



Assessment of Global Warming/Climate Change Impacts on Environment, Human Health, Land Use and Management in the West Coast Region in the Gambia, West Africa

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Abstract

Climate change is one of the most significant environmental issues facing humanity in the twenty-first century. Human activities that raise greenhouse gas emissions are the primary causes of climate change, resulting in major consequences like increased temperatures, extreme weather, and sea level rise. Rapid action is required to mitigate these effects and get ready for them. The study objective was to assess threats posed by changes in climate to the environment and the health of the public. A comprehensive analysis is provided on how climate change impacts the environment, human health, land use and management, food distribution, and agricultural productivity. These challenges are exacerbated in West Africa due to the region's high susceptibility to the consequences of change in climate. Prolonged environmental pollution over a period of time of approximately ten decades has significantly contributed to potential global warming. In The Gambia, it is essential to increase public knowledge of the harmful impact that persistent pollutants, especially gaseous particulate matter, have on humans and the environment. Air pollutants contribute to ozone layer depletion and contamination of hydrological resources. Standardized air quality monitoring equipment was used for weekly data collection, measuring various air pollution parameters. A statistical analysis of central tendency and dispersion was conducted using a Casio scientific calculator (model FX-991MS) to categorize and standardize pollutant levels. Pollutants were classified into categories based on the concentration levels indicated in terms of colors seen on the air quality meter screen to enable one to assess their impacts on human health, climate, and the environment. Results gotten from this study indicated that carbon monoxide (CO) had the highest mean concentration

value of $348.04 \pm 19.98 \mu\text{g}\cdot\text{m}^{-3}$, which is classified as hazardous in Category 6, having maroon coloration, followed by particulate matter (PM_{10}) with a mean concentration value of $230.72 \pm 38.26 \mu\text{g}\cdot\text{m}^{-3}$ found in Category 5, with purple color, indicating unhealthy health conditions. Ozone (O_3), ammonia (NH_3), and particulate matter ($\text{PM}_{2.5}$) were all recorded with mean concentration values of $128.08 \pm 9.37 \mu\text{g}\cdot\text{m}^{-3}$, $126.91 \mu\text{g}\cdot\text{m}^{-3}$, and $131.38 \pm 39.78 \mu\text{g}\cdot\text{m}^{-3}$ respectively. All of them were found in Category 3 having orange colors, which signifies health risks to some sensitive groups of people.

Subject Areas

Environmental Sciences, Global Health

Keywords

Air Pollutants, Climate Change Impacts, Greenhouse Gases Emission, Human Health Effects and Adaptation Mitigation Measures

1. Introduction

Climate change, according to the United Nations, is defined as a long-term shift in weather patterns and temperatures [1]. There are numerous and varied effects on human health as the world's climate continues to undergo severe changes [2]. More than just a global problem, many people believe that one of the biggest injustices of these days is climate change, which is a major threat to humans [3]. Since the nineteenth century, human activities have been the main cause of climate change due to the excessive burning of fossil fuels like coal, oil, gas, etc., which raises greenhouse gas emissions. The global temperature increases, causing ocean acidification and posing health risks. High levels of air pollution are particularly prevalent in urban areas in the Gambia. Five main categories of compounds are known as fundamental air pollutants because they are discharged into the atmosphere in their unaltered forms in sufficient amounts to be harmful to human health worldwide. These include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter (PM), and volatile organic compounds (VOCs). In the presence of sunlight, primary air pollutants can combine to generate new compounds like ozone (O_3), which are secondary air pollutants that frequently above the limits advised by international standards. The global population's health is seriously at stake because of this, according to [4] [5], contaminants like particulate matter and gaseous substances are major pollutants of air and soil that are adversely affecting agricultural productivity. Industrial activity is the primary contributor to greenhouse emissions, transportation, construction, energy production, industry, and agriculture being the leading sectors. Climate change impacts both physical and mental health. Increasing global temperatures directly and indirectly threaten human well-being [6]. Air pollution is closely

linked to climate change, which further compounds these risks. The strategic tactics of change in climate adaptation and mitigation are reducing greenhouse gas emissions through the use of sustainable energy and sustainable agriculture. Increased energy efficiency is the main goal of mitigation. Through community relocation plans, climate-resilient crops, and infrastructural improvements, adaptation entails enhancing resilience. According to [7], measures are critically needed because global temperature was predicted to increase by 1.5 °C from 2030 to 2052 if present emission rates continue. Global warming/climate change, air pollution and human health are closely related to the effects of greenhouse gas emissions from fossil fuels. To combat these challenges of climate change, lowering exposure to air pollutants can be accomplished by shifting away from fossils towards sustainable energy sources. Sustainable energy sources, such as solar, wind, and hydroelectric power, not only reduce greenhouse gas emissions but also improve air quality and promote public health. By investing in these technologies, we can create a cleaner environment and foster a more resilient economy for future generations. According to a study carried out by [8], noted meteorological issues like heat stress, poor air quality, rising sea levels, and food and water shortages. Changes in climate also lead to natural extreme weather events like hurricanes, earthquakes, volcanic eruptions, floods, and droughts. Additionally, ailments like diarrhea, infectious diseases, vector-borne illnesses, respiratory and cardiovascular issues, and malnutrition may spread more easily due to changes in climate [9]. The relationship between climate change impacts, environment, human health, land use, and management is examined in this article as per [10]. Even in cases when air pollution is low, climate change has substantial effects on the public to varying degrees, which is primarily noticeable in those with compromised or vulnerable immune systems. Furthermore, research in this area has demonstrated that diabetes is triggered by extended exposure to atmospheric contamination [11]. This connection highlights the urgent need for integrated strategies that address both environmental sustainability and public health. Effective land use and management practices can mitigate some of these adverse effects, fostering healthier communities and ecosystems alike. However, exposure to vulnerable harmful pollutants, particularly when young people are involved, has been linked to respiratory and cardiovascular problems, mental and perinatal illnesses, and newborn death. Research in several parts of the world, according to [12], has found a link between daily particulate matter level, daily mortality change, and global warming is only making the problem worse. Even for individuals with sound immune systems, exposure to microscopic and ultrafine particulate matter is associated with severe illness, according to research on the health effects. This is as a result of rapid particles' absorption into the bloodstream. Due to causes of unchecked urbanization, fast population increase, overpopulation, and industrial expansion, this issue is considerably more acute in emerging countries [13]. Air pollution has also resulted from low-income nations' home use of fossil fuels. These energy sources are used domestically by more than three billion people worldwide

[14], and the WHO has declared climate change and air pollution to be the “most significant threat to human health”. Heats are trapped in the atmosphere by CO₂, CH₄, black carbon (PM_{2.5}), etc., and human activities like industrialization, fossil fuel combustion, and mineral exploitation account for over 64% of anthropogenic global warming [15]. Short-lived climate pollutants (SLCPs), though transient, have a disproportionately high warming effect compared to CO₂ [16]. Air contamination causes respiratory and cardiovascular diseases like lung cancer and chronic bronchitis. Fine particulate matter (PM_{2.5}) penetrates the bloodstream, triggering systemic inflammation and exacerbating conditions like asthma and diabetes. Children, the elderly and immunocompromised individuals are most vulnerable. Three important aspects determine an individual’s susceptibility to climate change: exposure, sensitivity, and adaptive capacity. Throughout their lives, people may experience varying degrees of climatic effects, underscoring the complex interplay of these factors [17].

1.1. Changes in Air Pollutant Distribution and the Dynamics of Climate Change

Climate change alters pollutant dispersion, disrupting ecosystems and human health. Urbanization and industrialization elevate PM_{2.5} levels, complicating sustainable development [18]. CO₂ concentrations, now accounted 40% higher than pre-industrial levels, reflect accelerated fossil fuel use since 1970 [19]. The relationship between air pollution and climate change is well acknowledged by the scientific community. The “greenhouse effect” refers to the process by which heat from the sun is stopped from escaping into space and instead stays in the Earth’s atmosphere. These activities are responsible for more than 64% of the global warming caused by humans. Carbon dioxide (CO₂) can linger in the atmosphere for many years, leading to long-lasting impacts on ecosystems and human health. As human activities release more of these gases, a vicious cycle ensues, further preventing the sun’s rays from escaping. While CO₂ persists for extended periods, other gases contributions are known as short-lived climate pollutants (SLCPs) in relation to climate change. Despite their shorter atmospheric lifespan, SLCPs such as methane, ground-level ozone, and black carbon (PM_{2.5}) have a more potent warming effect than CO₂ and cause significant environmental harm. Given the link between greenhouse gases and air pollution, reducing fossil fuel use would improve various aspects of human health.

1.2. Climate Change’s Effect on Regions

The impacts of change in climate vary across different regions of the world. Consequences include shifts in temperature, rainfall patterns, and drought frequency. These changes affect both human populations and ecosystems, with species unable to adapt or migrate towards facing extinction. The most pronounced temperature increases are expected in terrestrial areas and Polar Regions. As temperatures rise, global average precipitation is projected to increase, though unevenly.

High-latitude regions are likely to experience heavier rainfall, including snowfall near the poles, leading to increased flooding. In contrast, equatorial regions may face reduced rainfall. In Africa, an estimated 75 to 250 million people are at risk of drought, which could severely impact food security due to declining crop yields. Coastal areas and islands worldwide are also vulnerable to rising sea levels. In Nigeria, for example, regions along the Niger Delta, Benue, and Niger rivers are particularly vulnerable to excessive floods.

1.3. Contagious (Infectious Diseases)

Diseases are categorized as communicable and transmissible if they show visible symptoms. According to [20], they are caused by infection and the growth of pathogens within an organism host. Depending on the type of infection and its symptoms, direct and indirect contact between people is the main way that infectious diseases are spread. Weather can also have an impact. People can get infected by coming into contact with an animal that is harboring a pathogenic organism. Pandemic diseases have been a major source of death worldwide, particularly for young children and in underdeveloped countries. Infectious diseases caused by pathogens, including parasites and protozoa, transmitted by hematological arthropods are referred to as vector-borne diseases. Black flies, bedbugs, and biting midges are examples of hematophagous vectors, kissing bugs, and fleas. The range of vector-borne illnesses also includes sandflies, ticks, and mosquitoes. Change in climate can significantly affect how infectious illnesses spread through vectors. Temperature, humidity, changes in rainfall patterns, soil water, and rise in sea level are some of the variables that might cause this. Determining how these factors might impact likelihoods of diseases carried by vectors is a complicated procedure. Seasonal trends are common for vector-borne illnesses, and the effects of rainfall and temperature are well known. Certain areas also show notable annual fluctuations in vector-borne illnesses, such as malaria, which are at least partially attributable to climatic conditions. The impact of change in climate on vector-borne illness distribution and transmission has been the subject of much research.

Lung illness and other respiratory system components are impacted by respiratory disorders; causes include infections, tobacco use, and exposure to asbestos, radon, and other air pollutants. Common conditions include asthma, occupational pulmonary diseases, pulmonary hypertension, and chronic obstructive lung disease. Respiratory health is directly threatened by climate change can exacerbate pre-existing diseases or increase exposure to risk factors. Particularly at risk are people who already have respiratory or cardiovascular diseases [21]. Climate change impacts multiple aspects of human life, including weather patterns, air and water quality, food security, and economic stability. For example, temperature increase can disrupt biological and physical systems globally, leading to serious respiratory and other health issues. Elevated sea levels are due to the melting of polar ice caps, depriving some regions of freshwater and causing water degradation and population displacement. Mass migrations due to climate-induced disruptions,

along with extreme weather events like heatwaves and harsh winters, further exacerbate respiratory health risks [22].

The Pan American Health Organization defines non-infectious ailments, often known as non-communicable diseases, as those that usually require continuous care and treatment, have long-term health impacts, and are not primarily caused by a serious infection. CO₂, CH₄, and NO_x concentrations have significantly increased due to socioeconomic causes and the world's growing population. These gases are mostly produced by burning fossil fuels. The effect that these gases produce after being released into the atmosphere traps solar heat and raises global temperatures. The frequency of natural disasters, including extreme flooding, droughts, storms, and heat waves, will increase as the earth's temperature rises. Majority of low- and middle-income nations are experiencing the current and anticipated increase in NCD-related mortality [23]. These diseases are brought on by infections such as bacteria, viruses, and protozoa; compounds released into the environment by human activity; and poisons produced by cyanobacteria, sometimes referred to as blue-green algae. These toxins can be ingested by contaminated fish and shellfish or through drinking water that has been contaminated.

1.4. Impacts of Climate Change on Stress Disease Due to Heat

Diseases due to heat stress are dangerous illnesses brought on by the body's inability to withstand high temperatures. The typical temperature of the human body is between 36 and 37 degrees Celsius. Heat stress, which includes heat cramps, fatigue, syncope, and stroke, is caused when the body is unable to control its temperature. This disorder manifests as confusion, difficulty speaking, unconsciousness, excessive perspiration, dry skin or profuse perspiration, convulsions, and extremely high body temperature. One is susceptible to heat stroke when their body temperature exceeds 40.5°C. Long-term exposure to intense heat can cause heat-related diseases, particularly when combined with high humidity and physically demanding activities. Change in climate is the main factor contributing to heat stress.

1.5. Climate Change's Effect on Cardiovascular Diseases

Cardiovascular events, like heart attacks, strokes, etc., can be made more likely in people who are already at risk for them by either directly or indirectly exposing human health to heart illness due to poor air quality brought on by heat waves or particle pollution. Due to air pollution, the number of mortalities from harmful chemical substances has increased. As a result, these pollutants affect the respiratory, cardiovascular, and blood vessel systems, resulting in serious illnesses.

1.6. Implications of Change in Climate and Land Use in Gambia

Over the past century, greenhouse gas emissions have steadily increased, which has caused these gases to gradually build up in the Earth's atmosphere. Climatol-

ogists prophesied that further buildup will lead to a gradual global warming, a phenomenon that had been predicted by [24]. Although the severity of climate change consequences is expected to differ by region, there are still questions about the exact scope of these differences, necessitating more research. Beyond the effects of change in climate, the main causes of deforestation and land use in Gambia are infrastructure development, such as housing estate projects and peri-urban settlements, timber production, indiscriminate urbanization, and urban growth. According to recent data, The Gambia's urban population proportion has been steadily rising, rising from 41% in 1993 to 62% in 2019. High fertility and low death rates drove population growth, which inexorably necessitated the development of land areas for settlement, sometimes encroaching on agricultural and forest ecosystems. Therefore, these land use changes are expected to have a broad impact on the quality of water resource availability, as well as on soil erosion dynamics. Since 1940s, modifications brought about by humans to the biophysical features of Gambian territory have been common, and as a result, about half of the country's forest lands have been lost. The agriculture industry in The Gambia contributes significantly to carbon emissions because of unsustainable manure management and rice production practices [25]. The Gambia's forest cover has shrunk by more than twenty-two thousand hectares in the past thirty years, in which eighteen percent, accounting for more than 20,000 metric tons of CO₂, have been released as a result [26]. Significant differences in the distribution of vegetation along the major river have been found in recent studies done by [27], which looked at the dynamics of land cover throughout Gambia. According to [28], for example, the North Bank Region of Gambia has significantly drier agricultural lands than other regions because of ongoing drought condition. The Gambia is among African countries most susceptible to adverse consequences of change in climate-related calamities, with three-quarters of the nation situated below 10 meters above mean sea level and around half of the entire land below 20 meters. If global temperatures and sea levels continue to increase significantly, a large area of the nation may be submerged [29] [30]. Adopting a variety of climate-smart agricultural techniques is crucial to improving The Gambia's resilience to climate change. Among these is agroforestry, which combines crops and trees to boost soil fertility, biodiversity, and carbon sequestration, all of which aid in adaptation and mitigation. Furthermore, water-saving methods like solar-powered drip irrigation systems and rainwater collection can greatly increase water efficiency and lessen drought susceptibility [31]. The agriculture sector's growing use of sustainable energy sources is a step in the right direction towards lowering greenhouse gases emissions due to the industry's heavy reliance on fossil fuels for a variety of processes, including irrigation, drying, harvesting, cooling, grinding, and transportation. About 30% of global greenhouse gases emissions is caused by this and methane released by animal farming [32]. Since agriculture accounts for 24% of the nation's GDP, integrating renewable energy technologies into the industry will benefit the economy as well as the environment [33]. Moreover, irrigation powered by solar, sustainable energy sources, including animal wastes, biofuels, etc.,

has brought about promoting a sustainable economy [34]. Dependability can be increased via hybrid sustainable energy systems that include sun, wind, biogas, etc., especially in remote areas [35]. Renewable energy-powered precision agriculture technologies can further optimize input and water consumption, improving climate resilience and yields [36].

2. Human Health Sensitivity, Vulnerability and Adaptation

Regarding to Intergovernmental Panel on Climate Change, human health's susceptibility to change in climate is determined by three factors: sensitivity to weather, exposure to hazards related to climate, and adaptation measures and actions implemented to lessen the impact of particular negative health outcomes. According to [37], adaptation methods can significantly lessen many of the possible negative effects of change in climate on health [38]. These changes, however, would also be influenced by the ecological and topographical conditions of the area, additional factors that determine the susceptibility of the local populace, and the strength and presence of public health defense [39]. In most highland areas, the prevalence of diarrheal illness is rising due to a decrease in the supply of high-quality water [40]. Cholera's present prevalence in specific Gambian regions may make it a serious health concern as well. Furthermore, following a climate-related disaster, rural populations face immediate threats to livelihoods and food security due to the significant damage to property and livestock [41].

3. Methods of Research

The study employed a qualitative research technique, which is frequently used to reveal the current level of scientific evidence in this particular topic. With an emphasis on Africa, this study introduces the main issues raised in the literature about land use, climate change risk, and renewable energy before focusing on the Gambian setting. This research method does not require interviews or questionnaires but rather measurement of reading relationships of different detected parameters of ambient air pollutants and scientific experimentation and observations. Air quality parameters (CO, NO, O₃, PM₁₀, and PM_{2.5}), ammonia, temperature, pressure, weather, dew point, wind speed, and humidity were measured once a week over six months using an electronic air meter (Model 460 DG) and a (Thermometer++ app) which uses phones sensors to measure both indoor and outdoor temperature, humidity, pressure and wind. Triplicate measurements yielded 1,080 sample samples. Pollutants were classified using the Pollution Standard Index (PSI) and color-coded categories [42].

3.1. Study Area

The study was carried out in the Kombo North, in The Gambia, during Organization of Islamic Countries (OIC) road construction along the Senegambia axis to the airport junction at Yundum. The West Coast Region in the Gambia was reorganized and renamed by the Brikama Local Government Area (BLGA) but

still maintained the same size of land. The Gambia's Kombo North District is precisely plotted in zone 28P of the Universal Transverse Mercator (UTM) coordinate system. Its precise location inside the global grid is provided by its UTM Northern coordinate of 1478073.3871203 and its UTM Eastern coordinate of 644384.62981753. Additionally, the position of Kombo North District is encoded in the GeoHash system as edkhh9rdqryh, a compact representation that is helpful for a variety of geospatial applications. The coordinates of Kombo North District are latitude $13^{\circ}22'0.012''$ N and longitude $-16^{\circ}40'0.012''$ E. The Gambia West Coast Region 8 (WCR-8) is 183.70 kilometers square, with a population density of 1847.50 cubic grams per centimeter, and currently has 339,377 residents, both male and female.

3.2. Data Collection

A total of one thousand and eighty (1080) samples consisting of fifteen (15) different air pollutant parameters were collected with an air meter and analyzed for a total of six (6) months. Data collection was done in the early hours of the morning between 8:00 am and 10:00 am on each sampling day. Data were collected once a week, four times a month, making a total of twenty-four (24) field visits for samples. For each parameter, a triplicate reading (measurement) was taken, before the average value for every interval of six minutes during the field visit, for the duration of the study. Each air pollution parameter recorded a total of forty-five samples for one month; in six months, it accounted for a total sample size as expressed below.

3.3. Size of the Sample

A sample size (N) of one thousand and eighty (1080) was obtained during the sampling period. Fifteen (15) different air pollutants were recorded by the air quality meter. A second digital thermometer was also utilized to measure the temperature over the six-month data-collecting period in conjunction with the Model-460 DG draft gauge electronic. Fifteen air parameters were measured in a given week; each air parameter was measured three times (triplicates) at an interval of six minutes before the average reading was taken, resulting in a final set of forty-five (45) parameters. Since data collection was done once in a week, four times in a month. Each month data, gave a total of one hundred and eighty (180) samples (*i.e.*, 4×45). For the whole six-month sampling periods, it will amount to a total of one thousand and eighty that is ($6 \times 180 = 1080$).

3.4. Assessment of Air Pollution

Measures of ambient air pollution were assessed using a Thermometer++ app which uses phones sensors to measure both indoor and outdoor temperature, humidity, pressure and wind; as well as an electronic air meter. The majority of air pollutant parameters that were found were examined and put through the pollution standard index (PSI) as a guide to determine the impacts of the concentration on human health with reference to our respiratory system and atmospheric ozone.

Color serves as a signal for identifying air pollutants in the area. Even though it is used to classify them based on the color displayed on the air meter screen. Green color indicates (good) and ranges from 0 - 50; yellow color represents (fair or moderate) and ranges from 51 - 100; orange color (unhealthy) ranges from 101 - 150; red color (not healthy) ranges from 151 - 200; purple color (very unhealthy) ranges from 201 - 300; and maroon (hazardous) ranges from 301 and above.

3.5. Statistical Analyses

This study employed a central tendency and dispersion trial to standardize and classify each contaminant update [43]. Information gathered about different air pollutants falls into different classes depending on their levels of concentration, and comparisons were also made in terms of color detections displayed on a detector screen during data collection periods to know their levels of effect on humans, land, and the environment. The country's selected study area demonstrates notable shifts in the presence of air pollutants in terms of class/category, air color, index value of pollution and levels of indication according to [44] (See **Table 1**).

Table 1. Categories of air color and air quality.

Categories/Classes	Air Color	Index Value	Levels of Indication
1	good	0 - 50	Green
2	Yellow	51 - 100	Fair/moderate
3	Orange	101 - 150	Not for some group of people
4	Red	151 - 200	Unhealthy for everyone/endangers everyone
5	Purple	201 - 300	Very Unhealthy
6	Maroon	301 above	Hazards

Results obtained from data analysis are shown in **Table 2** above, indicated five main contaminants; such as carbon monoxide, Ozone, ammonia and particle matters as the main cause of climate change effects the environment due to their pollutant level of concentrations. Carbon monoxide found in category 6, with maroon color indication, showed health hazard issues to humans, particulate matter 10, found in category 5, had purple color indication, revealed very unhealthy health challenges to humans. Particulate matter 2.5, ozone and ammonia, all falls in category 3 respectively, with an orange coloration indication, meant unhealthy for some sensitive group of people. However, other pollutants with green and yellow coloration indications, do not pose any threat to humans because they appear green or yellow in color, indicating good, fair or moderate.

Table 2. Spatial assessments variation of global warming/climate change impacts on human, land use management in West Coast Region in The Gambia, West Africa.

Air Pollutants	Symbols	S. I Units	N	SD	Mean \pm SE	Min - Max
Air Quality Index	AQI	$\mu\text{g}/\text{m}^3$	24	3.20	7.50 ± 0.61	1.00 - 12.00
Carbon monoxide	CO	$\mu\text{g}/\text{m}^3$	24	97.92	348.84 ± 19.98	180.00 - 370.00
Nitrogen monoxide	NO	$\mu\text{g}/\text{m}^3$	24	155.66	66.74 ± 31.77	0.10 - 200.00
Nitrogen (IV) oxide	NO ₂	$\mu\text{g}/\text{m}^3$	24	155.32	67.46 ± 31.70	0.13 - 200.00
Ozone	O ₃	$\mu\text{g}/\text{m}^3$	24	45.92	128.08 ± 9.37	29.00 - 150.00
Sulphur (IV) oxide	SO ₂	$\mu\text{g}/\text{m}^3$	24	15.26	7.40 ± 3.11	0.20 - 20.00
Ammonia	NH ₃	$\mu\text{g}/\text{m}^3$	24	310.86	126.91 ± 63.45	0.01 - 400.00
Particulate Matter	PM ₁₀	$\mu\text{g}/\text{m}^3$	24	187.44	230.72 ± 38.26	16.00 - 289.00
Particulate Matter	PM _{2.5}	$\mu\text{g}/\text{m}^3$	24	194.88	131.38 ± 39.78	2.04 - 357.00
Temperature	T	$^{\circ}\text{C}$	24	4.61	32.26 ± 0.94	23.00 - 39.00
Pressure	P	Hg	24	23.08	49.34 ± 4.71	1.00 - 50.00
Weather	W	degree	24	7.84	52.66 ± 1.60	20.00 - 32.00
Dew Point	DP	degree	24	18.54	26.30 ± 3.78	1.00 - 25.00
Wind-speed	WS	m/s^1	24	5.05	17.13 ± 1.46	11.00 - 27.00
Humidity	H	%	24	25.65	61.83 ± 7.41	29.00 - 89.00

Here, n = 24, all displayed values are expressed as mean \pm S.E (Range).

4. Results and Discussion

Serious threats to both humans and the environment was observed, with some primary air pollutant parameters found in categories 3 to 6 of the air pollutant baseline classes. Those found in categories 1 and 2, marked green and yellow coloration; do not have adverse effects, as shown in **Figure 1** and **Figure 2**. Improved air quality is a global issue that may worsen, due to climate crisis when compared to Pollution Standard Index (PSI) as a major global concern, since the PSI serves as a benchmark for comparison of other air pollutant parameters, as the air meter records Air Quality Index (AQI). Key pollutants affecting the environment, human health, land use and management include:

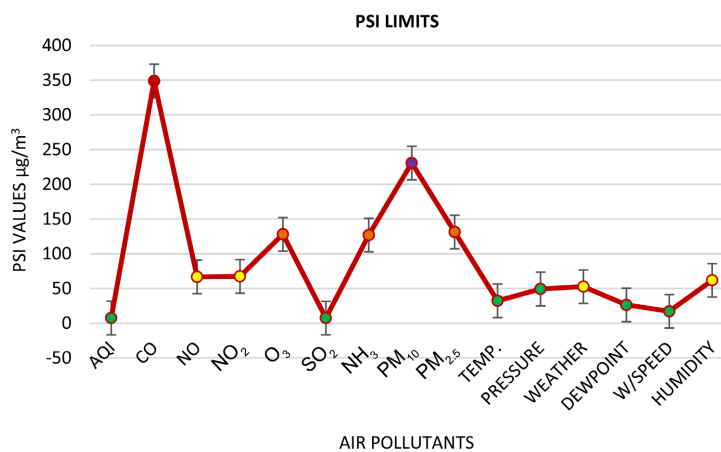


Figure 1. Spatial variation trends of global warming/climate change impacts assessment on human, land use and management.

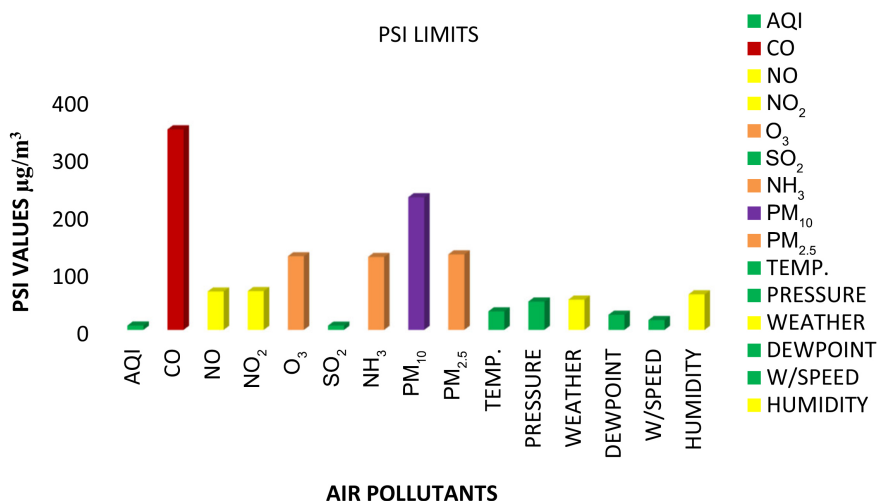


Figure 2. Spatial air pollutants risk assessment impacts level color indication on human and the Environment.

The Air Quality index (AQI), as shown in Table 2, ranged from 1.00 to 12.00 $\mu\text{g}/\text{m}^3$; recorded mean value of $7.50 \pm 0.61 \mu\text{g}/\text{m}^3$. This corresponds to green color, indicating good air quality for humans and the environment in relation to the baseline pollution standard index. This parameter does not pose any threats on its own to the environment, human health, land use and management in the study locations, this disagreed with the work done by [45] that recorded high air quality index in Nigeria due to population increase as well as industrialization expansion.

Carbon Monoxide (CO): This is a colorless gas which contains one carbon atom as well as an oxygen atom with concentrations ranging from 180 to 370 $\mu\text{g}/\text{m}^3$. The mean value recorded was $348.84 \pm 19.98 \mu\text{g}\cdot\text{m}^{-3}$, placing it in category 6 (maroon coloration), which indicates hazardous levels. CO emissions primarily result from burning fossil fuels for power, transportation, and industrialization. It was noticeable because in the presence of atmospheric air (oxygen) during burning, it forms carbon dioxide, a dominant greenhouse gas that causes global warming and climate change. As a poisonous, flammable gas, thicker than air, oxides of carbon (CO & CO₂) significantly contribute to climate change and are the highest determinant among air pollutants, as illustrated in zigzag form, in Figure 1, showing the trends to which global warming and climate change effects alternatively operate. Since Wood, gasoline, charcoal, natural gas, and kerosene are examples of carbonaceous fuels that generate carbon monoxide, a deadly gas that is colorless, odorless, and tasteless, when they don't burn fully [46].

Nitrogen Monoxide (NO): With a range of 0.10 - 200 $\mu\text{g}\cdot\text{m}^{-3}$ and a mean value of $66.74 \pm 31.77 \mu\text{g}\cdot\text{m}^{-3}$, NO falls into category 2 (yellow coloration), indicating moderate levels. Due to human actions like deforestation and intensive farming that exacerbate its environmental impacts. NO contributes to smog formation, reduces plant photosynthetic capacity, traps atmospheric heat, and damages the ozone layer. Its fluctuating trend relative to the PSI is shown in Figure 2.

Nitrogen Dioxide (NO₂): Ranging from 0.13 - 200 $\mu\text{g}\cdot\text{m}^{-3}$, NO₂ had a mean

value of $67.46 \pm 31.71 \mu\text{g}\cdot\text{m}^{-3}$, categorized as moderate (yellow). It harms human health and ecosystems by degrading air, soil, and water quality. NO_2 emissions drive tropospheric ozone (O_3) and fine particle pollution, with reactive nitrogen contributing to 15% - 30% of $\text{PM}_{2.5}$ in rural and urban areas, respectively [47].

Ozone (O_3): The mean ozone concentration was $128.08 \pm 9.37 \mu\text{g}\cdot\text{m}^{-3}$ found in category 3, having orange coloration, indicating unhealthy levels for all, particularly children, elderly, and outdoor workers. Prolonged exposure impairs lung function and exacerbates asthma [48].

Sulfur Dioxide (SO_2): This is generated by fuel combustion and volcanic activity, SO_2 ranged from 0.20 - 20.00 $\mu\text{g}\cdot\text{m}^{-3}$, with a mean value of $7.40 \pm 3.11 \mu\text{g}\cdot\text{m}^{-3}$, which is found in category 1, as green color indication. It contributes to acid rain, respiratory illnesses, and material corrosion. Although it doesn't pose any health effects in this study due to its low concentrations.

Ammonia (NH_3): This has a mean concentration value of $126.91 \pm 63.45 \mu\text{g}\cdot\text{m}^{-3}$ found in category 3, with orange coloration, NH_3 promotes fine particle formation and reflects sunlight, influencing climate patterns. Uncertainties remain in modeling its atmospheric impact.

Particulate Matter 10 (PM_{10}): Ranging from 16.00 - 289.00 $\mu\text{g}\cdot\text{m}^{-3}$, it had a mean value of $230.72 \pm 38.26 \mu\text{g}\cdot\text{m}^{-3}$, PM_{10} falls into category 5 (purple color), labeled as "very unhealthy". It causes respiratory and cardiovascular diseases and damages ecosystems via acid rain. In fact major cause of global warming and climate change is gaseous substances and particulate matters of different sizes.

Particulate Matter 2.5 ($\text{PM}_{2.5}$): This have a mean value of $131.38 \pm 39.78 \mu\text{g}/\text{m}^3$, it is found in category 3, with orange color, $\text{PM}_{2.5}$ contributes to global warming, infiltrates the bloodstream and reduces agricultural productivity.

Temperature: This ranged from 23.00°C - 39.00°C , mean value of $32.26^\circ\text{C} \pm 0.94^\circ\text{C}$, aligning with baseline data [49]. Rising temperatures directly reflect climate change. The air humidity has a stronger effect on $\text{PM}_{2.5}$ concentration than temperature, the relationship between temperature and $\text{PM}_{2.5}$ concentration varies depending on the location in regard to AQI.

Pressure, Weather, Dew Point, Wind Speed, and Humidity: All parameters here, fell within safe acceptable range for both human health and the environment. Apart from humidity that had moderate $61.83\% \pm 7.41\%$, which may cause fatigue as the case maybe.

With regard to AQI, the relationship between humidity and $\text{PM}_{2.5}$ concentration varies by region.

4.1. The Effects of Global Warming on Human Health

The two main factors contributed to global warming/climate change that have an impact on people's health were elucidated by the US Environmental Protection Agency. These factors are the prevalence of pre-existing health issues or unexpected health issues or new locations. Pest-related illnesses (including Lyme disease), illnesses linked to food and water, injuries, fatalities, and heart and respira-

tory conditions are some of these impacts on people’s health. Many climatic consequences can be experienced simultaneously by people at varying stages of their lives, highlighting the fact that exposure, sensitivity, and adaptation capability are the three main characteristics that determine an individual’s susceptibility to the effects of climate change.

Figure 1 above, illustrates the trends in which global warming variability leading to climate change occurred, and **Figure 2** showed the risks and color indications of these air pollutants indication that results to global warming/climate change. Green & yellow color indicates low risk, while other colors signify escalating threats. Africa experienced the sharpest rise insecurity in aspect of food during 2014 to 2017, as well as the state of food security and nutrition in the world 2018 according to [50].

4.2. Strategies for Climate Change Adaptation and Mitigation

The threat posed by climate change to world health is increasing, necessitating urgent action [51]. Mitigation (reducing emissions) and adaptation (managing impacts) are critical. Transitioning to sustainable energy and improving efficiency of energy can reduce air pollutants, thereby enhancing public health.

4.3. Methods for Climate Change Adaptation and Mitigation

The diagram below in **Figure 3** outlines strategies such as carbon pricing, sustainable energy policies, deforestation frameworks, and public awareness campaigns.

Mitigation actions for reducing emissions that causes climate change	Relationship between mitigation actions and adaptation actions.	Adaptation actions to minimize or prevent the negative impacts of climate change
<ul style="list-style-type: none"> • Sustainable transportation • Energy efficiency • Renewable energy • Capture and landfills and digester gas • More active transportation (cycling and walking) • Reduce air travel 	<ul style="list-style-type: none"> • Education • Local food system • Water conservation • Complete communities • New energy systems • Urban forest 	<ul style="list-style-type: none"> • Food protection • Disaster management and business continuity • Infrastructure upgrades • Health programs • Emergency and business planning • Continued planning for extreme weather event • Help for vulnerable people

Figure 3. Strategy for mitigation and adaptation to climate change.

4.4. Mitigation Methods to Decrease Emissions of Greenhouse Gas

Worldwide coordination, cleaner technologies, and energy efficiency standards (e.g., DAC, CAFE, and LEED certification) have reduced energy consumption by 10% [52].

5. Recommendations

Based on the study carried out, the following are recommended as:

- 1) Implement climate mitigation policies to curb global warming.
- 2) Adopt hybrid electric vehicles (HEVs) to reduce emissions.
- 3) Transition to renewable energy for sustainable environments.
- 4) Distribute portable air quality meters to monitor pollution levels.

6. Conclusions

The study identified five key air pollutants driving climate change impacts on human health, the environment, land use, and management in the Kombo North, West Coast Region of the Gambia. Hazard levels were coded in terms of color: maroon (≥ 300 concentration, hazardous), purple (very unhealthy), and orange (limited vulnerability) were used as baselines based on the mean values of different parameters detected.

Capacity building, education, public participation, public awareness, and coordination are the major elements for immediate strategies for climate change impact amelioration, like community innovation, policy changes, and technologies are urged to combat heat stress, disease shifts, respiratory and cardiovascular issues, and food system risks. Further efforts should be focused on global cooperation and education to advance climate resilience.

The use of sustainable energy, transportation, agriculture, and ecosystem restoration, can improve air quality, nutrition, and overall well-being while reducing greenhouse gas emissions. Collaboration and cooperation among governments, international organizations, medical professionals, researchers and business communities can foster innovative solutions and shared vision for future generations' healthier planet, depending on our commitment to environmental stewardship and responsible resource management.

Conflicts of Interest

Authors disclose no conflicting financial interest's connections influencing this work.

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