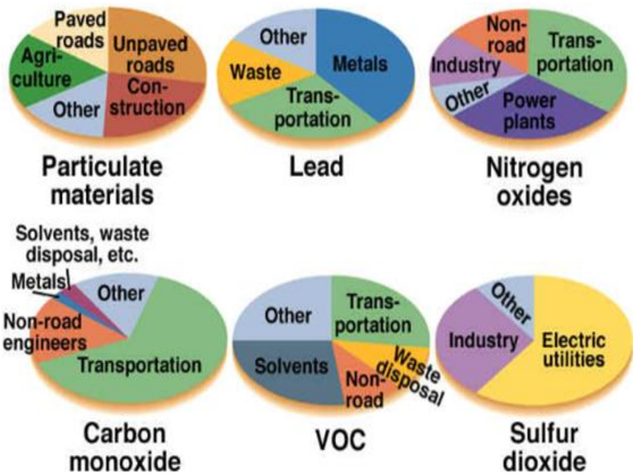

Figure 4: Primary air pollutants and their sources [14]

It has been established that burning of biomass in open fires or traditional stoves increase indoor concentration of PM to a level that is far beyond corresponding outdoor concentration [9]. Besides emission of gases, combustion also releases significant amounts of particulate matter into the atmosphere. It has been estimated that over 75% of Africans cook by burning one form of biomass or the other [15]. Nigeria ranks 13th for biomass burning worldwide [16]. Automobiles contribute over 90% of

CO, 25% of PM, 40% of NO_x and 35% of VOC in the air.

Table 1: Common air pollutants and their sources

Pollutants	Source	Chemical Composition	Characteristics	Odor threshold	WHO Guideline value [17] (inclue dsourse)
Sulphur dioxide	• Burning of coal • Volcanic eruptions • Smelting • Oil refinery • automobiles	SO_2	• Colourless • soluble in water • Harsh, irritating smell	0.67 – 4.75 ppm	20 μg/m^3 (24-hour mean) 500 μg/m^3 (10-minute mean)
Nitrogen dioxide	• Burning of coal and gas • Automobiles • Lightening • metal refining	NO_2	• Reddish-brown • soluble in water • Odorless and odorless at low concentrations	0.1 – 0.4 ppm	40 μg/m^3 (annual mean) 200 μg/m^3 (1-hour mean)
Ozone	• Reaction of NO_x and VOC	O_3	• Colourless • Highly irritating • Soluble in water • Unstable • Sweet smell	-	100 μg/m^3 (8-hour mean)
Hydrogen Sulphide	• Wastewater treatment • Solid waste dump • Oil refinery • Volcanoes • Oil and gas exploration • Paper and pulp manufacture	H_2S	• Rotten egg smell • Colourless • Odorless • Soluble in water	0.5 ppb	7 μg/m3, (30-minute average)
Carbon monoxide	• Gas flaring • Electric generators • Automobile • Gas stove and oven • Biomass burning	CO	• Colourless • Odorless • Sparingly soluble	-	
Particulate Matter	• Gas flaring • Electric generators • Automobile • Gas stove and oven • Biomass burning • Forest and waste dump fires	Diverse	•	N/A	**$PM_{2.5}$** 10 μg/m^3 (annual mean) 25 μg/m^3 (24-hour mean) **PM_{10}** 20 μg/m^3 (annual mean) 50 μg/m^3 (24-hour mean)

3.0 IMPACT OF AIR POLLUTION

3.1 General Health Impacts of Air Pollution

There is no gainsaying the fact that industrial revolution has brought much ease and comfort to man, but has also left irreparable damage in its wake. There is a very high correlation between industrialization and urbanization on the one hand, and the spate of deadly diseases on the other. While some of these diseases are caused by microorganisms, many are caused by physical and chemical factors or a combination of the two. Air pollution has been identified as a leading cause of myriads of adverse health conditions, and the fourth or third leading cause of death worldwide [18][19][20]. At first, when the deadly nature of air pollution was still unknown, it was said that the city of London was so well known for its dark smokes that even poets drew inspiration from it. However, the story changed in 1952 when 1000 persons died in a period of five days due to a bad smog precipitated by extreme levels of SO_2 and smoke. The latest UN report shows that 800 persons die of air pollution every hour, amounting to 19,200 deaths every day. Figure 5 adapted from WHO (2018) and modified shows that four of the ten top causes of death globally are directly or indirectly linked to air pollution (Figure 5). In fact, Kelly and Fussel [9] reported that air pollution has overtaken poor sanitation and lack of safe drinking water as a cause of premature death. Air pollution can trigger a wide range of short term and long term health problems which affect the respiratory system, nervous system, the skin, the heart, the kidney and the eyes (Table 2; Figure 6). Diseases related to air pollution account for two thirds of all life years lost to environmentally related deaths and disabilities. In the ***short term,*** air pollution can cause minor health disorders such as flu, dryness of throat, headaches, dizziness, general weakness and cough; but sustained exposure to polluted air can result in ***terminal or chronic*** health conditions such as cancer, chronic obstructive pulmonary disorders (COPD), bronchitis, emphysema, asthma, cardiac failure, impairment of the immune system and reduced lung function. Air pollution can trigger ***psychological disorders*** or cause complications in persons with pre-existing conditions. Stress, depression, anxiety, irritation, quick temper, mood swings, aggression, violent behaviours and pre-disposition to crime have all been linked to polluted air [21]. The hazards associated with air pollution are so pervasive that not even unborn babies are spared. Air pollution causes enlarged head circumference and reduced birth weight in babies.

Table 2: Health and Environmental Effects of Air Pollution

Pollutants	Nature in air	Health Effects	Environmental Effects
Nitrogen dioxide (NO_2)	Gaseous	• Respiratory irritation • Exacerbation of pre-existing respiratory conditions • Bronchial hyper responsiveness • Decrease in lung function	• Causes acid rain • Combines with VOCs to for ground level ozone
Sulphur dioxide (SO_2)	Gaseous	• Respiratory irritation • Exacerbation of pre-existing respiratory conditions • Decrease in lung function	• Causes acid rain
Lead (Pb)	Particulate	• Neurological damage • Renal failure • Cancers	• Affects plant growth
Particulate matter	Particulate	• Nose and throat irritation • Lung damage • Bronchitis • Stroke • Cancers • Premature death	• Defacing of building facades • Reduction of property value • Discolouration of structures
Carbon monoxide (CO)	Gaseous	• Headaches • Nausea • Confusion • Death by asphyxiation	• Formation of ground level ozone • Oxidizes to form CO_2, thereby causing global warming
Volatile organic compounds (VOC)	Gaseous	• A wide range of cancers • Neurological damage • Reproductive disorders • Birth defects	• Formation of ground level ozone
Ozone (O_3)	Gaseous	• Eye irritation • Respiratory tract irritation • Exacerbates asthma	• Damages plants and trees •

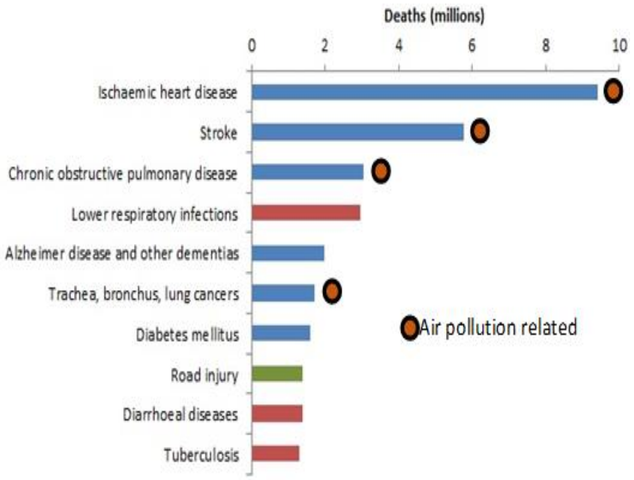

Figure 5: Top ten causes of death globally [22]

In 2015, air pollution accounted for 19% of all cardiovascular deaths, 21% of deaths due to stroke and 4% of deaths due to ischemic heart diseases [23]. Of the 3.7 million deaths caused by air pollution in 2017, 40% was due to ischemic heart diseases, 40% was due to stroke, 11% was due to chronic obstructive pulmonary disease, 6% was due to lungs cancer and 3% was due to acute lower respiratory infections in children. Up to 70% of cancer risks attributable to inhalation of toxic air pollutants arise from diesel exhaust which contains about 40 known toxins, among which are formaldehyde, benzene and arsenic [24].

The World Health Organization [25] reported:

- Average of 4.2 million deaths every year as a result of exposure to ambient (outdoor) air pollution.
- 3.8 million deaths every year as a result of household exposure to smoke from dirty cook stoves and fuels.
- 91% of the world's population lives in places where air quality exceeds WHO guideline limits.

The following air pollution-related health facts about Nigeria is worth mentioning

- Nigeria has the highest prevalence of asthma in Africa [26].
- There has been an increase in cases of lung cancer in urban-based non-smokers aged below 60 [27].
- 94% of Nigerians are exposed to levels of air pollution above the WHO guidelines[28].

Because polluted air is a complex and heterogeneous mixture of a wide range of substances with varying physical and chemical properties, the health impact caused by this combination of substances can be:

- Causative
- Interactive/reactive
- Associative
- Synergistic
- Additive

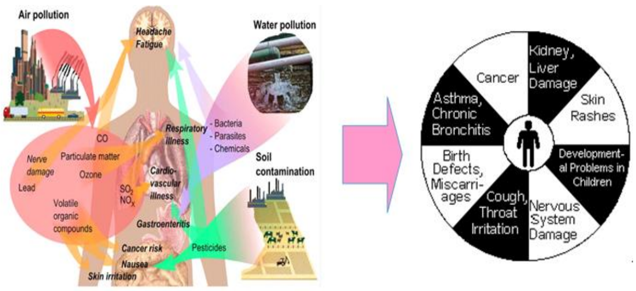

Figure 6: Interaction between air pollution and the human body [29] [30]

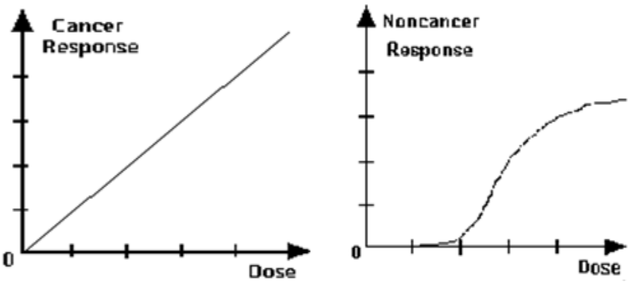

Figure 7: Dose – response curves for air pollutants [29]

The potential of air pollutants to cause harm depends on the dose assimilated, length of exposure, toxicity of the pollutant and the ability of the body to neutralize the toxin. Like many reactive substances, the health effects of air pollutants follow a dose-response pattern. Figure 7 shows that carcinogenic air pollutants follow a linear dose response curve which represents a high risk at low concentration and even more virulent risk at high concentrations. This implies that additional intake of specific air pollutants will produce a corresponding and cumulative damage to the body.

3.2 Carbon Monoxide (CO) – The Silent but Sure Killing Machine

Carbon monoxide is one of the most lethal human poisons emitted by man into the atmosphere, resulting from incomplete combustion. Like most toxic gases, it is colourless, odorless and tasteless, with a similar molecular configuration as oxygen and nitrous oxide. This deadly air pollutant is always in stiff competition with oxygen, and is sure to win almost all the time. The affinity of carbon monoxide with blood (hemoglobin) is 200 times that of oxygen. Hence, when CO is inhaled alongside oxygen, hemoglobin will bind with carbon monoxide as a matter of preference forming carboxyhemoglobin (COHb). CO shuts out oxygen supply to the blood stream and results in asphyxiation. In America, the total annual hospital emergencies due to carbon monoxide poisoning was 40,000 and 400 deaths [31]. Accidental CO poisoning is estimated to result in societal costs of over 1.3 billion USD annually in direct hospital costs and lost earnings in the US [32]. The ugly truth is that this wicked substance is always with us – in our homes, cars, offices, etc.

Figure 8: Generator as an alternative source of power in developing countries

CO poisoning has always been associated with inadequate ventilation for outward diffusion of high concentration of carbon monoxide from living or recreational facilities [33]. The greatest risk of asphyxiation is associated with keeping running generators in the hallway at night [24]. The CO fumes released linger longer after the generator has been shut down. In most developing countries, there is usually a deficit of public power supply, thus necessitating the use of electric generators in homes, offices and the industry. Ziqing [34] observed that lack of access to sufficient and sustainable power supply affects about 85% of people living in developing countries. Hence, ownership of generators in these countries has become almost indispensable both for the rich and poor (Figure 8).

For instance, sixty million Nigerians invest about #1.6 trillion on purchase and maintenance of generators annually [35][36]. Nigeria tops the list of generator-importing countries since 2002 and accounts for 35% of the total amount spent by spent by African countries on generator importation [37]. Companies and businesses must own electric generators to remain in business or close down. Besides being a major source of air pollution, use of generators imposes huge financial burdens on businesses (Figure 9). Given that the combustion process in electric generators is not nearly as efficient as in automobiles, it is expected that the release for carbon monoxide from generators will be higher. Emissions from electric generators are particularly dangerous because of their proximity to the home and high concentration. Akin [36] reported that a 5.5 kW generator emits six times the amount of carbon monoxide emitted by an idling car.

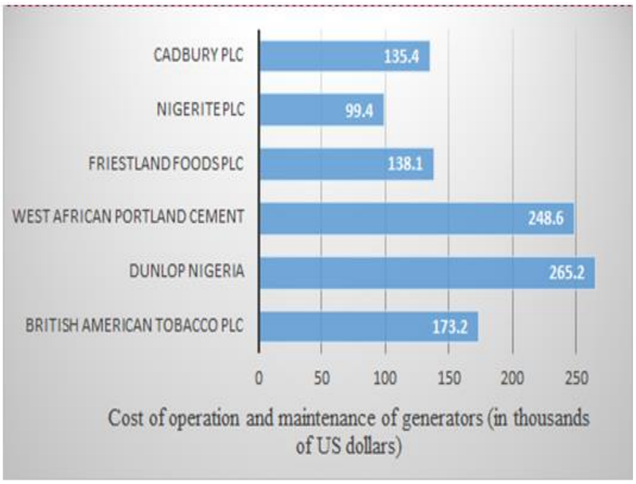

Figure 9: Cost of maintenance and operation of some firms in Nigeria (illustrated with data from [37]

3.2.1 Death in the car due to carbon monoxide

The dangers presented by air pollution are so diverse that it now appears that almost every activity of man has either direct or indirect impact on the atmosphere. Who would have suspected that the air inside an automobile can be so polluted as to cause death? Carbon monoxide poisoning can occur in defective vehicles, especially old and poorly-maintained ones. Automobile exhaust contains up to 100,000 ppm of carbon monoxide which can find its way into the vehicle cabin. Deliberate exposure to car exhaust fumes which contains up to 10% CO, is a very effective form of suicide [42]. There have also been cases where people commit suicide by locking up themselves in an idling car with the air conditioner turned on, and they end up dying by carbon monoxide poisoning. Carbon monoxide poisoning in moving vehicles can be due to faulty exhaust pipe, defective ventilation system, emission from other vehicles and cigarette smoking.

The danger of carbon monoxide asphyxiation is at a peak when sleeping in a stationary car with the air conditioner turned on. Almost everybody is at the risk of carbon monoxide poisoning because of the numerous routes of exposure. However, the categories of persons who are most at risk of carbon monoxide poisoning are: auto service personnel, exhaust pipe repair personnel, persons who cook using charcoal stove, petrol pump attendants and traffic wardens. McCann [43] also reported that one fifth of lower-income families could be regularly exposed to elevated levels of carbon monoxide.

3.3 Particulate Matter (PM) – The Tiny Giant Killers

Many people are not aware of the damaging effect of particulate matter (PM) – the seemingly harmless but complex mixture of finely suspended particles emitted during combustion, construction, industrial processes, cooking and many other anthropogenic activities. There is very little awareness regarding the dangerous nature of particulate matter especially because the resultant ailments are not easily traced to them. Dockery et al. [44] reported that 3 – 7 million deaths over the past few decades were caused by cardiovascular diseases (CVDs) associated with continuous exposure to excessive levels of airborne PM.

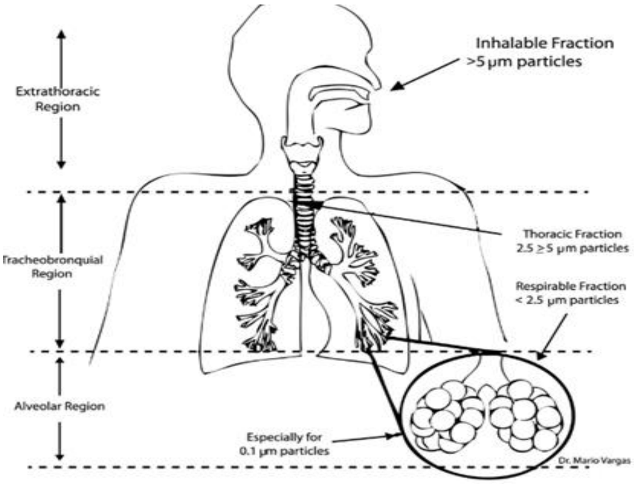

Figure 10: PM penetration into the lungs [45]

There are three categories of PM viz: ***coarse PM*** (PM_{10}) ranging from 2.5 – 10 μm which are usually from abraded soil, road dust, construction debris and aggregation of smaller particles; ***Fine PM*** ($PM_{2.5}$) ranging from 2.5 to 0.1 μm and ***ultra-fine PM*** smaller than 0.1 µm, usually emitted during combustion of fossil fuel (Table 3). The health effects of PM depend on several factors, including the size and composition of the particles, the level and duration of exposure, and the gender, age and sensitivity of the exposed individual [45]. The finer particles pose more health risks because of their ability to penetrate delicate organs of the body when inhaled (Figure 10). $PM_{2.5}$ is responsible for 29,000 premature deaths annually. In Europe, life expectancy has been reduced by 8.6 months owing to $PM_{2.5}$ pollution alone.

Table 3: EPA classification of Particulate Matter [38]

EPA Description	Particle size (µm)	Source
Super coarse	> 10	Abraded soil, agglomeration of smaller particles
Coarse (PM_{10})	2.5 – 10	abraded soil, road dust, construction debris, tyre and brake lining wear, and aggregation of smaller particles
Fine ($PM_{2.5}$)	0.1 – 2.5	Burning of fossil fuel, bush fire, tyre and brake lining wear, construction, cooking and tobacco smoking
Ultrafine	< 0.1	As for $PM_{2.5}$

Nearly half of the coarse PM is ordinary dust and the same proportion of $PM_{2.5}$ are emitted from transportation (22.7%) and waste burning (27.5%). However, over a third of all $PM_{2.5}$ are result from activities that occur indoor or in the home environment. Such activities are cooking and heating producing 11.3% of $PM_{2.5}$ and use of electric generators which accounts for 14.6% of all $PM_{2.5}$ emissions (Figure 11). This suggests that indoor air quality might pose more risk to humans than outdoor air quality, depending on prevalent activities taking place. Kelly and Fussel [9] observed that with respect to PM:

- The burden of ambient PM pollution on health is significant even at low concentrations
- There is no safe lower limit
- Effect of PM on health follows a linear dose – response function

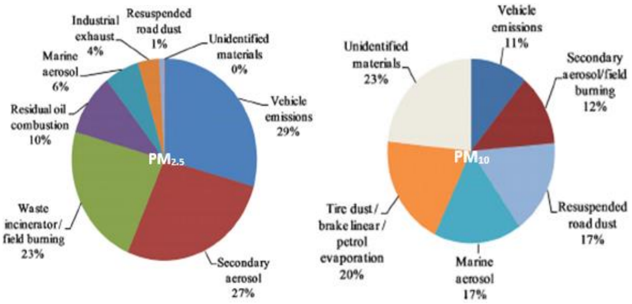

Figure 11: Sources of PM and their contributions [46]

The risk associated with PM emission depends on the nature of the particles. Atmospheric PM contains significant amounts of heavy metals such as lead, arsenic, chromium, etc. Symptoms of exposure to PM include ***cough, sore throat, burning eyes and chest tightness.*** These particulate heavy metals are usually emitted from automobile and electric generator exhaust, tyre abrasion and brake lining. Bake Abrasion associated with vehicle brake lining and tyre are the primary sources of air-borne Cu, Fe, Sb, (III), Sb (V), Sn, Ba, Zr, Al, S, Ze and Si [47]. The typical amount of PM emission into the air due to brake wear is 2.0 to 8.8 mg/km. The release of significant amounts of PM indoors is associated with the following activities: cooking - frying, toasting, barbequeing; cleaning – dusting, sweeping, vacuuming; movement of people and objects; and fungal growth/mould

Besides the associated health risks of PM, it also causes severe damage to the environment. In many developing countries where heavy constructions involving earth-moving activities, tons of thousands of particulate matter are kicked into the air. The situation is compounded by unpaved urban and semi urban roads with heavy traffic raising clouds of dust on a daily basis. The most visible environmental effect is the defacing of residential and historic buildings by dust particles and deposition of these particles on the leaves of plants. Kuzmichev and Loboyko [48] observed that dust deposition is one of the key causes of the degradation of building facades. These dust particles, lower the respiratory and photosynthetic activities of these plants, thereby reducing productivity. Exhaust fumes from diesel generator caused significant reduction in the productivity of plants and decreased seedling length, root and shoot dry weight [49]. Sett [50] gave a robust list of the possible effects of PM on plants as follows:

- Mechanical injury, if PM is inert
- Necrotic spotting, if PM is soluble and of toxic chemical nature
- screening of light
- plugging of stomata openings
- direct injury to plant tissue by the chemical reactions of dust particles on leaf surfaces.
- Decrease in rate of CO_2 exchange,
- Decrease in carbon assimilation
- Decrease in transpiration and net photosynthesis.

Particle having size lesser than diameter of stomata apertures directly enters the sub-stomata cavity and comes in contact with the spongy parenchyma of the leaf tissue [50]. This process can lead to gradual accumulation of heavy metals and other toxic substances in edible pants, which is subsequently transferred to man and animals when consumed. In addition, dust particles soil clothes, cars and other materials leading to increase in water demand for sanitation and hygiene.

3.3.1 Indoor air quality and the sick building syndrome

There is a widespread assumption among the uninformed that the risk of air pollution is more pronounced outdoors than indoors. This has generated a state of illusory security where people feel safer indoors in the belief that the air they breathe at home is devoid of pollutants. However, it has been established that indoor air quality is generally worse than outdoor air quality [51]. A wide range of pollutants are generated indoors during normal household activities. The enclosure of the home and limited space for dispersion and dilution causes a high plume of polluted air to linger in the home space for a long time. This poor rate of dissipation coupled with continuous emission of these pollutants results in a gradual build-up of dangerous gaseous substances that are capable of causing death or permanent disabilities. Even when the indoor air quality is safe, polluted outdoor air can infiltrate into the home without any visible or noticeable sign. Sources of indoor air pollution are cooking, electric generators, insecticides, smoking, stored chemicals such as paint, cleaning, wall paints and wooden items. Children who spend the most times at home and women who do most of the cooking are the most susceptible to indoor air pollution. Indoor air pollution has been implicated in absenteeism from school and workplaces as well as corresponding hospital visits.

Besides, activities taking place in the home, building materials and household items can also be a source of air pollution, giving rise to a perpetual state of discomfort and ill health to occupants. Poor indoor air quality can give rise to a phenomenon called the sick building syndrome (SBS). SBS consists of various non-specific symptoms that occur in the occupants of a building. SBS can result from any or a combination of the following sources:

- Contaminants generated indoors
- Infiltration of outdoor pollutants
- Biological contaminants such as pollen, spores, bacteria, virus, fungus and mold that accumulate on moist/damp surface.
- Inadequate ventilation

One of the major causes of SBS worth mentioning is the emission of VOCs from wall paints, wooden household items impregnated with preservatives and wood varnish as well as escape of molecules from stored chemicals in the home [51]. Paint contains over 10,000 chemicals and over 300 known toxins [52]. In fact, paints are the highest emitters of VOCs after automobiles. The danger of VOC-related indoor air pollution is higher in new or repainted building. Other sources of VOC are aerosol spray, disinfectants, air fresheners, fuel, pesticides, insecticides, glues, adhesives and whiteboard markers. VOCs can cause a wide range of health-related problems including eye, nose and throat irritation, headaches, loss of coordination, nausea, kidney and liver damage, cancers, allergies, fatigue and dizziness.

In order to minimize episodes of indoor air pollution and attendant health risks, the air flow rate should be maintained at 20 cubic feet of air per minute (cfm)/person in homes, 20 cfm/person in offices and 60 cfm/person in smoking lounges [53]. Unfortunately, ventilation for the purpose of indoor air quality control is rarely a consideration in many developing countries.

3.4 Air Pollution and Climate – A Classical Case of Cause and Effect Gone Awry

Air pollution is very closely related to climate change. Climate is a synthesis of weather conditions in a given area which is characterized by long-term statistics of meteorological elements in an area. Climate change is the variation in global or regional climate over time. Climate change is usually caused by the processes internal to the earth or external forces and more recently human activities. Human activities are the key factor that causes air pollution which is a driving force of climate change. Hence, increase in air pollution result to climate change. Ozone depleting substances such as CFC, CO, CO_2, methane, and SO_2 which trigger climate change are air pollutants.

Air pollution and climate change influence each other through a series of complex interactions in the atmosphere. Growing levels of greenhouse gases (GHGs) alter the energy balance between the atmosphere and the surface of the earth, which can lead to temperature changes that alter the chemical composition of the atmosphere. The major source of air pollutants globally is the extraction and burning of fossil fuels which are the main cause of increasing GHG emissions that are responsible for climate change [54]. Many air pollutants and GHGs have common sources and interact in the atmosphere. Common GHGs are CO_2, CH_4, NO_x, O_3, CFCs, and NH_3. Global warming has been linked to greenhouse gases (GHG) which have the ability to retain heat from the sun. Global warming is the gradual but sustained increase in the temperature of the earth surface caused primarily by anthropogenic activities. Many air pollutants affect the amount of sunlight that is reflected and absorbed by the atmosphere and can either cause a heating or cooling of the earth's atmosphere. These short-lived climate forcing pollutants (SLCPs) contribute to greenhouse effect and include methane, black carbon, ground level ozone, hydro-fluorocarbons and sulfate aerosols [55]. They remain in the atmosphere for much shorter periods than Carbon dioxide (CO_2) yet their potential to warm the atmosphere can be many times greater. These short lived pollutants are the most important contributors to global greenhouse effect after carbon dioxide, and are responsible for up to 45% of current global warming. Black carbon, also known as soot is a component of fine particulate matter (PM 2.5) and is a product of incomplete combustion of fossil fuels. It absorbs solar radiation and contributes to global warming [54]. Hydro-fluorocarbons are man-made greenhouse gases used as coolants in fridges and air conditioners, fire extinguishers and aerosols. Methane is emitted by human activities and livestock production and is the precursor to tropospheric ozone, which causes asthma and other respiratory diseases [56]. Tropospheric ozone on its own is formed by the interaction of sunlight and hydrocarbons with nitrogen oxides emitted from power plants, refineries, vehicles etc.

Today, the effects of a changing climate due to increasing GHG emissions threatens the health and survival of humans in various ways: food scarcity as a result of droughts or crop failure, increasing incidence of hydrological disasters such as flooding, hurricanes, tornadoes and cyclones. The gradual buildup of these gases in the atmosphere leads to an increase in the heat retention of the earth. The atmospheric concentrations of CO_2 and CH_4 have increased by 31% and 149% respectively since 1750. The melting of the polar ice-caps resulting from increasing ambient temperatures, and the accompanying rise in sea-level will leave some area uninhabitable [57][58].

The Intergovernmental Panel on Climate Change (IPCC) [59] Special Report on the impact of global warming has advised that the reduction of non-CO_2 climate forcers, particularly black carbon (soot) and methane, are very essential to climate change mitigation. When combined with significant measures to cut CO_2 emissions, SLCPs play an important role in reducing the rate of global warming to help achieve the 2°C target set by the Paris agreement. Reducing short-lived climate air pollutants such as the methane, black carbon and tropospheric ozone will have the effect of preventing climate tipping points that could worsen climate impact and make coping and adaptation much harder for the poorer more vulnerable populations.

4.0 PRACTICAL STEPS TO MITIGATE AIR POLLUTION AND ITS IMPACTS

Up till now, climate change has been attracting more international attention and cooperation than air pollution. As with every other environmental problem, the best management approach is prevention of air pollution. However, prevention appears to be very far from the horizon considering the innumerable and ubiquitous sources/causes of air pollution. Prevention can be achieved by a combination of policies, technological modifications, education /awareness and adaptation strategies. Hence it was a step in the right direction in December 2015, when a total of 195 countries ratified a universal agreement to combat climate change in Paris [60]. However, most of the steps taken to address climate change will invariably reduce air pollution to a tolerable level. This is because of the intricate connection between greenhouse gases and air pollution.

One of the fundamental policy-oriented air pollution control measures is the setting of emission standards which places a ban on the release of certain substances into the air or restricts the concentration to be emitted. One such policy is the United States Clean Air Act (CAA) of 1970 which creates a complicated set of relationships and responsibilities among federal, state, and local governments as part of a complex regulatory system, which authorizes setting of standards and objectives, design and implementation of control strategies, assessment of status, and measurement of progress [61]. Similarly, China has imposed restrictions on major pollution sources including vehicles, power plants, transport, and industry sectors and promulgated the "Atmospheric Pollution Prevention and Control Action Plan" in September 2013, which was intended to reduce PM2.5 by 25% by 2017 relative to 2012 levels [62]. The major challenge facing policy-oriented air pollution control is lack of implementation and enforcement. Many countries have excellent environmental standards but fail with respect to implementation. Yamineva and Romppanen [63] noted that the EU has adequate air policy, but has been failing in the aspects of implementation and compliance.

Some progress has already been made, but a lot still needs to be done. For instance, many countries have outlawed the use of leaded petrol, but some others, especially developing countries, are still reluctant to phase out this killer element [64][65]. This is despite indications that the reduction and elimination of leaded gasoline has probably been the major factor in recent times in reducing population blood lead levels [66]. Many researchers and stakeholders have also advocated improvement in the diesel engine technology as an additional means of reducing air pollution. Besides reduction, Sierra-Vargas and Teran [45] noted that afforestation, carbon sequestration, establishment of urban forests and use of green roofs are effective mitigation measures. They also reported that in the US, trees remove about 711,000 metric tonnes of CO, NO_2, O_3, CO_2, SO_2 and PM from the atmosphere. In Indonesia, the “one man one tree” programme is being used to instill environmental consciousness and awareness in students [67].

4.1 Replacement of Fossil Fuel with Renewable Energy

As opposed to fossil fuel which can be depleted because the quantity available is fixed, renewable energy is constantly replenished by nature’s regenerative process. The most common types of renewable energy forms are solar, hydropower, wind and bioenergy. Solar energy is gradually taking the centre stage in global energy supply. This is because solar radiation is available everywhere and it can be installed both at distributed and grid (utility) scale. Besides, solar energy reaching the earth is far beyond the global energy demand. Owusu and Asumadu-Sarkodie [68] observed that energy from solar radiation falling on the earth’s surface is more than 7,500 times the world’s total annual energy consumption. Solar photovoltaic (PV) electricity generation is a promising technology for tackling both GHG emission and air pollution.

There are currently over 350 solar PV companies globally with the highest number located in China (43), followed by Germany (21), USA (19) and Taiwan (15). Yang et al. [69] observed that deploying distributed PV maximizes potential CO_2 reduction. Increase in PV fleet will eliminate atmospheric SO_2 and carbonaceous aerosols, thereby increasing solar irradiance for increased rate of solar power generation [70]. One case worth mentioning is the Chinese massive investment in solar PVs. China has been tagged as the world’s largest emitter of anthropogenic air pollutants, contributing a total of 53% of the global CO_2 emission [70]. This narrative is gradually changing as China has become the largest investor in solar energy generation and increased from a PV electricity generation of 50 GW in 2012 to 110 GW in 2012 [69].

Labordina et al. [70] projected that by 2040, solar PV fleet in China would produce between 85 to 158 TWh/year of additional clean energy, generating additional revenue of 6.9 to 10 billion USD which can be used to partly offset the cost of effective air pollution control measures. Several other countries are also neck-deep in the race to attain solar energy self-sufficiency. Table 4 gives a list of the top five largest solar power plants in the world. One major drawback with respect to PV penetration is the high capital investment required for initial installation. But studies in various parts of the world such as Nigeria, Brazil, Thailand and South Africa showed that PV cost effective in the long run [71].

Table 4: Top five largest PV Plants Globally [72]

Country	PV Project	Capacity (MW)	Cost (million £)	Unit Cost (£/W)
Ukraine	Active Crimea Solar Plant	300	1193.81	3.98
USA	California Valley Solar Ranch	250	1056	4.22
China	Yichun City Hongxing Solar Power Project Phase II	250	660	2.64
Chile	AES Los Andes Solar PV	220	343.2	1.56
Chile	Fotories de Chile Crucero Sola PV	180	290.4	1.61

4.2 Replacement of Conventional Cars with Electric Vehicles (EV)

It has been established that transportation is one of the largest causes of air pollution. Vehicles in motion endlessly discharge their gaseous and particulate waste product into the atmosphere. There is no doubt that curbing the emission from the transportation sector will go a long way in mitigation air pollution and its attendant adverse health effects. The twin menace of air pollution and global warming have made the adoption of electric vehicles (EVs) inevitable. If electricity generated from fossil fuel sources will still be used to charge EVs, there may not be a significant reduction in air pollution because additional fossil fuel will be used to generate electricity required to charge EVs. Hence, EVs help to combat air pollution only if the energy source for charging the vehicle is from a renewable source. This can be achieved by installing solar boards at EV charging stations [73].

In the US, demand for EVs jumped from 17,375 in 2011 to 52,835 in 2012 [73]. However, this is a joke when compared to the 254,639,386 registered vehicles in 2012. The scenario is even less encouraging in other countries. Rhamani et al [60] adduced that the reasons for the low market penetration of EVs are: high cost of purchase, less power, lack of awareness and limited autonomy. Liu [74] reported that EVs consume an energy equivalent of one gallon for about 90 miles which is higher than that of any other car. The widespread reluctance to embrace EVs can be mitigated by the use of subsidies. For instance, Norway was able to meet a set target of 50,000 EVs in 2015 through a combination of monetary and non-monetary incentives which include: VAT and registration exemption, access to priority lanes, free parking, free travel on ferries, free municipal recharging, reduced annual road tax and exemption from company car tax [60].

4.3 Air Quality Monitoring

What makes air pollution very dangerous is that people generally do not know the constitution of the air they breathe. Since most air pollutants are either colourless or odourless or both, the air can be heavily polluted without any visible sign. This therefore calls for intensive investment in air quality monitoring and data gathering. Air quality monitoring can serve several purposes including: provision of database for future use and trend establishment, ascertainment of the level of risk associated with a particular environment, association of air quality with the health status of the populace, air quality assurance, etc. Air quality monitoring has been made a lot easier by the development of portable, lower-cost air pollution sensors reporting data in near-real time at a high-time resolution, increased computational and visualization capabilities, and integration of wireless communication/infrastructure [75]. Long-term measurements at monitoring stations may be used to investigate the relationship between the population exposure to air pollutants and the incidence rate of diseases [76].

Air quality monitoring can be undertaken by physical, chemical, electronic or mathematical methods. Industrial grade and consumer grade air quality monitoring devices which can provide intermittent hourly air quality reports are available. Some of the devices are connected to the mobile phone via a mobile app and are able to transmit reports to a central database for anyone to view using the mobile app. Most of these devices simply measure specific pollutants and converts the concentrations to an air quality index (AQI) which specifies the level of risk associated with those pollutants (Table 5). AQI is an integrated value that assesses the overall health risk associated with the pollutants in the air. Closely related to the AQI is environmental quality index (EQI) which is a holistic concept that encompasses elements of indoor air quality (IAQ), indoor lighting quality (ILQ), acoustic comfort, and thermal comfort [77].

Table 5: EPA Air Quality Index Categorization [29]

AQI	Colour Code	Category	Description
0 – 50	Green	Good	There is little or no health risks
51 – 100	Yellow	Moderate	Moderate risks exist
101 – 150	Orange	Unhealthy for sensitive groups	The most sensitive members of the population such as children and persons having pre-existing conditions may be affected
151 – 200	Red	Unhealthy	A greater proportion of the population are at risk. Those belonging to the sensitive group may experience more intense health effects.
201 – 250	Purple	Very unhealthy	Air pollution reaches a dangerous level where nearly everybody is at risk and may suffer various levels of adverse health effects.
251 – 300	Maroon	Hazardous	Severe and widespread health effect, including death.

However, there is very little penetration of air quality monitoring stations in many countries especially developing ones. These further increases the risk associated with air pollution. Obanya et al [78] reported that 85% of the 2.9 million deaths in 2016 due to air pollution occurred in low- and middle-income countries. There is also the problem of haphazard location of such stations such that there could be an excessive cluster of air quality stations in a particular location and a grossly inadequate number in another. Yu et al. [79] proposed a satellite-based method for more effective monitoring of air quality. Wu et al [80] developed field-portable cost-effective platform termed c-Air integrated with a smartphone for high throughput quantification of particulate matter. The device screens 6.5 L of air in thirty seconds and provides microscopic images of PM. Tiele et al [77] developed a rechargeable low-cost and portable device for monitoring indoor environmental quality (IEQ) for less than ₤200. The IEQ scoring index are presented in Table 6. There are also portable air android-enabled air quality monitors which monitor both indoor and outdoor air quality. An example is AirVisual ™ which can collect air quality data of an area using a combination of high-accuracy laser air quality sensor with artificial intelligence. Anyone with an android device can access the air quality information of the area through the AirVisual app (Figure 11). The major problem however is that individuals have to purchase the air quality monitor at 295USD and designate it as a public station for data generated to be uploaded to the server. Hence, only few locations are covered by the scheme.

Table 6: IEQ scoring index [77]

IEQ Parameter	Good	Average	Poor	Bad
Humidity (%)	40 - 50%	50 - 60%	60 - 70%	70>H>40%
Temperature (°C)	20 - 24	16 - 20	24 – 26	26>T>16
PM2.5 (μg/m^3)	0 - 10	15-Oct	15 – 35	>35
PM10 (μg/m^3)	0 - 50	50 - 80	80 – 150	>150
VOC (ppb)	0 - 200	200 - 350	350 – 500	>500
CO2 (ppm)	350 - 500	500 - 1000	1000 – 5000	>5000
CO (ppm)	0 - 3	3 – 8	8 – 10	>10
Indoor air quality (ppm)	0 - 10	10 - 25	25 – 50	>50
Illuminance (lux)	300 - 500	200 - 300	100 – 200	<100
Sound levels (dB)	0 - 40	40 - 70	70 – 80	>80
Scoring impact	0	0.2	0.5	1

Figure 11: Display of AirVisual App Interface.

4.4 Personal Protective Measures against Air Pollution

Several reviews have linked increasing levels of exposure to air pollutants with various adverse health effects [81][82]. The health problem is managed most effectively by involving the various sectors of the society to control primary emission and also the precursors that interact to form secondary air pollutants. Avoiding unnecessary exposure to air pollutants is especially important for individuals who are susceptible to respiratory diseases. People with chronic cardiovascular or pulmonary disease, children and the elderly should be protected from the effects of air pollution. When air quality is perceived to be poor either by visual indication, odour or health symptoms, personal protective measures should be adopted. Personal protective measures to reduce ambient air pollution include:

- Remaining indoors: In areas where outdoor air quality is poor, it is advisable to remain indoors as much as possible. This is especially important in developing countries where massive construction of roads and structures can drag on for months, releasing huge amounts of particulate matter into the atmosphere. Persons living near permanent sources of air pollution such as gas-flaring stacks should spend less time outdoors or relocate to a safer place.
- Reducing exposure in microenvironments nears sources such as traffic or construction sites and sources of combustion such as burning of wood or biomass
- Avoiding outdoor activity during periods and in locations where pollutant levels are higher is another protective measure. Ambient air pollution levels vary diurnally and also seasonally. It is advisable to avoid microenvironments with higher pollutant levels or avoid locations or times of the day when air pollution levels are likely to be elevated.
- Reducing outdoor air infiltration to indoors. Adopting the use of air filters indoors can reduce the concentration of indoor air pollutants. This can be achieved using indoor filtration systems to filter air from indoor or outdoor origins. Example of this is the use of heating ventilation and air conditioning systems as well as portable filter-based cleaners.
- Reducing physical exertion when outdoors or when close to pollution sources can reduce the amount or dose of air pollutants inhaled [83]. It can also alter the fraction of the pollutant deposited or absorbed by the different parts of the respiratory tract. Breathing through the mouth at higher levels of exertion increases the dose of pollutants that reach the lower respiratory tract.
- Personal protective equipment like respirators and nose masks can be used to remove pollutants from air being inhaled. The ability of the respirator to filter inhaled air depends on the type of filer, respirator type, the contaminant and the conditions of use. No single or combination of adsorbents is however able to efficiently remove

the numerous gas phase air pollutants that may be encountered.

Studies have also shown that minimizing exposure to air pollutants at a population level improves health outcomes [82]. However, there is limited evidence to support that individual protective actions are effective in reducing cardiopulmonary health risk associated with personal exposure to air pollution (Laumbach et al, 2015)

5.0 CONCLUSION

Air pollution is deadly and is responsible for millions of deaths annually. Virtually all anthropogenic activities are either directly or indirectly linked to air pollution, thus making it difficult to eliminate. Research findings have established that most developing countires have the worst air quality and are more suceptible to its dangerous effects. One of the most dangerous causes of air quality related deaths is carbon monoxide which is one of the major products of transportation and electric power generators. Thousands of deaths worldwide have been linked to carbon monoxide poisoning. Also responsible for millions of deaths and disability adjusted life years (DALYs) is particulate matter which affects both man and plants. However, the problem of air pollutiotion is not intractable, but mitigating air pollution requires very tough trade-offs.

Specific and targeted policies (for instance, the Paris Agreement) are among the greatest and sutainable tools for mitigating air pollution. Such policies have given rise to the global quest to phase out the use of leaded petrol and to replace fossil fuels with renewable sources of energy, amongst many others. At individual levels, people should be conscious of their indoor and outdoor air quality and specifically take adequate measures to protect themselves.

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