# Climate, Urbanization and Environmental Pollution in West Africa

Subjects: Environmental Sciences

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The need to elucidate the urbanization–climate–pollution nexus in West Africa arose from the several reported, but disjointed cases of climate extremes and environmental degradation in the sub-region. Since colonization and subsequent independence of nations in the West African region, several urban cities began to spring up and gradually grow. Urbanization was essentially characterized by population growth without complementary infrastructural development, weak coping strategies against climate extremes, numerous economic challenges, and high risk of environmental pollution. Initiative for urban renewal, urban greening and smart city development was low, and preparedness against future impact of extreme climate events and climate change is uncertain.

urbanization–climate–pollution nexus environmental pollution mitigation and control measures urban restoration smart city sustainable development goals international cooperation West Africa

## 1. Introduction

Studies have shown that the nexus between urbanization and environmental change within the context of climate change patterns is both interactive and complex, requiring understanding of regional and inter-regional scenarios [1][2]. Urbanization (a general increase in population, infrastructural development and industrialization [3]) is recent in the West African region, as only a few settlements were urban before colonization [4][5][6]. Yukon [7] argued that urbanization in the West African region had evolved in connection with industrial revolution in Europe and America. Prior to that, most West African settlements were principally rural and agrarian, although trans-Saharan trade and, later, the slave trade had created a few urban cities before colonization. However, since colonization and subsequent independence of nations in the West African region, several urban cities began to spring up and gradually grow [6]. According to Castells-Quintana & Wenban-Smith [8], urbanization is now a sign of the times, and urban rural migration which started in the developed nations has gradually reached developing nations, and many people have moved to cities in hopes of better, more prosperous ways of living. Urban growth was further exacerbated by a combined improvement in technologies, sanitation and medical services, which caused both mortality and birth rates to decline, while net population increased [9].

The increasing human population in many urban areas appears to put some level of pressure on many aspects of urban life. It is now estimated that by 2050, 66–70% of the world's population will live in urban areas. However, this varies from one country to another in West Africa [9][10], increasing from the least urbanized to the most urbanized. Urbanization is estimated at over 60% in Gambia, being the most urbanized country in the sub-region, and 20% in Niger, the least urbanized country in West Africa [11][12]. Urbanization level is between 50% and 60% in Ghana, Mauritania, Liberia, Nigeria and Cote d'Ivoire [11][12]. There are clear indications that some countries in West Africa may attain the world estimated peak of 70% by 2050.

The consequences of urbanization are multifarious and diverse; some are advantageous, others disadvantageous. Paradoxically, it is the same set of development projects that also give rise to disadvantageous consequences [13]. Developmental projects include physical infrastructure for improved industrial and agricultural production, advancement in commerce, healthcare delivery, energy production and utilization; especially biomass energy, road and rail transportation and built-up infrastructure, among others [14][15]. Unraveling the environmental impact of urbanization in any region will essentially involve elucidation of the impacting developmental projects, their types, age and spread in different areas of the region. In West Africa, for instance, an analysis of the stochastic distribution of environmental impacts in different countries of the region, must first begin with an elucidation of developmental projects in each nation. A higher-level analysis will require an assessment of the correlation between the project clusters and environmental impacts in each nation and whether the impact of the projects on the overall sustainability of the environment may lead to a fatal flaw (i.e., limited to the project or the nation) or fundamental impediment (i.e., spread beyond the project and probably across borders to other nations). The outcome of such an assessment will clearly define the most feasible goal of environmental management among environmental restorations, rehabilitation or abandonment [16]. It will also help to determine the best action or strategy required to achieve the preferred goal. Given the rising concerns for climate variability/change and extreme events, studies (e.g., [17][18]) have shown a complex and non-linear relationship with urbanization, probably due to differences in planning policies and response strategies. In Africa, information on the urbanization–climate variability is complex and relatively undefined [18].

Furthermore, although scattered information on development projects and their environmental impacts may be available in the different nations of West Africa, very limited efforts have been made to collate such information for a comprehensive analysis of environmental pollution sources and impacts. Such analysis will help to establish a region-wide action plan for sustainable environment of the sub-region. Although the sub-region has an environmental policy whose goal is to improve on the management of the environmental heritage to support development, the policy did not emphasize actions to improve on the management of development to sustain environmental heritage. This is the major objective of this entry. An effort to review the climate, urbanization and environmental pollution in West Africa promises to be as enormous as it is interesting. It presents an opportunity to unravel the degree to which urbanization contributes to environmental pollution in a region characterized by complex and diverse climatic situations.

The complex and diverse climatic conditions are a reflection of the fact that West Africa is large and expansive. It occupies a land area of 6.14 million km$^2$, spanning 20 Latitudes north of the equator (4–23° N) and 33 Longitudes symmetrically spread across the west and east regions of the Greenwich Meridian (17° W–16° E) [19]. It is located in the westernmost part of Africa, bulging southwards to the Atlantic Ocean and extending northwards to the southern edge of the Sahara Desert, at an elevation of 400 m [20][21][22]. According to the latest United Nations estimates, the current population of West Africa is 420,802,185 which is equivalent to 5.16% of the total world population and more than half the population of Europe [23]. The climate of West Africa is generally tropical but varies significantly from one country to the other according to the latitudes and longitudes. According to Nicholson [21], high-latitude Sahel countries at the fringes of Sahara Desert, such as Mali, Niger, and Burkina Faso, experience only one rainy season. This lasts from one to six months per annum, while low latitude coastal countries bordering the Atlantic Ocean, from Gambia to Nigeria, are characterized by two rainy seasons, a long one and a shorter one separated by a short dry spell known as harmattan.

# 2. Relationships among Climate, Urbanization and Pollution

## 2.1. Effects of Climate on Human Health

Reviews of studies across the West African region indicate that human and physical environments are vulnerable to the effects of climate change, extreme climatic conditions and vulnerability [24][25][26][27][28][29][30]. The effects are both direct and indirect, direct effects being an increase in morbidity and mortality cases [28][31], while indirect effects include the impact on livelihoods, such as food and water resources. A report by the International Development Research Centre (IDRC)-funded *AfricaInteract* project noted the following in their summary [32]:

- Temporal variability of cholera incidence and epidemics was consistently associated with both local rainfall and the global climate variability in coastal West African countries;
- Of the 14 diseases meeting World Health Organization (WHO) criteria for using climate data in predicting epidemics, six vector-borne diseases (malaria, African trypanosomiasis, leishmaniasis, yellow fever, dengue and Rift Valley fever) are present in West Africa;
- The six diseases, with schistosomiasis, are already major contributors to the disease burden in West Africa;
- The decrease in malaria prevalence and incidence is associated with the decline in rainfall, in Sahelian part of the West African regions;
- Links between climate change and human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) are still conjectural, but they are becoming a subject of increasing concern and study.

Direct effects of climatic conditions on infectious diseases across the region are summarized with specific diseases in **Table 1** [33]. Thomson et al. [33] noted that many of the vector-bone (malaria, Rift Valley fever, yellow fever; relapsing fever, lymphatic filariasis, onchocerciasis) and non-vector-borne (diarrheal and measles) infectious diseases that are linked with the very high rates of child mortality are climate-related, whereby the transmission [29] often varies with or is influenced by weather or climatic conditions (see **Table 1**). In general, Orimoloye et al. [26], in a review of publications from the period 2000–2018 on the climate–human health relationship in West Africa, recognized ‘extreme temperature’, ‘altered rainfall pattern’ and ‘sea level rise’ as main concerns in the region. With relevance to extreme temperature, Orimoloye et al. [26], among others, reported that an association between climate change and the health impact of temperature on mortality or non-infectious disease outcomes were inconsistently recognized in studies from the region. The authors also argued that cardiovascular and infectious respiratory diseases exhibited a strong association with mortality and morbidity risks caused by the increased temperature in the region. The review [26] also noted that many rainfall-related studies on the region have predominantly focused on the impact of infectious and vector-borne diseases, but with a lack of consistent associations, while the relationship between rainfall and non-communicable diseases is still poorly known. The poor knowledge in this regard and the report that no known study has associated the health outcomes of sea-level rise to either or both of infectious diseases and non-communicable diseases in the region indicate a knowledge gap in this respect.

**Table 1.** Common climate-related major causes of morbidity and mortality in West Africa [33].

| Disease (and Causative Organism) | Mode of Transmission/Vector | Potential Climate/Environmental Determinants |
|---|---|---|
| Malaria (*Plasmodium* sp.) | Mosquitoes (*Anopheles* sp.) | Rainfall, humidity, temperature, surface water and change in vegetation greenness |
| Rift Valley fever (*Phlebovirus*) | Mosquitoes (*Aedes* sp.) | Rainfall, humidity and temperature |
| Yellow fever (*Flavivirus*) | Mosquitoes (*Culex* sp.) | Surface water and change in vegetation greenness |
| Lymphatic filariasis (*Wuchereria bancrofti* in Africa) | Mosquitoes (*Anopheles* sp., *Aedes* sp., *Culex* sp.) | Rainfall, humidity, temperature, surface water and change in vegetation greenness |
| Relapsing fever (*Borrelia*) | Soft ticks (*Ornithodorus*) | Rainfall, humidity, temperature and change in vegetation greenness |
| Trachoma (*Chlamydia trachomatis*) | *Musca sorbens* and mechanical transmission | Temperature and humidity |
| Meningococcal meningitis (*Neisseria meningitides*) | Airborne aerosol | Absolute humidity, dust and temperature |
| Pneumonia (viral, bacterial, mycoplasmas, and other causes) | Airborne aerosol | Cold temperatures |
| Cholera (*Vibrio cholerae*) | Filth flies (e.g., *Musca* sp. and mechanical transmission) | Poor water sources, flooding of excess pits, and algal blooms |
| Diarrheal diseases (rotavirus and other viral and parasitic infections) | Filth flies (e.g., *Musca* sp. and mechanical transmission) | Poor sanitation associated with water shortages |
| Schistosomiasis/bilharzia (*Schistosoma* sp.) | Snails (e.g., *Bulinus africanus*) | Surface water |
| Sleeping sickness (*Trypanosoma brucei gambiensis*) | Tsetse (*Glossina* sp.) | Gallery forests and savanna woodland |
| Blackflies (*Cyclops* sp.) | Blackflies (*Cyclops* sp.) | Surface water |
| African eye worm (*Loa loa*) | Blackflies (*Chrysops* sp.) | Forest canopy and forest soils |
| River blindness (*Onchocerca volvulus*) | Blackflies (*Simulium* sp.) | Wind and river discharge |

## 2.2. Effects of Utilization of Public Utilities on Pollution and Human Health

Public utilities such as electricity, water, transportation, and telecommunications are crucial for socio-economic growth, and their absence would negatively impact the economy [34]. **Table 2** and **Table 3** compare the levels of accessibility of the population to water, sanitation services as well as air pollution in the different countries in the region. The accessibility of the rural population to basic drinking water and sanitation services was relatively much lower than that obtained in the urban areas, in all the countries (**Table 2**). Mauritania, Niger and Sierra Leone recorded the least access to basic water and sanitation services in the region. On the other hand, the urban population were better served, although accessibility was relatively lower in Mauritania and Niger than other countries in the region (**Table 2**). While a lack of data made it impossible to compare the accessibility for safely managed water for all the countries, those with available data showed very weak levels of accessibility, with Cote d'Ivoire (54.5–56.9 %) being the most served country in terms of safely managed water supply, in the region. **Table 2** reveals that no country in West Africa served its rural population up to 30% safely managed water and sanitation services, and that the population of Cape Verde were relatively better served in these facilities than any other country in the region. Van den Berg and Danilenko [35] linked the poor access to water and sanitation utilities in the region to rapid population expansion, which the utilities were not provided to cover.

**Table 2.** Access to water and sanitation services in West African Countries.

| | Basic Drinking Water Services (% of Population) | | | Safely Managed Drinking Water Services (% of Population) | | | Basic Sanitation Services (% of Population) | | | Safely Managed Sanitation Services (% of Population) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Total** | **Rural** | **Urban** | **Total** | **Rural** | **Urban** | **Total** | **Rural** | **Urban** | **Total** | **Rural** | **Urban** |
| Benin | 62.2–65.4 | 52.7–58.1 | 77.5–73.3 | * | * | * | 9.2–17.0 | 2.6–8.0 | 19.9–26.5 | * | * | * |
| Burkina Faso | 58.1–47.2 | 53.5–32.7 | 79.1–80.1 | * | * | * | 10.6–21.7 | 2.3–13.5 | 40.3–48.5 | * | * | * |
| Cape Verde | 79.1–88.8 | 70.1–80.1 | 86.9–93.1 | * | * | * | 39.6–79.1 | 21.1–71.9 | 55.7–82.7 | * | * | * |
| Cote d’Ivoire | 71.4–70.9 | 56.2–55.7 | 91.4–85.1 | 34.2–35.2 | 14.6–17 | 54.5–56.9 | 21–34.6 | 7.4–20.5 | 38.9–47.7 | * | * | * |
| Gambia | 73.8–80.9 | 65.2–69.2 | 83.1–88.0 | 23.5–44.7 | 4.3–7.6 | 44.4–66.9 | 46.9–51.1 | 25.5–59.5 | 42–59.6 | 43.2–29 | 57.3–24.2 | 27.9–31.8 |
| Ghana | 63.8–85.8 | 53.2–71.9 | 77.5–96.1 | 13.3–41.4 | 0–16.1 | 30.2–60.3 | 7.4–23.7 | 3.0–17.4 | 13–28.4 | 4.4–13.3 | 2.6–15.0 | 6.6–12.1 |
| Guinea | 53.2–64.0 | 42.2–50.7 | 77.8–86.6 | * | * | * | 8.8–29.8 | 3.2–20.5 | 21.3–45.6 | * | * | * |
| Guinea-Bissau | 56.0–59.0 | 43.4–49.8 | 78.2–70.6 | 17.6–24.3 | 4.7–11.2 | 40.3–40.9 | 5.2–18.2 | 0.7–5.2 | 13.1–34.7 | 3.3–12.2 | 0.5–4.2 | 8.2–22.2 |
| Liberia | 61.7–75.3 | 49.1–64.1 | 77.4–85.5 | * | * | * | 13.2–18.2 | 4.0–6.4 | 24.7–29.0 | – | – | – |
| Mali | 49.5–82.5 | 39–72.1 | 75.9–95.9 | * | * | * | 15.7–45.4 | 8.2–37.3 | 34.8–55.8 | 6.1–19.9 | 5.8–28 | 7.0–9.6 |
| Mauritania | 41.0–71.7 | 25–49.9 | 67–89.3 | * | * | * | 17.4–49.8 | 7.0–18.9 | 34.5–74.8 | – | – | – |
| Niger | 36.8–46.9 | 26.1–39.2 | 92.6–85.8 | * | * | * | 5.3–14.8 | 1.8–7.4 | 23.3–51.7 | 5.8–16.2 | 2.5–10.8 | 23.2–43 |
| Nigeria | 43.2–77.6 | 30.4–61.7 | 66.9–92.4 | 13.7–21.7 | 9.5–17.7 | 21.5–25.4 | 28.6–42.7 | 28.0–33.0 | 29.8–51.7 | 21.3–30.5 | 21.9–25.6 | 20.1–35.1 |
| Senegal | 59.6–84.9 | 40.2–75.2 | 88.3–95.3 | * | * | * | 37.5–56.8 | 21.2–46.2 | 61.5–68.1 | 14–24.1 | 12.9–23.9 | 15.6–24.4 |
| Sierra Leone | 40.6–63.8 | 25.8–52.8 | 67.3–78.4 | 4.8–10.6 | 1.7–9.2 | 10.5–12.5 | 10.2–16.5 | 4.3–9.9 | 20.9–25.3 | 8.8–14.0 | 4.3–9.7 | 16.8–19.8 |
| Togo | 45.3–68.6 | 28.8–52.1 | 78.9–90.6 | 10–19.6 | 4.2–6.7 | 21.7–36.8 | 9.6–18.6 | 2.9–8.2 | 23.2–32.5 | 5.5–9.1 | 2.6–6.8 | 11.4–12.3 |

**Table 3.** Access to selected public utilities services in West African Countries. (Data source: www.databank.worldbank.org/source/world-development-indicators/preview/on# (accessed on 15 August 2022).

| Countries | Greenhouse Gases Emissions in 2000–2019 | | | Access to Electricity (% of Population) in 2000–2019 | | |
|---|---|---|---|---|---|---|
| | **$CO_2$ Emissions Overall (Kt)** | **$NO_2$ (000 Metric Tons of $CO_2$ Equivalent** | **Kt Of $CO_2$ Equivalent (2000–2019)** | **Rural** | **Urban** | **Total** |
| Benin | 1420–7300 | 2380–2720 | 7030–15020 | 5.4–18.2 | 47.5–66.1 | 21.5–41.4 |
| Burkina Faso | 940–5000 | 6390–10120 | 16130–32210 | 2.3–4.7 | 40.3–65.8 | 9.1–19.0 |
| Cape Verde | 220–650 | 80–60 | 370–810 | 31.5–93.5 | 81.9–94.5 | 58.4–94.2 |
| Cote d’Ivoire | 6490–10830 | 3030–3090 | 25870–24860 | 23.7–43.1 | 81.5–94.5 | 48.7–69.7 |

source:

| Countries | Greenhouse Gases Emissions in 2000–2019 | | | Access to Electricity (% of Population) in 2000–2019 | | |
|---|---|---|---|---|---|---|
| | $CO_2$ Emissions Overall (Kt) | $NO_2$ (000 Metric Tons of $CO_2$ Equivalent | Kt Of $CO_2$ Equivalent (2000–2019) | Rural | Urban | Total |
| Gambia | 240–580 | 310–330 | 2290–2340 | 18.8–31.6 | 51.2–80.6 | 34.3–62.3 |
| Ghana | 5740–20040 | 4490–5370 | 17630–37650 | 14.9–74 | 80.5–94.7 | 43.7–85.9 |
| Guinea | 1490–3950 | 3030–6670 | 11470–28330 | 0.6–19.3 | 55.9–88.1 | 15.1–44.7 |
| Guinea-Bissau | 150–330 | 520–780 | 1540–2580 | 2.1–15.2 | 24–56.3 | 1.3.–33.3 |
| Liberia | 430–1180 | 170–350 | 840–2220 | 1.0–8.4 | 6.9–45.2 | 3.0–27.5 |
| Mali | 1410–5830 | 8100–14260 | 21680–44150 | 1.8–16.5 | 33.7–94.1 | 9.6–50.6 |
| Mauritania | * | * | * | 2.6–3.1 | 45–88.4 | 18.7–47.3 |
| Niger | 670–2150 | 5690–12590 | 19010–42720 | 2.0–13.4 | 40.7–48.4 | 6.5–19.3 |
| Nigeria | 97220–115280 | 26310–40280 | 235930–308180 | 21.3–24.6 | 84–83.9 | 43.1–55.4 |
| Senegal | 4060–10620 | 4960–5650 | 17760–29230 | 12.8–47.4 | 74.6–95.2 | 37.7–70.4 |
| Sierra Leone | 330–900 | 440–1300 | 2440–6080 | 3.7–4.8 | 23.4–54.7 | 7.8–26.2 |
| Togo | 1270–2370 | 1170–1790 | 4390–7890 | 6.4–24 | 38.5–94.1 | 17.0–54.0 |

Asterisked (*) section has no data/record available as of the time of compilation.

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nufacturing
ere are no
data on their sources to correctly determine where they come from. Nonetheless, studies have shown that industrial activities and transportation are major sources of greenhouse gases in the regions [36][37].

## 2.3. Effects of Utilization of Land and Water on Biodiversity and Physical Resources

Utilization of land and water resources occurs at different spatial magnitudes and intensities in West Africa, causing different levels of impact on the biodiversity across countries in the region. **Table 4** documents the varying levels of vulnerability of the land resources to different degrees of vulnerability to desertification, due to the extent of land use and climatic influences among West African countries, as of 2001 [37]. From **Table 3**, 82.9% of land resources in Gambia was considered to be 'highly' vulnerable to desertification, but no piece of land was considered to exhibit 'low' vulnerability in Mauritania, where 93% of the land area is climatically dry. Niger, Mauritania and Mali were considerably dry and vulnerable to drought conditions; these three countries have also experienced severe drought conditions in recent times—up to 2015 [38]. In general, Romankiewicz [39] reported that many of the countries in the region that are off the coastlines have experienced high rate of desertification, wind erosion and deforestation, with significant influence on the worsening conditions of migrations and inter-tribal conflicts in the region. With respect to water-related stress, Liberia was estimated to be the most vulnerable to water-based stress in the region, with a 93% index, probably because of the relatively smaller proportion of the land area of the country to water bodies, compared to countries such as Nigeria. Other vulnerable countries, including Cote d'Ivoire, Ghana and Sierra Leone, were not as vulnerable (**Table 4**).

**Table 4.** Percentage of total area distribution across countries in West African region, based on degree of vulnerability and stress conditions (dryness or wetness). Data are from [37].

| Country | Degree of Vulnerability | | | | Stress-Based Vulnerability | |
|---|---|---|---|---|---|---|
| | Low | Moderate | High | Very High | Drought-Based Stress | Water-Based Stress |
| Benin | 5.4 | 63.1 | 31.4 | 0 | 0 | 0 |
| Burkina Faso | 11.6 | 37.8 | 45.3 | 4.6 | 0.6 | 0 |
| Cote d'Ivoire | 16.4 | 63.3 | 0.03 | 0 | 0 | 20.3 |

| Country | Degree of Vulnerability | | | | Stress-Based Vulnerability | |
|---|---|---|---|---|---|---|
| | Low | Moderate | High | Very High | Drought-Based Stress | Water-Based Stress |
| Gambia | 1.1 | 11.2 | 82.9 | 4.8 | 0 | 0 |
| Ghana | 7.5 | 48.8 | 15.2 | 1.1 | 0 | 27.6 |
| Guinea | 15.2 | 73.2 | 0.4 | 0 | 0 | 11.2 |
| Guinea Bissau | 15.4 | 83.7 | 0.2 | 0.7 | 0 | 0 |
| Liberia | 0.8 | 2.8 | 1.3 | 2.8 | 0 | 93.3 |
| Mali | 1.4 | 9.6 | 17.7 | 4.2 | 67.2 | 0 |
| Mauritania | 0 | 0.39 | 1.4 | 5.2 | 93.0 | 0 |
| Niger | 1.3 | 0 | 8.7 | 8.6 | 81.4 | 0 |
| Nigeria | 6.5 | 56.24 | 28.6 | 3.2 | 0.4 | 5.0 |
| Senegal | 5.5 | 21.25 | 46.5 | 19.5 | 7.4 | 0 |
| Sierra Leone | 65 | 16 | 1.4 | 1.1 | 0 [40][41] | 16.5 |
| Togo [42][43][44][45] | 17.7 | 60.8 | 21.3 | 0 | 0 [44] | 1.2 |

...est African ... he climate ... ns in West Africa will decline by 8–22%, and annual rainfall average will reduce about 20% by 2100. Studies also indicated the negative impact of poorly planned urbanization, environmentally imbalanced dam construction, road and housing projects, mining, lumbering, subsistence and large-scale agriculture to promote a decline in biodiversity across West African countries [45][46][47][48][49].

## 2.4. Influence of Urbanization on Air Quality and Human Health

Residents of many urban areas in West Africa are exposed to a wide range of gaseous and particulate air pollution concentrations, which frequently exceed specified air quality guidelines [50]. According to the WHO [51], there are over 3000 distinct anthropogenic air-polluting compounds identified, the bulk of which are organic, and up to 500 distinct compounds exist in vehicle emissions, which dominate the source of air pollution in West African cities [52]. Vehicular emissions account for 25% of all energy-related greenhouse gas emissions, and this is a problem in the west African cities because of a lack of strong control of the importation of second-hand automobiles into the region. Millions of old automobiles transported from Japan, Europe and the United States to West Africa are of low quality, adding considerably to air pollution and impeding attempts to ameliorate the consequences of climate change [53]. The used vehicles, typically 16–20-year-old cars, whose condition often falls below European Union emission standards, account for more than 85% of all vehicles that are brought into the region, on an annual basis [54]. Specifically, for instance, over 60% of automobiles imported into Gambia and Nigeria, in the region, in the last five years, were on average 18.8–20 years old [55].

**Table 5** shows the annual average greenhouse emissions, $PM_{2.5}$ concentration, percentage of exposed population and mortality attributed to household and ambient air pollution per 100,000 population, for the period of 2015–2019, in West African countries. Nigeria was shown to emit the largest amount of greenhouse emissions in the sub-region (**Table 5**). The country is the most populous, with the most large cities (e.g., Lagos, Ibadan, Kaduna, Warri, Kano and Onitsha) and transportation, commercial and industrial activities in the region. Mali, Niger, Ghana and Burkina Faso, with few cities, including Accra (Ghana), Bamako (Mali) and Ouagadougou (Burkina Faso), recorded relatively huge amounts of greenhouse gases. The low variability, as determined by the values of coefficient of variability (less than 5%; **Table 4**), indicate relative consistency in the emission rate within the study period.

**Table 5.** Annual average greenhouse emissions, $PM_{2.5}$ concentration and mortality attributed to household and ambient air pollution per 100,000 population, between 2016 and 2019 [56].

| Country | Total Greenhouse Gas Emissions (Kt of $CO_2$ Equivalent) | | $PM_{2.5}$ Air Pollution | |
|---|---|---|---|---|
| | Mean Annual | Coeff. of Var (%) | Annual Mean Concentration (μg/m) | Mortality (/'00,000) |
| Benin | 14,693 | 3.5 | 39.0 | 205 |
| Burkina Faso | 31,240 | 2.4 | 42.9 | 206.2 |
| Cape Verde | 777 | 3.2 | 34.8 | 99.5 |
| Cote d'Ivoire | 24,433 | 1.3 | 25.9 | 269.1 |

| Country | Total Greenhouse Gas Emissions (Kt of $CO_2$ Equivalent) | | $PM_{2.5}$ Air Pollution | |
|---|---|---|---|---|
| | Mean Annual | Coeff. of Var (%) | Annual Mean Concentration (μg/m) | Mortality (/'00,000) |
| Gambia | 2247 | 3.9 | 34.0 | 237 |
| Ghana | 35,893 | 3.9 | 34.7 | 203.8 |
| Guinea | 27,083 | 3.3 | 26.1 | 243.3 |
| Guinea-Bissau | 2520 | 2.3 | 29.8 | 214.7 |
| Liberia | 2160 | 3.0 | 18.0 | 170.2 |
| Mali | 42,480 | 3.1 | 38.5 | 209.1 |
| Mauritania | 13,820 | 2.7 | 47.4 | 169.5 |
| Niger | 40,837 | 3.7 | 94.1 | 251.8 |
| Nigeria | 300,530 | 2.0 | 71.8 | 307.4 |
| Senegal | 28,260 | 2.5 | 40.7 | 160.7 |
| Sierra Leone | 6383 | 4.2 | 21.6 | 324.1 |
| Togo | 7587 | 3.4 | 35.7 | 249.6 |

...ere ranked ...uinea and ...licates the [57][58] ...ion is now recognized as one of the biggest contributors to premature death and morbidity from cardiovascular diseases [59]. In **Table 5**, the mortality rate due to air pollution across the West African region is rated 99.5–324 per hundred thousand population, with Sierra Leone and Nigeria being worse affected than other countries, and Cape Verde and Mauritania being least impacted. There is, however, a need for more data from the region to obtain a better understanding of the temporal trends.

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