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Review

Climate, Urbanization and Environmental Pollution in West Africa

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Abstract: The need to elucidate the urbanization–climate–pollution nexus in West African arose from the several reported, but disjointed cases of climate extremes and environmental degradation in the sub-region. This review analyzed several scenarios, to appraise the trends and relationships among the individual elements in the nexus and to ascertain the status of sustainable development in the sub-region, using the expository review methods. 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. However, there is clear evidence that the concept of sustainable development is growing in the sub-region. This is intensified by the international funding agencies insisting on the incorporation of environmental issues into development, the enactment of environmental laws and policies, and the establishment of institutions of enforcement in each country. The review concluded that although the sub-region is at the brink of severe effects of population explosion and environmental degradation, the growing awareness and implementation of the sustainable development goals may come to the rescue.

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

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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 [4–6]. 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 review. 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 [20–22]. 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.

The main aim of the review is, therefore, to unravel the specific issues affecting three major areas of climate, urbanization and environment nexus, viz., appraisal and trends, relationships among climate, urbanization and pollution, and mitigation and control measures. The specific objectives are to appraise pollution levels in relation to the relation to the demographic, socio-economic and land-use trends in the sub-region; assess pollutant sources, levels and distribution patterns in the sub-region; and assess the impact of climate, urbanization and pollution nexus on public health, socio-economic activities and livelihoods, utilization of public utilities, as well as soil, water and air quality. Finally, impact of the international communities on the policies, treaties and institutional frameworks in the various countries were reviewed to determine the capacity of the region to integrate sustainable development and environmentally sound technologies, such as urban renewal and restoration, ecological and environmental remediation, urban greening and green technology to achieve a smart city in the sub-region.

2. Appraisals and Trends

2.1. Urbanization in the West African Region

Urbanization in sub-Saharan Africa has been in the global context due to the overriding issue of population growth combined with the challenging economic situation that is on the rise [24]. The uncertainties creeping into the economic system as a result of urbanization and urban growth still leave the developing countries, especially those in West Africa, at high risk of population explosion. Urban population growth is determined by economic development, and it changes over time [25]. It is established that a correlation exists between urban population growth and population increase, and so, urbanization has strategic influence to bear on the spatial dispersal of the rural population. Though the urbanized countries are typically more advanced regarding economic growth, the intricacy of urbanization, urban population increase and the heterogeneity in the West African region are critical to development.

Rapid urban increase and economic development through urbanization in the West Africa are evident, with specific indicators (traffic congestion, economic and quality education) in place. A reflection of these indicators is the presence of slum quarters in the urban centers, civil unrest, insecurity, weather inconsistency resulting in flooding, drought, climate change, and deepening poverty [26]. As of 2020, the United Nations estimates indicated that 47.7 % (191,841,724) of the West African population is urban, but the rate varies among countries (Figure 1).

When compared with the global trend, the UN Population data indicates that the percentage of urban population in Cape Verde and Gambia has exceeded the global average since 2000, and urban population has been on an increasing trend in most countries in the region since the 1960s, except for Liberia, which experienced a crash in urban population in the 1990s, probably due to the civil war [27]. The region, which is segregated into small, medium and large population sizes, is also described as experiencing a rapidly (1.6–3.1% per year) growing urban population; this population increased tenfold between 1950 and 2000 [28,29], and 50% of the population is projected to be urban by 2030 [30]. On the other hand, the West African region is still regarded as home to a large proportion of urban slum dwellers [31], but improved education and an improved economy across the region, as well as improved health care, sanitation and income, with governance, are predicted to enhance human capacity for improved livelihoods in the region [32]. The current population increase is driven by immigration rather than natural birth, which varies

among countries in the region: 2.29% and 6.95% of 5–6 births on average for Verde and Niger, respectively; 5.23%–5.92% of 5–6 births in Burkina Faso, Gambia, Nigeria and Mali were recorded; and 3.89% of fewer than 4 births per woman were recorded in Ghana [28].

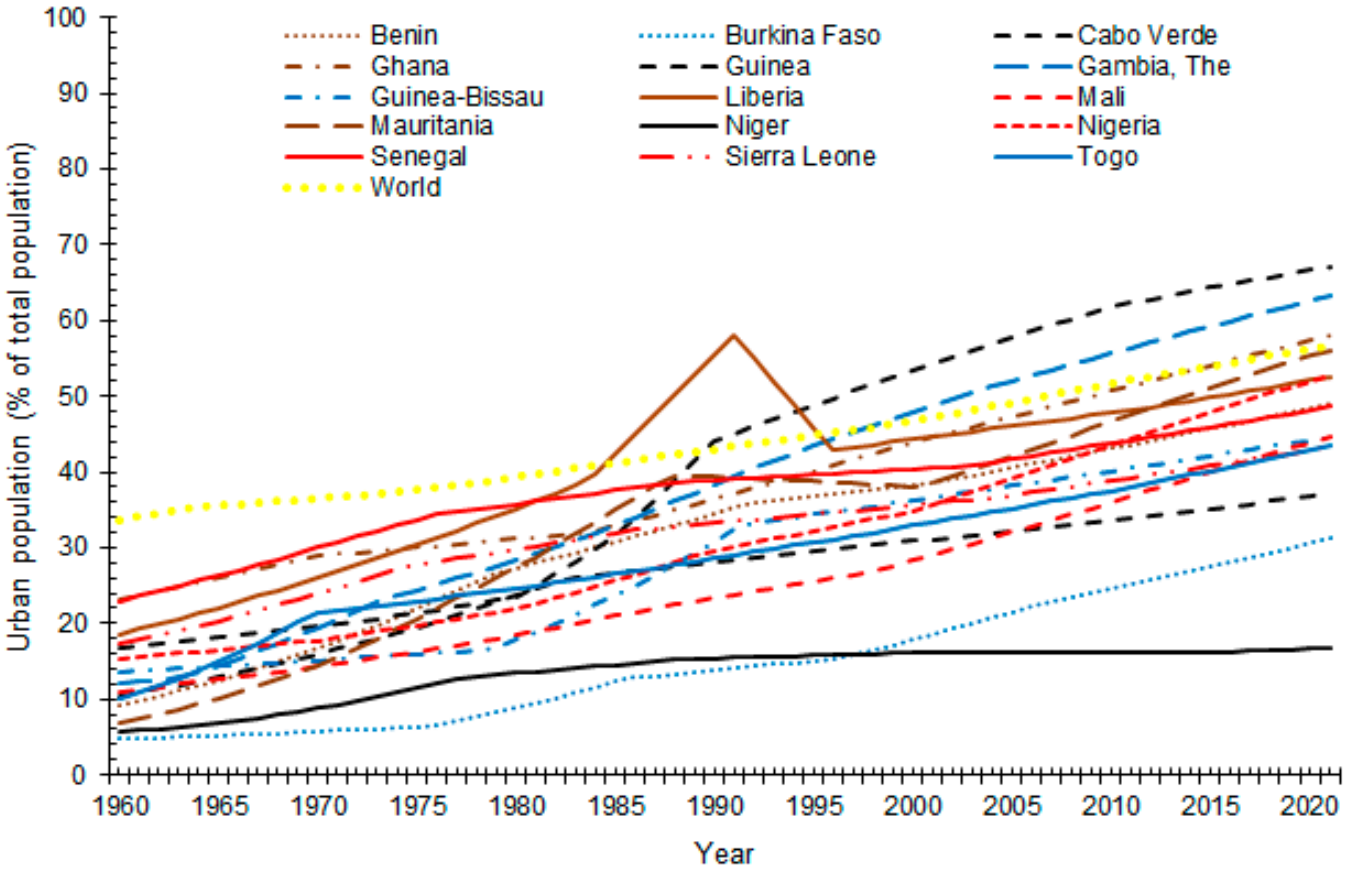


Figure 1. Annual change in urban population in West African countries relative to global urban population (https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=ZG&name_desc=true, accessed on 10 September 2022).

2.2. Demographic and Socio-Economic Distributions

2.2.1. General Demography

Demographic dividend as a product of interaction between population parameters and economic growth has a significant positive impact on the per capita income growth and has accounted for 2.28% economic growth in the region [30–33]. The demography of the West African continent has been described as unique and a better instrument for actualizing an accelerated development if harnessed. Concerning population age structure in West Africa, studies established that the youth account for the majority of the population. Population dynamics is a major factor influencing the development, but rapid population growth, though expected to promote sustainable economic goals in the region, has become a burden due to poor governance and unsustainable economic policies [34,35]. The situation of rapid population is compounded by poorly planned environmental management and monitoring systems, and these have culminated in social distress and economic losses among a large part of the population, namely, the youth, women and children in the region [35]. The situation became worse during the COVID-19 lockdowns, when efforts by different countries in the region towards the attainment of the sustainable development goals (SDGs) and targets at the regional and global level were disrupted [36–38]. In general, the population of the West African region was estimated at 400 million as of 2020, with 200 million in Nigeria, and with a reported decrease in infant mortality [29].

2.2.2. Socio-Economic and Livelihood Activities

The advent of COVID-19 pandemic, with its ravaging impact, has introduced tremendous change in the global socio-economic and livelihood of the people. With the associated high mortality and contracted global economy, the West African region's gross domestic product (GDP) is projected to improve to 2.8% (in 2022) from 2.5% (in 2021), and the challenge for the socio-economic and livelihood persists [30]. According to UNECA [30], the region is experiencing increased poverty and inequality, unemployment, civil unrest leading to heightened school dropout and food scarcity, and poor access to quality basic education and health services.

Obviously, different countries in the region are battling their various challenges in the post-COVID-19 era, at different range. Major countries, such as Nigeria and Ghana, which have the oil sector as a main anchor in the sustenance of the countries' GDP, are affected by the low global oil price. Currently, Nigeria specifically is challenged with a reduction in the total export [39]. Studies revealed that reduced financial intervention from external sources and movement restrictions impacted significantly on the technology, extractive and tourism sectors and on the ECOWAS' average GDP growth (e.g., [40]). It is predicted that in the post-COVID-19 period, the region will still struggle with the impacts on the sub-regional sectors such as the agriculture, extractive, tourism, transport, trade, monetary and public finance sectors, leading to a higher rate of unemployment [40,41]. The region is yet to survive the persisting high inflation, which depicts a bleak outlook on the socio-economic and livelihood recovery. Age, educational status as well as income were the major socio-economic factors influencing livelihood of the people in the region; Nigeria represents an actively farming and trading population with ages between 54 and 63 years [42,43]. Generally, West Africa is confronted by the global climate circumstances and conflict risk, varying poverty rates as well as socio-economic crises that portend significant consequences for environmental management in the region.

2.3. Pollutant Sources, Levels and Distribution

The issue of environmental pollution is on the front burner of the global discussion, due to its health risks and consequential obstacles to development. The exploitation of the natural resources as well as production, consumption and utilization of goods and services have contributed to extreme pollution in some parts of the West African region [44–47]. Air pollution is a major challenge in nearly all countries in West Africa. Table 1 presents some results of case studies of air, soil and water pollution as well as the availability of legislation for electronic wastes (E-waste) management across countries in West Africa. Except for Ghana, Côte d'Ivoire and Nigeria, most countries in the region lack legislation for the treatment and management of E-wastes, which, according to Adenuga et al. [44], suggests poorly managed E-wastes that poses significant threats to health of humans and the entire ecosystem in the part of the region. Studies also showed evidences of contamination of food items in Ghana by chemicals that have been used as herbicides and pesticides (Table 1, [45–47]). Furthermore, research reports revealed that vehicular emissions and biomass combustion in homes are the major sources of air pollution in all countries, and that the level of such pollution varies according to the population of countries, the volume and age of vehicles as well as the quality of used-vehicle regulatory standards adopted by each nation. As can be deduced from Figure 2, the regulatory standards in most West African countries are very weak, and none of these nations has adopted the light duty vehicle (LDV) Euro emissions standards for used vehicles (or its equivalent), and none has an age limit on used vehicles imported to the country. Where such limits exist, as in Nigeria, they are not strictly enforced. In addition to vehicular emission and other sources already mentioned, Sahelian dust is a major contributor to air pollution in the high-latitude Sahel countries such as Mali, Mauritania, Burkina Faso and, to a lesser extent, Senegal (see Table 1) ([45–53]).

Table 1. Concentration of environmental pollutants in different nations of West Africa [54–63].

Countries	Environment	Pollutants Concentrations	Availability of E-Waste Legislation [61]	Sources of Pollutants
Benin	Air	$PM_{2.5}$ (335.1 μgm^{-3}), CO (500–1800 μgm^{-3}), Pb (0.01–2 μgm^{-3}), NO_2 (10–150 μgm^{-3}), O_3 (10–100 μgm^{-3}), SO_2 (5–400 μgm^{-3}), Hydrocarbons (400–2000 μgm^{-3})	No	Dust, fumes, mist and smoke from motor vehicular emissions
	Surface water	NO_2 (2–15.5 $\mu g/L$), NH_4 (0.11–0.22 mg/L), BOD_5 (11.5–36.6 mg/L), PO_4 (3760–8020 $\mu g/L$), PAHs (38.8–123.9 mg/L)		Effluent discharge
Burkina Faso	Air	CO_2 (1.9×10^6 metric tons), NO_2(14–62 μgm^{-3}), SO_2 (0.3–10.5 μgm^{-3}), $PM_{2.5}$ (0.3–706.1 μgm^{-3}), PM_{10} (0.05–10,200.5 μgm^{-3}), PAHs (9.6 μgm^{-3} of o-xylene; 68.8 μgm^{-3} of toluene)	No	Desert dust, vehicular emissions and the use of fuelwood
	Groundwater	Fe^2 (0–4.2 mgl^{-1}), NH_4^+ (0–0.3 mgl^{-1}), NO_2^- (0–0.1 mgl^{-1}), Zn (0–2.2 μgl^{-1}), Mn (0–101 mgl^{-1}), As (1–5.2 μgl^{-1})		Water abstraction
Cape Verde	Air	$PM_{2.5}$ (7.2–47.3 μgm^{-3}), PM_{10} (10.9–83.5 μgm^{-3})	No	Vehicular emissions, biomass burning and dust
Côte d'Ivoire	Air	NO_2 (7–20.9 μgm^{-3}), NH_4 (20.7–84.9 μgm^{-3}), HNO_3 (0.6–1.3 μgm^{-3}), SO_2 (1.1–4.2 μgm^{-3}), O_3 (8.9–17.2 μgm^{-3})	Yes	Traffic, industrial emission, firewood burning and waste burning
	Rainwater	Benzo(a)pyrene (0–98 μgm^{-3}), Naphtalene (0–369 μgm^{-3}), Indeno (1.2.3-cd), pyrene (0–71 μgm^{-3}), Chrysene (0–308 μgm^{-3}), Phenanthrene (0–1842 μgm^{-3}), Benzo(k)fluoranthrene (0–312 μgm^{-3}), Benzo(ghi)perylene (0–342 μgm^{-3})		Wood combustion and vehicular emissions
Gambia	Air	$PM_{2.5}$ (12.5–126.5 μgm^{-3}),	No	Cooking fuels
Ghana	Air	$PM_{2.5}$ (71.9–13.2 μgm^{-3}), PM_{10} (85–322 μgm^{-3}), Hg (0.01–0.16 μgm^{-3}), Zn (40.6–309 μgm^{-3}), Cu (18.9–278 μgm^{-3}), Cd (0.03–0.66 μgm^{-3}), As (0.69–73.5 μgm^{-3}), Cr (29.6–249 μgm^{-3}), Co (1.87–14.6 μgm^{-3}), Pb (19.1–171 μgm^{-3}).	Yes	Wood combustion, traffic and industrial emissions
	Food items (Cheese, yoghurt, tomatoes, and lettuce).	DDT (10.6–402 μgm^{-3}), Endosulfan (0.02–9.06 μgm^{-3}), Lindane (24–196 μgm^{-3})		Mining, energy production and commercial centers
	Blood samples	Pb (10–15 μgm^{-3})		
Guinea Bissau	Air	POPs: 4,4′-DDT (210–780 μgm^{-3}), 4,4′-DDE (1400–3400 μgm^{-3}), β-HCH (38–180 μgm^{-3}), γ-HCH (53–130 μgm^{-3}), PCBs (110–230 μgm^{-3})	No	Normal ambient air exposure
	Drinking water (piped and wells)	NO_2^- (0.01–4.66 μgm^{-3}), Fe^2 (13–17 μgm^{-3}), SO_3^{2-} (0.11–13.34 μgm^{-3}), TP (0.01–0.1 μgm^{-3}), Cu (0–0.37 μgm^{-3})		Land use

Table 1. *Cont.*

Countries	Environment	Pollutants Concentrations	Availability of E-Waste Legislation [61]	Sources of Pollutants
Liberia		$PM_{2.5}$ (30.9 μgm^{-3}), PM_{10} (78.5 μgm^{-3})	No	Traffic, biomass burning
Mali	Air	NO_2 (16.2 μgm^{-3}), NH_4 (46.7 μgm^{-3}), HNO_3(0.6 μgm^{-3}), SO_2 (3.6 μgm^{-3}), O_3(5.1 μgm^{-3}), $PM_{2.5}$ (9–300 μgm^{-3}), PM_{10} (10–2500 μgm^{-3}),	No	Saharan dust, traffic, industrial production, domestic emissions and the workplace
Mauritania	Air	TSP (50–2630 μgm^{-3}), PM_{10} (50–1942 μgm^{-3})	No	Saharan dust
Nigeria	Air	$SO_2{}^+$(0.06–63.0 mgl^{-1}), NOx (0–0.3 mgl^{-1}), O3 (1.8–61 mgl^{-1}), NH3(91.4–689 mgl^{-1}), CO (0.01–48 mgl^{-1}), $PM_{2.5}$ (4.1–336 mgl^{-1}), (15.2–327 mgl^{-1}), PM_{10}(0–2 mgl^{-1}),	Yes	Traffic, gas flaring, biomass burning, storage tanks, pipeline explosions, Saharan dust, sea spray and industrial production
	Land/soil	VOC (1033–40,000 mgl^{-1}), TSP (6–0.3 mgl^{-1}),		Indiscriminate waste disposal, erosion and flooding
	Surface water	Macroplastic (0–0.3 mgl^{-1}), Micro and macro plastics (440–1556 particles /L 2057.3 of the items)		
Senegal	Air	NO_2 (31.7 μgm^{-3}), NH_4 (21.1 μgm^{-3}), HNO_3 (1.3 μgm^{-3}), SO_2 (15.9 μgm^{-3}), O_3 (7.7 μgm^{-3}), $PM_{2.5}$ (10.5–38 μgm^{-3}), PM_{10}(24–165 μgm^{-3})	No	Traffic and Saharan dust
Sierra Leone	Air	CO (400–82,000 μgm^{-3}), NO_2 (25.82–57.6 μgm^{-3}), SO_2 (199.5–864.79 μgm^{-3}), $\sum$PAHs (3.26–39.88 $\times$ 10^{-6} μgm^{-3}), $\sum$BaPeq (1.97–23.23 $\times$ 10^{-6} μgm^{-3}),	No	Firewood and charcoal burning, and traffic
Togo	Air	CO (400–22,570 μgm^{-3}), CO_2 (391–405 ppm), CH_4 (371–386 $\times$ 10^7 μgm^{-3}), SO_2 (371–386 $\times$ 10^7 mol/cm^2), NO_2 (81.4–161.6 μgm^{-3}), CO_2 (1,265,080–1,632,790 μgm^{-3}), CO_3 (0–1 μgm^{-3})	No	Traffic

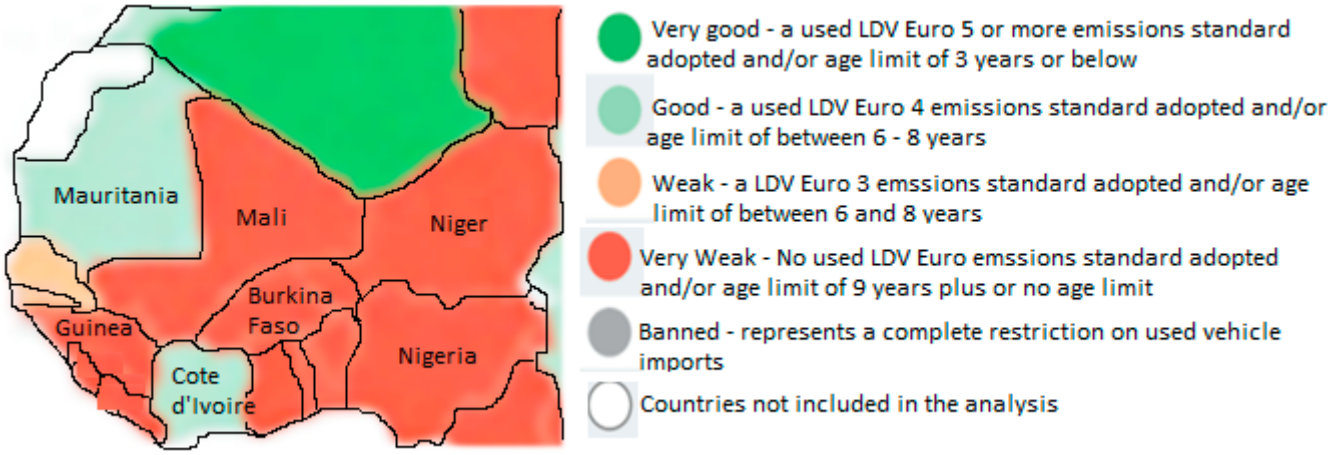


Figure 2. Regulatory environment ranking and used light duty vehicles (LDV) in West Africa [64].

Studies also shown that aerosols and other suspended particulates tend to vary seasonally across the West African region, albeit with more concentrations in the harmattan/dry periods than the wet season [48–52] (not reflected in Table 1). However, the pollution level also has a highly significant spatial distribution across the sub-region. It is also associated with high risks to health. According to the US EPA air quality index, the levels of PM2.5 and PM10 in Benin, Burkina Faso, Gambia, Liberia Mali, Nigeria and Senegal may be associated with health risks ranging from unhealthy to hazardous. This suggests an increasing likelihood of serious respiratory diseases such as cough, shortness of breath and asthma [53–55].

This review also identified that a high level of PM_{10} in the northern part of West Africa may be linked with the Sahelian dust. For instance, it reached a concentration of over 2500 $\mu g/m^3$ in Mali and 10,200 $\mu g/m^3$ in Burkina Faso (Table 1) [56]. This is a potential disaster persistently ignored, and its effects 1 treated as seasonal normal. In addition to the particulates, other major air pollutants in West Africa are CO, Pb, NO_2, O_3, SO^2, NH_4, HNO_3, as well as some toxic persistent organic pollutants such as the polychlorinated aromatic hydrocarbons (PAHs), DDT, benzene, and its derivatives, and many more (Table 1). Although these pollutants are spread by wind, there is no study that has elucidated its cross-border behavior in West Africa. Such information is required to establish equity between environmental pollution and benefits.

Atmospheric deposition also contaminates the water sources and soil resources. Table 1 also showed that the discharge of untreated industrial and municipal effluents are the major sources of surface water pollution and soil pollution in the region [57]. The major pollutants in water are NO_2^-, NH_4, PO_4, heavy metals and some POPs such as PAHs, DDT and many more. The proximity of the sources of drinking water to sources of these pollutants and other sanitary facilities increases the concentration of the pollutants in water. Sources of soil pollution include oil exploration, agricultural activities, mining, roadside emissions, auto-mechanic workshops, refuse dumps and E-waste. E-waste also constitutes one of the highest sources of toxic substances (including Pb, Cu and Zn) in the region [44,58].

2.4. Waste Menace and Its Impact on the Environment

Wastes, by-products of human activities, including domestic/household, agricultural, construction, manufacturing, commercial, institutional and retail activities, are part of the human environment and have become of significant concern in many West African urban settlements in particular [59]. In a survey of hazardous wastes (comprising radioactive, hospital and/or electronic wastes; [60]) in West Africa, Akpan & Olukanmi [59] showed that Nigeria (2469 kilotons/year), Benin (428 kilotons/year) and Ghana (419 kilotons/year) top the list of hazardous wastes generation in the region, as of 2020 (Table 2). Table 2 also shows that the average generation was higher in Benin (65 kg/Person/year) than other countries in the region. Residents of the Republic of Benin reportedly generate more hazardous wastes (65 kg/person/per year) than an average individual in the region (20 kg/person/per year), probably due to the high cross-border trade in the country (Table 2).

Wastes in many countries of the region are estimated to increase by 40% by 2050, because of the absence or failure of existing waste management frameworks and procedures [61]. Simelane & Mohee [63] described the urban areas in West Africa as those whose attractiveness is marred by the inefficient waste collection, management, disposal and reuse, as less than half of the solid waste generated is collected. A review by Akpan & Olukanni [59] also revealed the dearth of an adequately controlled landfill in the entire region (Table 3). Other forms of wastes that have dominated the region are urban municipal wastes, which are generally characterized by comprising above 50% organic components with 30% recyclable or reusable materials (including mixed wood, garden waste, leather and rubber), compared to 30% organic with 51% recyclable (mainly glass and metals) wastes of the average for European countries [61,63].

Table 2. Generation of hazardous wastes by country in West Africa [59].

S/N	Selected Countries	×1000 Tons/Year	kg/Person/Year
1	Nigeria	2469	20
2	Benin	428	65
3	Ghana	419	20
4	Cote d'Ivoire	335	20
5	Burkina Faso	257	20
6	Mali	257	20
7	Senegal	202	20
8	Guinea	172	20
9	Sierra Leone	98	20
10	Liberia	66	20
11	Mauritania	57	20
12	Gambia	29	20
14	Guinea-Bissau	29	20
15	Niger	24	20
16	Cape Verde	10	20
17	Equatorial Guinea	10	20

Table 3. Review of landfills in West Africa and their ranking, based on the level of agreement to international rules [59].

	Level of Landfill Control	Rating	Landfills	Characteristics
1	No level of control	0	• Igbatoro (Nigeria) • Awotan (Nigeria) • Lapite (Nigeria), • Eneka (Nigeria), • Ajankanga (Nigeria), • Aba-Eku (Nigeria), • Unguwan (Nigeria), • Bakoteh (Gambia) • Antula (Guinea Bissau)	Controlled functions are limited, no leachate collection system, open dumping, and uncontrolled burning. The set of landfills are not capable of handling hazardous waste.
2	Semi-controlled Landfill	5	• Solous (Nigeria) • Mpape (Nigeria) • Epe (Nigeria) • Granville (Sierra Leone) • Kingtom (Sierra Leone)	Absence of leachate collection facilities and unsorted waste materials. These are not capable of handling hazardous waste.
3	Medium or ControlledLandfill	10	• Olusosun (Nigeria) • Dompoase (Ghana)	A segment of the trained workforce follows a set of instructions in daily operations, and facilities are available to capture particulates. Equipment may be managed appropriately. These are not capable of handling hazardous waste.
4	Engineered Landfill (Medium to High)	15	Not available in West Africa. They exist in South Africa and Botswana, however.	A high level of planning is taken in the location, with daily operation and emission control.
5	State of the art Landfill (Highly Controlled)	20	Not available in Africa	These are state-of-the art facilities, and they operate in compliance with international regulations and standards. Efficient hazardous waste management potential; leachate collection and gas harnessing are sustainable; plans are put in place for post-closure. They are capable of handling hazardous waste.

For all cases of wastes generated in West African countries, the main problem in management appeared to start from sorting at the point of generation [65], probably due to poor orientation and the lack of or inappropriate waste management education [66]. Consequently, hazardous waste materials are easily found in the environment, and this has led to groundwater contamination in some cases [57,66–68]. From Table 3, landfills in West African countries have significant shortcomings in handling hazardous waste, as they rate from a low-level of control to medium or controlled landfill. The lack of engineered and state-of-the-art landfills in the sub-region suggest the devastating vulnerability of the environment to toxic waste materials. In addition, waste disposal methods, such as open dumping and burning, have been implicated in the pollution of water and air, in the rise in health issues, and in the exacerbation of greenhouse (particularly CO_2 and CH_4) contamination of the atmosphere [69,69]. Nigeria, the most populated country in the sub-region, is expected to lead in waste generation by 2025, with over 20 million tonnes per year, while the least waste-generating countries (Cape Verde, Mauritania and Liberia) will generate between 100,000 and one million tonnes per year (Figure 3).

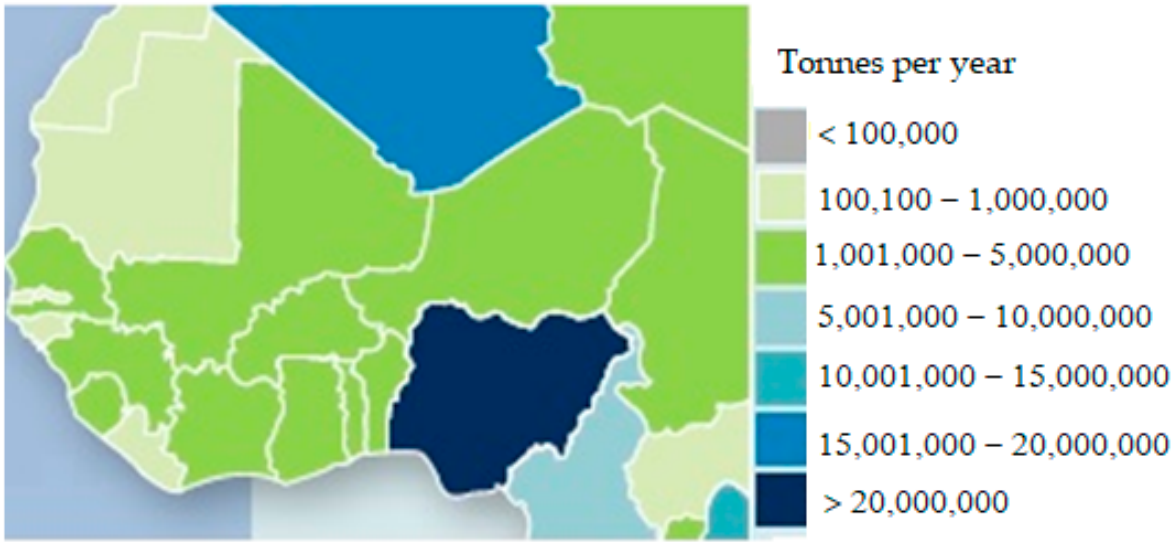


Figure 3. Projected solid wastes generation across West African countries by 2025 [17].

2.5. Climate Variability in the West African Sub-Region

The climate of the West African region has been well described in the literature as a reflection of the region's complex landscape ecosystem [70–72]. The climate in the sub-region is largely determined by the northwards and –southwards movements of the Inter-Tropical Convergence Zone (ITCZ), caused by the seasonally alternating prevailing influence of the hot dry continental north-east trade winds and the moisture-laden southwesterly or maritime air masses from the Atlantic Ocean [73] (Figure 4a). The ITCZ, a tropical belt of deep convective clouds, or the maximum in time-mean rainfall seasonally migrates towards a hemisphere that warms relative to the other (Figure 4b) in the sub-region [74]. Based on the Koppen Climate System [74], the West African sub-region is generally stratified into Tropical climate (designated as *A*)—consisting of tropical rainforest (*Af*), tropical monsoon forest (*Am*) and tropical wet and dry or savanna (*Aw* and *As*)—and dry climates (*B*), which includes hot semi-arid climate (Steppe climate; *BSh*) and arid (hot deserts; *BWh*) climate types (Figure 4c). The *Af* is generally described as hot, very humid and wet, with at least 60 mm monthly average precipitation. *Am*, on the other hand, is characterized by monthly mean temperatures above 18 °C, and a dry season with varying amounts of rainfall, while areas under *Aw* and *As* experience severe dry season, with drought conditions that often prevail through most parts of the year. In general, the area experiences at least an 18 °C monthly mean temperature and average annual rainfall that varies between 800 mm and over 1800 mm.

Areas under the dry climates, on the other hand, generally experience severe excess of evaporation over precipitation, and the soils are characterized as those with poor moisture-holding or retention capacity. The *BSh* is classified to exhibit hot, sometimes extremely hot, dry summers and warm-to-cool winters, with some exhibiting minimal precipitation and existing in the fringes of subtropical deserts. The *BWh*, on the other hand, is characterized by a 29–35 °C daily mean temperature (sometimes 43–46 °C in the afternoon) (see [22]). Annual precipitation in the dry climates is often less than 40 cm (Figure 4b). Hagenlocher et al. [75], while modeling the hotspots of climate change across West Africa showed that major natural hazards in the region are linked with rainfall variability, flood incidences, temperature and drought. The hotspots, which represent areas that are most vulnerable to changes in rainfall and temperature, as well as related extreme events (drought and flooding) were identified in the northern and northwestern part, including Mauritania and Algeria, as well as the center, including Niger, Burkina Faso, and the northern parts of Ghana, Togo, Benin, and Nigeria (Figure 4d). Additionally, the relative share of the climate-related indices (as visualized by a pie chart for each location) reveals spatial differences in the nature of the climate-related stress to which the area may be vulnerable.

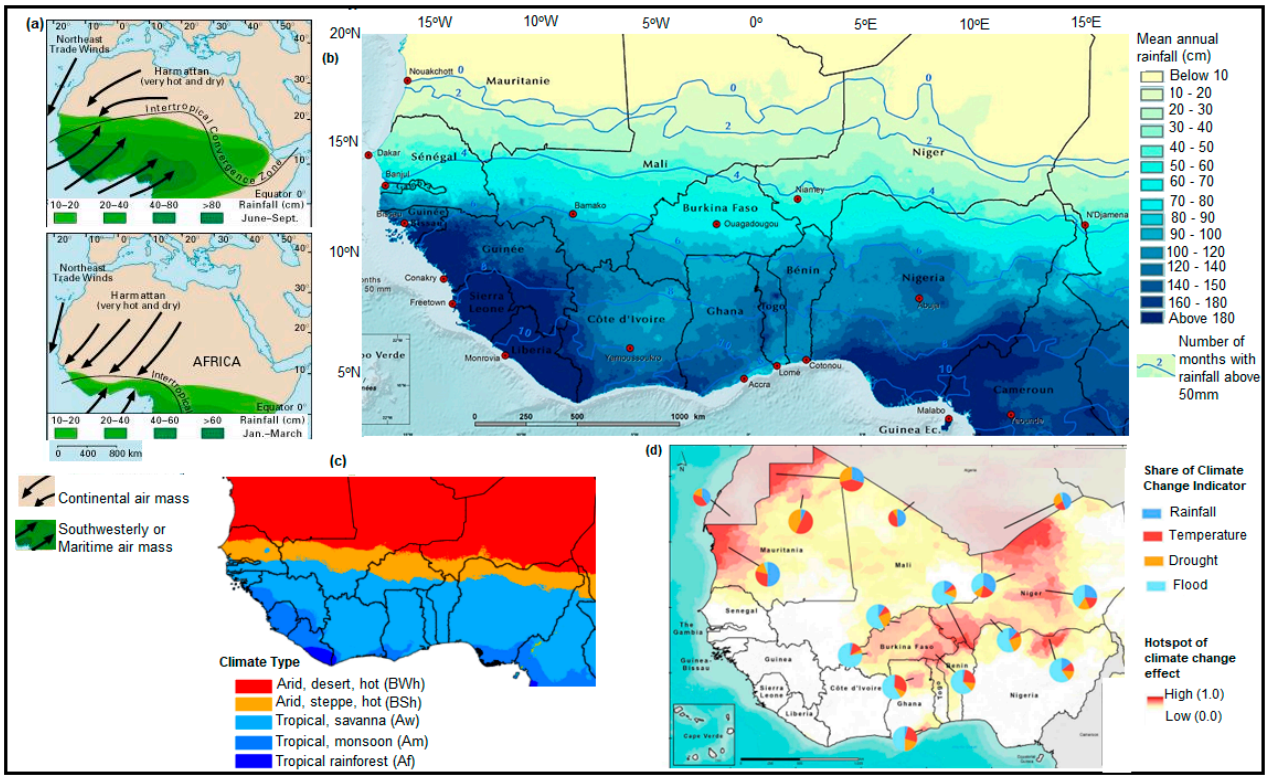


Figure 4. Some characteristics of the West African climate [22,72].

3. Relationships among Climate, Urbanization and Pollution

3.1. 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 [76–82]. The effects are both direct and indirect, direct effects being an increase in morbidity and mortality cases [80,83], 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 [84]:

- 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 4 [85]. Thomson et al. [85] 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 [81] often varies with or is influenced by weather or climatic conditions (see Table 4). In general, Orimoloye et al. [78], 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. [78], 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 [78] 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.

3.2. 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 [86]. Tables 5 and 6 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 5). 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 5). 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 5 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 [87] 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 4. Common climate-related major causes of morbidity and mortality in West Africa [85].

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

Table 5. 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

Asterisked (*) section has no data/record available as of the time of compilation. Data source: www.databank.worldbank.org/source/world-development-indicators/preview/on# (accessed on 15 August 2022).

Table 6. 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
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.

In terms of electricity, Cape Verde remains at the top, while Burkina Faso, Niger and Liberia were the least served, with electricity served to less than 20% of the total population (Table 6). Except for Senegal, Ghana and Cape Verde, less than 70% of the total population in the countries in the region have access to an electricity supply. The rural areas in Ghana and Cape Verde were equally far better served with electricity than all the other countries in the region, but the urban areas appear better served (Table 6). A World Bank [88] report associated the poor access to utilities with poor level of manufacturing activities in the region. Nigeria, Ghana and Cote d'Ivoire top the region in generation of greenhouse gases, but there 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 [88,89].

3.3. 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 7 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 [89]. From Table 6, 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 [90]. In general, Romankiewicz [91] 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 7).

Many studies appear to agree that the threats to biodiversity and land resources are, indeed, escalating in the West African region due to human population pressure on the environment [92,93] and climate change, variability or extreme climate conditions [94–97]. As regards water resources, Cotillon [96] predicted that by 2050, river flow in major basins in West Africa will decline by 8–22%, and annual rainfall average will reduce about 26% 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 [97–101].

Table 7. 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 [89].

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
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	16.5
Togo	17.7	60.8	21.3	0	0	1.2

3.4. 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 [102]. According to the WHO [103], 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 [104]. 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 [105]. 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 [64]. 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 [106].

Table 8 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 8). 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 7), indicate relative consistency in the emission rate within the study period.

Table 8. 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 [107].

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
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

The annual mean concentration of $PM_{2.5}$ varied as 18.0 μg/m–94.1 μg/m from Liberia to Niger. Niger and Nigeria were ranked first and second, respectively, in terms of the concentrations of $PM_{2.5}$, while Liberia, Sierra Leone, Cote d'Ivoire, Guinea and Guinea Bissau recorded less than 30 μg/m of $PM_{2.5}$. The pattern of the distribution of the $PM_{2.5}$ in the region indicates the need for public concern regarding poor air quality and an increase in health-related issues [108,109]. Urban air pollution is now recognized as one of the biggest contributors to premature death and morbidity from cardiovascular diseases [110]. In Table 8, 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.

4. Mitigation and Control Measures

4.1. Existing Relevant National, Regional and Global Policies and Institutional Frameworks

Since the Earth Summit of 1992 in Rio de Janeiro, the cornerstone of policies on urbanization among the West African nations has been hinged on sustainable development. The concept of sustainable development seeks development that balances different, and often competing needs with regard to environmental, social and economic limitations [111]. The policies encouraged individuals, companies and governments to approach development holistically, rather than trying to satisfy single needs. This is probably because development is typically purpose driven to assist nations, especially the developing countries, to achieve the three principal objectives of sustainable development, namely, economic development, environmental protection and preservation, and social improvement, according to AGENDA 2030, launched by the United Nations in 2015. The global policy termed Sustainable Development Goals (SDGs) has 17 goals, 169 targets and 232 indicators [112]. The SDGs form the first practical step to actualize the objective of the Brundtland Commission, which the World Commission on Environment and Development [112] hoped will enable nations to balance their economic and social needs while preserving and enhancing the natural resources and the environment.

Achieving this goal in the West African sub-region is recognized to be both complex and difficult for several reasons. The economic outlook in the sub-region is characterized by a growth regime that depends more on foreign aid rather than domestic income [113]. In addition, the foreign direct investment (FDI) in the sub-region does not significantly improve local skills in terms of employment and production, although it is required to boost incomes and reduce poverty. Additionally, the main exports from West African countries are essential raw materials rather than finished goods, causing less income and balance of payment deficits. For instance, Nigeria, a major oil-producing nation and the richest nation by gross domestic product (GDP) in the sub-region, exports crude oil and imports refined petroleum products, and it exports cocoa and imports chocolate. All of these lead to a balance of payment deficit. Furthermore, the agricultural sector is shrinking and remains peasant in nature, contributing only marginally to international balance of trade, in spite of its huge capacity to generate employment [114].

Social sustainability is one of the most difficult challenges to tackle in the sub-region, coming from the poor economic outlook described above. The human development index was ranked low in most countries of the sub-region, being medium only in Cape Verde and Ghana, and high to very high in none [115]. Both access to and quality of education and healthcare delivery are poor, while unemployment and underemployment are very high and rising in most countries. The rate of unemployment is greater than 25% in most nations, rising above 30% in Nigeria [116]. The high level of unemployment and underemployment is suspected to be responsible for the high poverty rate and social unrest in most of the countries, especially Nigeria, Burkina Faso, Mali and Chad. According to the World Bank [117], the poverty rate in the sub-region ranged from 23.4% in Ghana to 56.8% in Sierra Leone. Uzonwanne et al. [118] reported that urban unemployment and poverty are the core causes of rising social disorder and moral decadence in Nigeria and many other countries of the sub-region. For instance, most urban areas in West Africa are currently witnessing unprecedented levels of armed robbery, kidnapping, political assassination, and gender-based offences in the last two decades. In addition, incidents of banditry, terrorism and mass kidnapping have increased in Nigeria, Burkina Faso, Niger, Mali, Chad, Guinea, among others, and most parts of the sub-region are characterized by poor access to basic infrastructure. By the end of 2020, no country in the sub-region achieved any of the millennium development goals (MDGs), and halfway into the SDG deadline, there is no sign that any nation will achieve its goals and targets [113]. This scenario has been exacerbated by the persistent social, economic and political challenges in

many countries, thus plunging the sub-region into a vicious cycle of poverty and low per capita land resources due to land degradation, leading to more poverty, as described in Figure 5.

The regional environmental policies and actions to restore natural resources in West Africa are summarized in Figure 6. Although no specific studies have elucidated a direct link between poverty and environmental degradation in West Africa, several theories and hypotheses suggest that poor people, especially those in the rural areas, depend on the environment for their livelihood and source of energy. For instance, deforestation and soil degradation are associated with increased peasant farming activities, tree cutting, especially for firewood and charcoal production [119]. However, studies have described the nexus between poverty and environment as complex, probably because poor people are often impoverished by a declining resource base and, in turn, are forced by their circumstances to degrade the environment further [120,121]. These arguments notwithstanding, it is now obvious that in West Africa, the economic and social malaise has had significant negative effects on the environment, and these are being exacerbated by climate change, which has increased the threat and potential of the occurrence and severity of natural disasters. The increasing southward trend of the Sahel is pushing desertification to areas previously classified as forest. This has affected grazing potentials in Nigeria, Mali, Niger and many other countries. In many of these countries, the disappearing savannah has endangered civil conflict between farmers and herders [118].

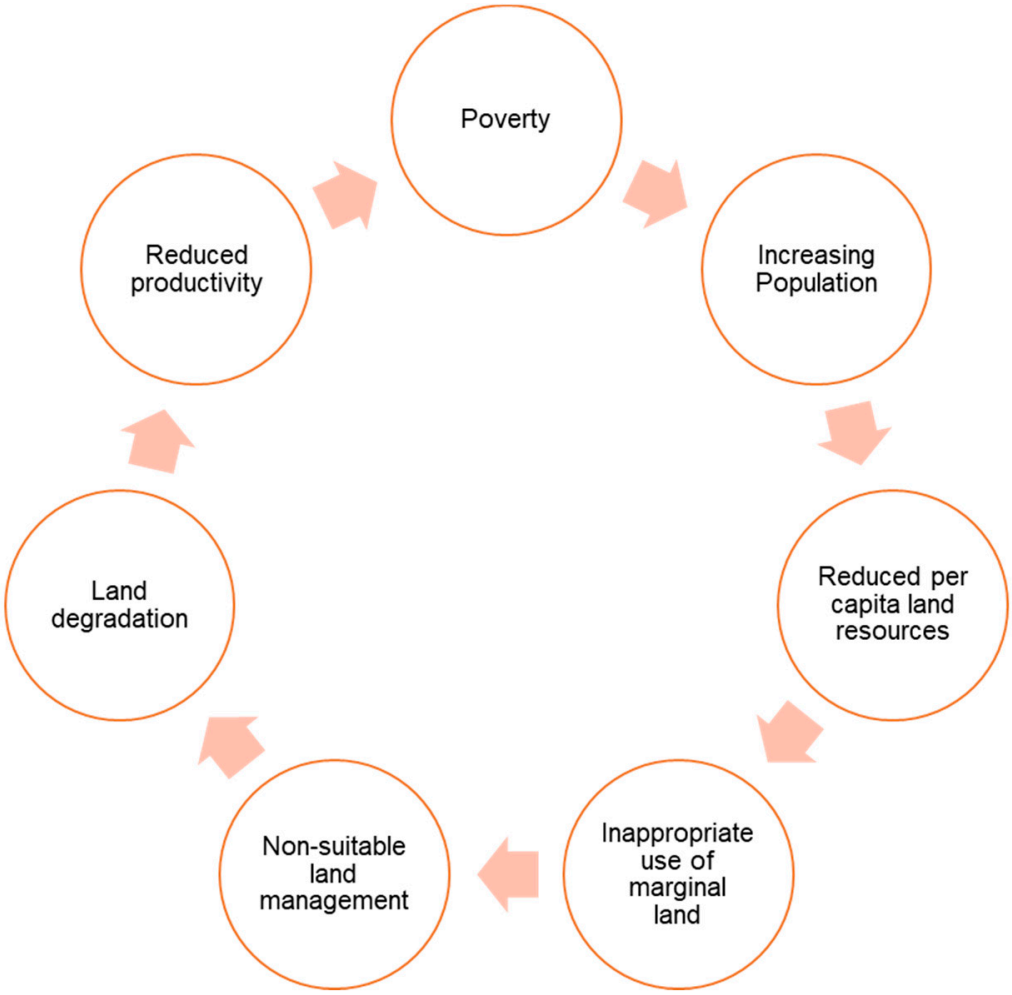


Figure 5. Vicious cycle of land degradation (drawn by the authors, adopted from [122]).

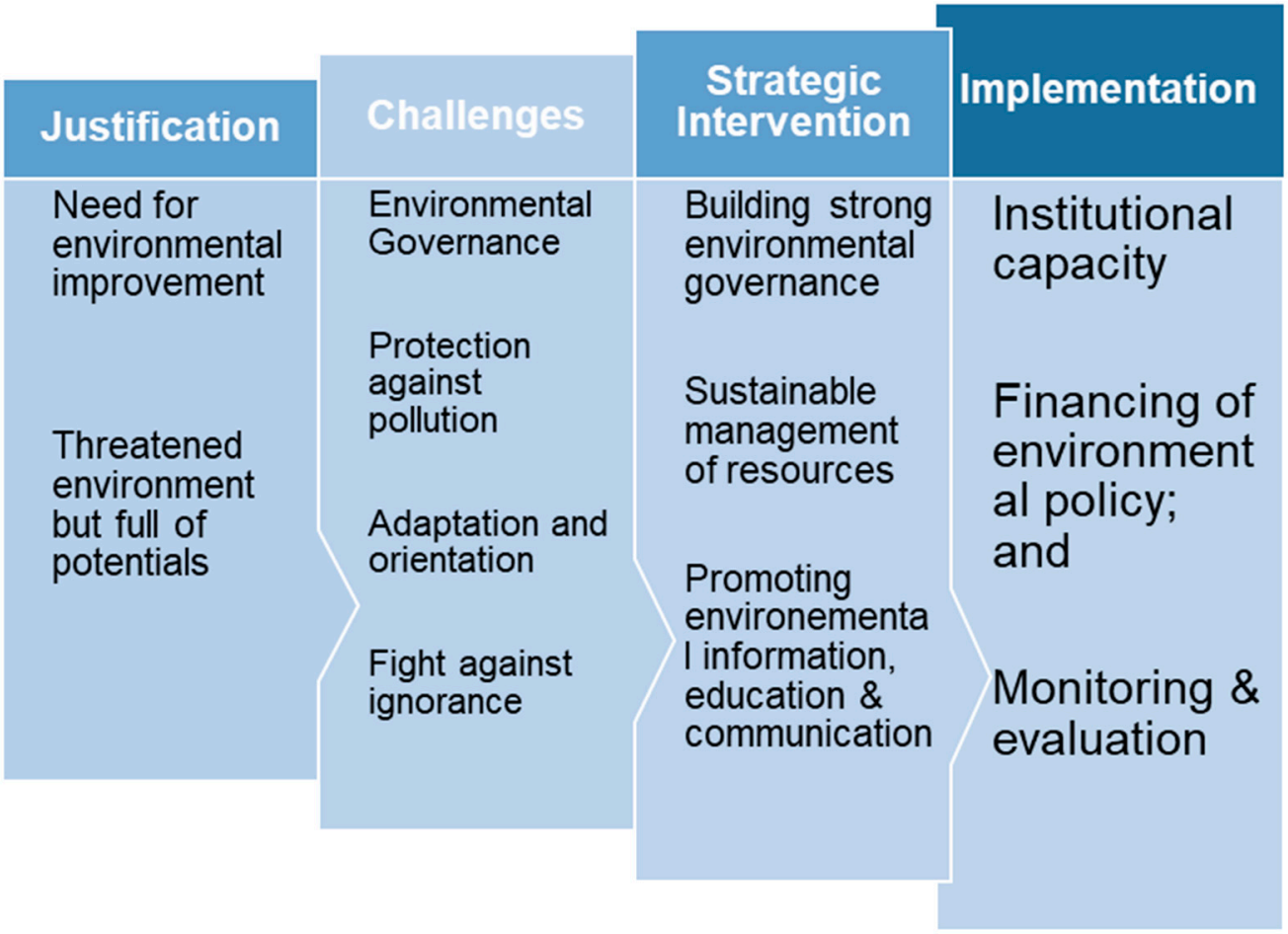


Figure 6. Issues on environmental policy in the West African region (drawn by the authors, adopted from [123].

The Sustainable Development Goal 17 identifies that sustainability cuts across social, economic and political boundaries, and it requires collaboration between communities, nations and regions. Consequently, implementation also requires both local, national and international actions. To achieve this goal in West Africa, several regional and national institutions were established with varying responsibilities. Figure 7 shows the coverage of the four major international commissions responsible for most regional monetary and economic policies and agreements in West Africa. At the national level, various countries in West Africa have established institutions and legislation to ensure compliance to SDGs and targets. Table 9 presents the key institutions of environmental administration in the different West African countries. In addition, all the countries in the sub-region operated a decentralized environmental governance structure, for which reason the administrative structure does not only exist at the center but also at state and district or local government levels. For instance, in Nigeria, in addition to the Federal Ministry of Environment, there is also a State Ministry of Environment in each of the 36 states. The ministries partner with international funding agencies to deliver sustainable development in their respective countries. To achieve this goal, the ministries and their departments and agencies implement all policies and laws, including environmental impact assessments made to ensure that development does not irreversibly harm the environment.

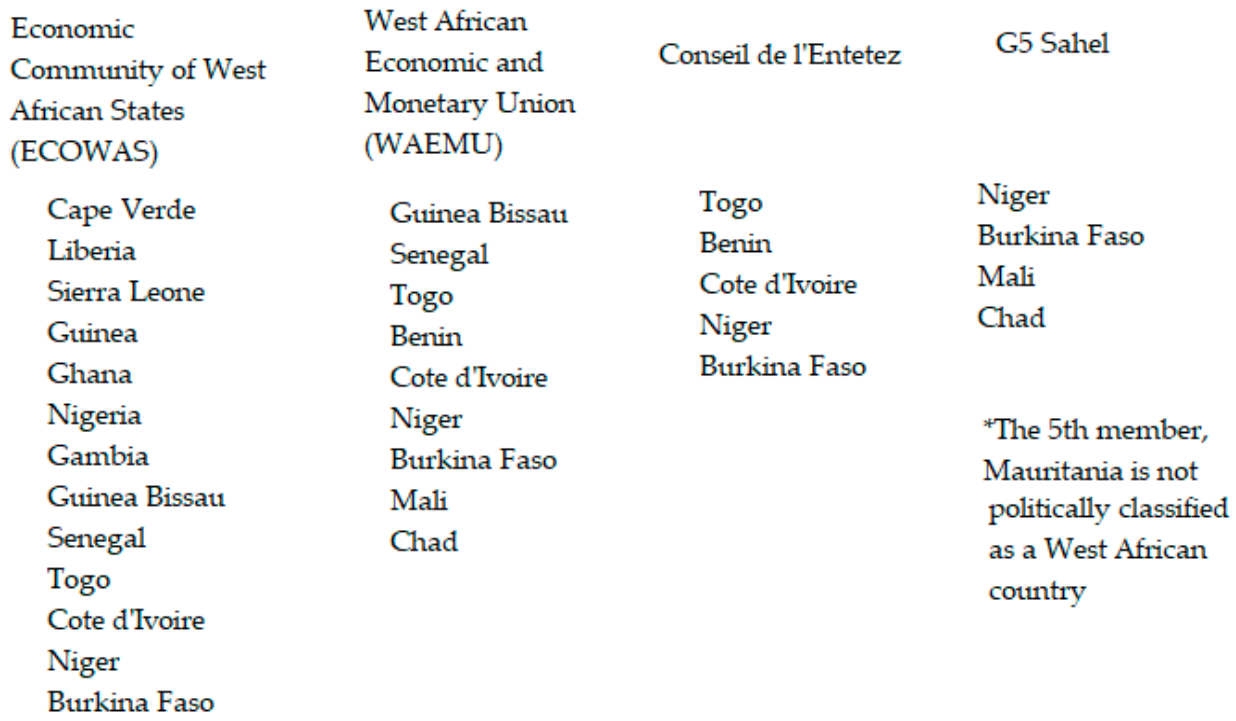


Figure 7. Existing regional collaboration among West African countries (drawn by the authors, adopted from [124]).

Table 9. Institutions of environmental administration in West Africa.

Country	Institution of Environmental Administration
Benin	Ministry of the Living Environment and Sustainable Development
Burkina Faso	Ministry of Environment
Cape Verde	Ministry of Agriculture and Environment
Cote D'Ivoire	Ministry of the Living Environment and Sustainable Development
Gambia	Ministry of the Environment, Climate Change and Natural Resources
Ghana	Ministry of Environment, Science, Technology, and Innovation
Guinea	Ministry of Environment, Water and Forest
Guinea Bissau	National Council for the Environment
Liberia	Environmental Protection Agency
Mali	Ministry of Environment and Sanitation
Niger	Ministry of Environment
Nigeria	Ministry of Environment
Senegal	Ministry of the Living Environment and Sustainable Development
Sierra Leone	Ministry of Lands, Country Planning and Environment
Togo	Ministry of Environment, Sustainable Development and the Protection of Nature

4.2. Integration of Environmentally Sound Technologies into Development

Environmentally sound technologies (EST), occurring in 'soft' and 'hard' forms, are defined in Agenda 21 as 'less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes' [125]. Hard forms of ESTs are the hardware equipment, machinery, physical infrastructure and their material

accessories, while the soft ESTs refers to the non-solid or non-visible processes such as management systems and practices, legislative and policy frameworks, financial tools, and other approaches that support environmental monitoring and evaluation, standards and recommendations for environmental performance. The ESTs are driven mainly through investment, trade and licenses, and in West Africa, as in other parts of Africa, they have been fairly achieved through some supportive policies for collaboration, scholarships and international cooperations between the source and destination countries [125–127].

Less & McMillan [128] identified government regulation and market-based instruments, trade-related policies and practices, intellectual property rights, capacity, and financing as main conditions for meeting successful EST transfer. These conditions often require strong political will as well as financial strength, which many West African countries may lack [129]. Nonetheless, there is a fair amount of evidence to indicate that West African countries have benefited from technology transfer over the years [128–131], although there is a need for more efforts.

4.3. International Development Assistance for Sustainable Development

The international community supports development in West African bilaterally and multilaterally. The multilateral partnership is driven by the Organization for Economic Co-operation and Development (OECD). Through its OECD development assistant committee (DAC), it offers official development assistance (ODA) to the West African countries. The OECD-DAC comprises most of the developed countries including the United States of America, United Kingdom, European Union, Australia, Japan, Canada and Korea [132]. Generally, ODA supports West African countries in the areas of education, capacity building, health including population and reproductive health, water supply and sanitation (WASH), government and democratic development, economic development in the areas of transportation including roads and railway transports, banking and business services, agriculture, forestry and fishing [133,134]. Ogiri [134] also reported that West Africa is one of the least developed regions in the world, for which reason OCED-DAC official development assistance had remained substantial in the last five decades (Table 10). Table 10 reveals that Nigeria, with a population of over 200 million and a GDP per capita income of about USD 2000, received the highest overall assistance of USD 5324 million for the five decades under consideration. In contrast, Saint Helena, with a population of less than 5000 and a GDP per capita of more than USD 7000, received the least overall assistance, amounting to USD 212 million. However, per capita assistance to Saint Helena (USD 42,400.00) is severalfold greater than that given to Nigeria (USD 26.62) [132,133].

In addition to the OECD-DAC assistance, the region also receives development support from several other multinational funding agencies. These include the International Development Association (IDA), European Union (EU) institutions, Global Fund, African Development Fund, Global Alliance for Vaccines and Immunization, UNICEF, Global Environmental Facility, UNDP, IFAD, IMF (Concessional Trust Funds), World Bank and many others [135]. To ensure that funding is properly and appropriately utilized, several of these funding agencies predicate disbursement of assistance on the implementation of environmentally sustainable principles by recipient nations. This principle commits recipient nations to ensure that socio-economic and ecological development projects do not compromise biodiversity and ecosystems' health at different temporal and spatial scales [136]. Subsequently, issues relating to the environment must be taken into consideration in the planning and execution of development projects. These issues include, but are not limited to how projects affect or may affect climate change, rainfall patterns, temperature, biodiversity, deforestation, desertification, water resources including pollution of waterways, soil degradation, etc. [136]. To achieve this goal, West African nations have enacted laws that make environmental and health impact assessments mandatory in their respective jurisdictions.

Table 10. Averages for official development assistance to West Africa by the OECD-DAC, between 1970 and 2020, in millions of USD (adapted from [132,135]).

Country	1970–1979	1980–1989	1990–1999	2000–2009	2009–2019	2020
Benin	149	235	324	424	535	341.76
Burkina Faso	289	461	532	720	972	419.49
Cape Verde	35	144	154	154	200	99.86
Côte d'Ivoire	312	404	1047	593	1130	305.12
Gambia	46	140	85	80	106	48.21
Ghana	291	566	782	1150	1453	624.71
Guinea	75	306	447	267	422	182.41
Guinea Bissau	56	151	155	107	111	30.6
Liberia	86	194	146	385	795	424.77
Mali	325	661	554	715	1115	749.76
Mauritania	331	409	292	319	305	68.17
Niger	347	512	403	484	770	447.32
Nigeria	301	135	282	2444	2162	1849.91
Saint Helena	15	35	22	30	110	71.64
Senegal	421	871	741	773	891	573.75
Sierra Leone	66	158	188	408	587	303.88
Togo	158	245	195	140	256	83.46
Total	3303	5627	6349	9193	11920	6624.82
% Total	9.08	15.46	17.45	25.26	32.75	

4.4. Pollution Control Measures

Existing pollution-control measures in the West African region vary in both spatial (local, national and regional) and temporal orientations. Important regional measures include the Abidjan Convention, with its protocol on Cooperation in Combating Pollution in the Event of Emergencies, which was signed in 1981. The Convention aims at cooperation for protection, management and development of the marine and coastal environment of the Atlantic Coast of the West and Central Africa. According to Adam et al. [137], the Abidjan Convention, as of 2019, adopted four main protocols (viz., the Calabar Protocol on Sustainable Mangrove Management, the Grand Bassam Protocol from Land-based Sources and Activities, the Malabo Protocol on Environmental Standards and Guidelines for Offshore Oil and Gas Activities, as well as the Pointe Noire Protocol on Integrated Coastal Zone Management). The United States Environmental Protection Agency (USEPA) also acknowledged collaboration with selected countries in the region (Cote d'Ivoire, Ghana and Nigeria) on pollution control measures, with a focus on water quality, exposure to toxic chemicals and air quality (https://www.epa.gov/international-cooperation/epa-collaboration-sub-saharan-africa (accessed on 25 August 2022)). In addition, individual countries in the region have additional laws and institutional frameworks for pollution control, which, according to Dada et al. [138], can be categorized into corruption control, law and order, and bureaucracy quality. Examples of the measures in the Nigerian environment include the National Effluent Limitation Regulation (S.I.8 of 1991) and Pollution Abatement and Facilities Generating Wastes Regulation (S.I.9. of 1991) that mandate manufacturing firms in Nigeria to install pollution abatement equipment or make provision for treatment, and as well prescribe guidelines for permissible limits [139].

Based on the report of the World Bank Group, Croitoru [10] and other studies, e.g., [140,141], the existing pollution-control measures are, apparently, ineffective. For ex-

ample, Croitoru [12] noted that whereas the global incidence of water-pollution-associated diseases is declining globally, the sub-Saharan Africa tops the most vulnerable list, especially in the slums, rural areas and peri-urbans. Additionally, the coastal areas in Benin, Cote d'Ivoire, Senegal and Togo lost 5.3% of their national GDP to environmental degradation, which also caused the deaths of people and destroyed livelihoods, as of 2017 [12,25]. Problems associated with poor pollution control in the region include poor or ineffective enforcement of pollution regulations, poor national databases, a lack of/inefficient/expensive pollution technology [142,143], ineffective community governance, and a lag in community mobilization and empowerment [144].

4.5. Urban Renewal

Urban renewal, redevelopment or regeneration is an important concept that seeks to address the poorly planned urbanization and urban growth through demolitions, evictions and other forms of activities involved in restructuring urban space and enforcing aesthetic norms of cleanliness, modernity and orderliness [143]. The significance of urban renewal is premised on the fact that the urban area has been degraded, typically characterized by ineffective or poor housing schemes that prompted the emergence of slums or 'blighted' communities, and the need for modernization of housing structures and improved urban facilities allocation, as documented in SDG 11 [145,146]. Some studies have described urbanization in West Africa as that which is wholly demographically driven, with no commensurate socio-economic dividends and benefits to the urban environment (e.g., [141,146]). Consequently, facility restoration and modernization which are targeted at meeting sustainable urban growth, improving human livability and correcting town/city centers that are at variance to urban regulations and master plans [147,148] have become an issue regarding development goals for the sub-region. In 2016, the UN Economic Commission for Africa (UNECA) provided a framework agenda (Africa Urban Agenda) for action on the improvement of cities and settlements in the region, as a step toward the region's structural transformation [24,149].

Urban renewal activities are aimed at improving or regenerating the social, physical, environmental and economic components of the urban area [148,150–152]. Main strategies of urban renewal include comprehensive redevelopment (complete demolition and reconstruction) of absolutely obsolete and decaying structures and facilities, rehabilitation or renovation of unacceptable neighborhood structures and facilities, as well as conservation or preservation of structures with cultural, historic and architectural and aesthetic importance [153]. Studies have, however, shown that the effectiveness of the strategies may vary depending on the interest of the responsible agency (governmental or non-governmental), methods of implementation (comprehensive or selective—social, physical or economic, boot-strap strategy), central factor for renewal decision (economic, ecological or environmental and people; [154]) and sustainability [153,155,156].

The ECOWAS environmental policy [157] identified problems relating to urban settlements in West Africa to include over-crowding of coastal areas and settlements along transport routes, probably due to comparative socio-economic advantages, poorly controlled rural–urban migration as a result of lopsided distribution of infrastructure, as well as land-use-associated pollution (noise, water and air) problems. Across West African countries, urban renewal has evolved directly or indirectly through government initiatives, local (community) efforts and international initiatives, and agents such as private developers, designated Land Development Corporations and housing societies [154]. In some West African countries (e.g., Nigeria, Ghana and Burkina Faso), studies noted that state creation and its associated territorial disaggregation, changes in government (specifically the election of a new party or set of elites into government), and the conspicuous need for major infrastructural or environmental development, probably based on public instigations or major disasters (such as flooding and accidents) are the main factors that have encouraged urban renewal (e.g., [143,158]). Agbaje [158] also argued that urban renewal may be initiated as an attempt to disguise national poverty in locations around a site of international

events, such as major sports events or festivals in some West African countries, such as FESTAC 77 in Nigeria, or during the hosting of world sporting events in parts of Lagos (Nigeria) and Accra (Ghana). There are also reported accounts of neoliberal redevelopment in Ouagadougou, Burkina Faso [159], but studies are unclear about the development in other parts of West Africa, including the West Point slum in Monrovia, Liberia, with more than 75,000 people [24,160]. Indeed, there is yet no comprehensive urban development plan in the sub-region; only 3 countries (13 in Africa) in the West African sub-region are in the formulation stage, 9 countries are at the process of implementation, while only Cote d'Ivoire (only 4 countries in the entire continent) was at the stage of evaluation, as of 2018 [160] (Table 11). Information is also unavailable for the Republic of Benin, Sierra Leone and Senegal.

The lack of a completed and well-evaluated urban policy in the sub-region may probably explain the problems of the many urban renewal attempts in some of the countries in the sub-region. For instance, Gbadegesin & Aluko [161] and Omodanisi et al. [162], among others, identify concerns about the poor compensatory, re-housing and resumption programs for affected victims, including vulnerable populations as well as backwash (socio-economic and cultural vices) effects on adjacent, poorly protected communities.

Table 11. Status of urban policy in West Africa (adapted from [160]).

Status of National Urban Policy	West African Countries	Other Parts of Africa
Prefeasibility	None	Burundi, Tanzania, Zambia
Diagnostic phase	None	Gabon, Malawi
Formulation phase	Cameroon, Liberia, Togo	Tunisia, Chad, Libya, Egypt, Uganda, Zimbabwe, South Sudan, Kenya, Mauritius, Namibia
Implementation	Burkina Faso, Cape Verde, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, Gambia	Angola, Equatorial Guinea, Comoros Island, Congo, Djibouti, Algeria, Sudan, Eritrea, South Africa, Somalia, Rwanda
Monitoring and Evaluation	Cote d'Ivoire	Botswana, Ethiopia, Morocco

4.6. Ecological Restoration and Protection

4.6.1. Ecological Conditions

Debates are inconclusive about the link between increased economic and urban activities and poor environmental quality, probably due to factors including temporal (short and long run) changes, the availability and efficiency of management regulations, and their implementations and sustainability plans [163,164]. The Environmental Kuznet Curve hypothesis suggests that economic development will initiate environmental pollution in the short run until a turning point is reached when an increase in a society's per capita gross domestic product will result in a decrease in environmental pollution. According to Kuznets [165], income inequality increases to a maximum and then starts to decrease as per capita income increases, whereas studies (including [166,167]) on different occasions showed that despite rising incomes in different parts of West Africa, concentrations of pollutants (especially CO_2), waste accumulation and exploitation of natural resources would worsen environmental degradation in the sub-region; other studies (such as [168,169]) revealed that the relationships between increased economic development and CO_2 emission was non-linear or U-shaped, suggesting the influence of certain intervening or explanatory variables, including corruption [170].

Areas requiring ecological remediation and environmental restorations in the sub-region include abandoned mine sites [171], waste dumpsites, oil and gas fields [172–174], soil quality and forest landscape [175,176]. Mansourian & Berrahmouni [177] listed major abandoned mines in the sub-region as sources of threats to the ecosystems and society, especially with the widespread artisanal and small-scale mining (ASM), as well as formal and large-scale mining activities that have been linked with heavy metals and acid mine

drainage and radioactive contaminants (e.g., Table 12). The sites include gold mines in Nigeria, Senegal, Mali, Burkina Faso, and Cote d'Ivoire; manganese and diamond mine sites in Cote d'Ivoire; as well as the 3Ts (tin, tungsten and tantalite), granite, marble, gravel and colored gemstones fields in Nigeria [178]. The United Nations Environmental Program [178] defines abandoned mines as sites of mining that are not operational, rehabilitated or actively managed but are capable of causing significant environmental or social problems, for which no one is currently accountable for site rehabilitation or remediation. With respect to soil quality, Lal [176] argued that soils in the sub-Saharan Africa, which includes the present study area, are widely degraded (in physical, chemical, biological and ecological composition) due to low external inputs, over exploitation, extractive farming, and poor management. In the West African sub-region, the components of the environment typically become vulnerable to damage at different spatial scales (catchment, local and regional scales) due to associated anthropogenic (mainly urbanization, intensive and poorly planned agricultural activities, including over grazing and indiscriminate tree felling, poor waste management) and natural factors (mainly drought and other consequences of extreme climate conditions) [179,180].

Table 12. Major research findings from abandoned mine assessments in West African countries (adapted from [177]).

Country	Sub-Region	Commodity	Main Concerns
Nigeria	Southwestern Nigeria	Multiple	ASM is widespread in Nigeria; abandoned mines are linked with land-use conflicts, insecurity and health risks for communities; due to unique geology, Nigeria faces severe human health risks from Pb-rich ore exposure in gold mining.
	Ishiagu, Southeastern Nigeria	Pb-Zn	Acid Mine drainage (AMD) identified as major hazard; agricultural plants (food crops and grasses) contain Pb concentrations above WHO allowable guidelines. Values of Pb (0.03 to <4 ppm) in all water samples, except the borehole sample (0.003 ppm/2.9 ppb), exceeded the EU/Canadian guidelines.
Senegal	Kedougou Region	Gold	Benefits from gold mining accrue to men, burdens borne by women; surface and groundwater contamination was detected; mercury (Hg) contamination from informal gold mining mostly affected children and women.
Burkina Faso	Poura gold mine	Gold	Abandoned mine tailings caused AMD (pH = 2.2) and contamination; high concentrations of heavy metals (e.g., Pb, Zn, As, Fe) in soils, surface and groundwater that exceed WHO allowable levels.
Ghana	Atiwa, East Akim and Fanteakwa	Gold	Informal gold mining is major source of environmental harm; Hg and CN endanger human and ecosystem health; Hg levels in sediments and soils.
Mali	Morila Gold Mine	Gold	High As, Fe and Mn in water, soil and plants exceed WHO allowable levels; accumulation of metals in crops/plants suggest phytoremediation options, and certain species show potential for phyto-stabilization of heavy metals in soils.
Cote d'Ivoire	Divo, LôhDjiboua Niakaramandougou	Gold, Manganese, Diamonds	Watershed level contamination detected, soil, surface and groundwater; loss of livelihood suspected due to burden of disease; ASM growth within the abandoned industrial gold and diamond mines.

4.6.2. Ecological Remediation and Restoration

Studies have reported that the need for ecological remediation and restoration in any part of the world is largely borne out of the health and risk implications of land uses on

humans and other living organisms (e.g., [173]). The Society for Ecological Restoration [181] defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed and ecological remediation refers to the physical, chemical and biological process of returning a contaminated part of the earth surface (land, soil, water or air) to its pre-contaminated state with the focus on improving the ecosystem service functionality of the part of the earth's surface (see [182]). However, many studies have not been able to distinguish the terms, often interchanging ecological restoration with remediation, rehabilitation and reclamation [183]. Countries in the West African sub-region is part of the 58 African countries that have agreed to the United Nations Decade on Ecosystem Restoration (2021–2030), and are therefore part of the contributors to the global restoration agenda. Basic principles of ecological remediation and restoration are presented in Figure 8, consisting of remediation by natural attenuation (RENA; also known as 'do nothing technology'), remediation, reclamation, rehabilitation and restoration. According to Zabbey et al. [174], the RENA approach, which was the traditional method for cleaning up the contaminated land in the Nigerian Niger Delta region by regulators and industry operators, was considered unsuitable for many parts of the sites of oil spillage, especially where the crude oil spilled below 5 m, as well as contaminated groundwater aquifers. In general, the RENA approach is not typically effective, and there is therefore the need to explore an approach that integrates a planned process or a combination of planned processes technologies. The remediation approach involves the physical replacement, chemical cleansing of contaminated parts of the earth's surface via use of water, reagents, and solvents that can leach the contaminants from soil or phytoremediation and bioremediation—the use of plants and any other methods that can facilitate natural degradation of contaminated soils and/or water resources.

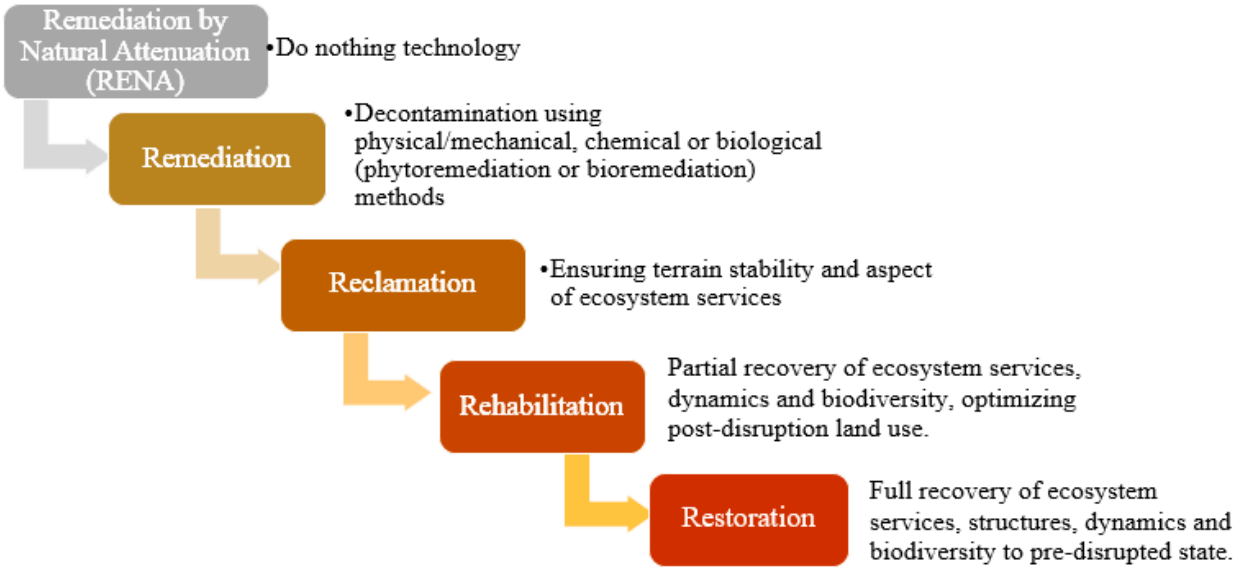


Figure 8. Types of ecological improvement approaches (conceptualized based on [172,174]).

Reclamation involves activities that encourages improving the capacity of the natural resources to ensure the stability of lost/contaminated terrain and ecosystem services of the earth resource [172]. Reclamation is an essential part of restoration of land resources, and it involves returning ecologically disturbed piece of land to an enhanced state or transforming ecologically disturbed land to its former state or other productive uses [174]. Although often used interchangeably with reclamation, ecologically damaged water, land and forest resources can be said to be rehabilitated when they are restored to their previous (pristine or native) condition [183]. Restoration, according to Stanturf & Mansourian [184], refers to a planned process that aims at regaining ecological integrity for the enhancement of human wellbeing in degraded landscapes. The concept of ecological restoration well builds within

target 15.4 of the SGDs, which is focused on ensuring 'the restoration and sustainable use of terrestrial and inland freshwater ecosystems' [185].

The countries of the West African sub-region have been involved in ecological restoration being signatories to the Pan-African Agenda on Ecosystem Restoration (whose membership includes Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan), Great Green Wall for the Sahara and Sahel Initiative (Nigeria, Niger, Mali, Senegal and Burkina Faso) and *AFR100* (all except Cape Verde, guinea Bissau and Gambia) [177]. A target of the Great Green Wall initiative is to restore 100 million hectares of damaged land across the African region by 2030 [186]. The challenges facing the commitments of the sub-region to achieve ecological restoration are largely related to governance, in particular, poor policy implementation and human and physical infrastructure, poor funding, as well as coping and resilience capacity in the face of the effects of climate change and extreme conditions (Figure 9a; see also [97,187]). Consequently, there is need for commitments towards setting specific regionally targeted restoration goals, clearly defined strategies for effective response to local goals, institutional frameworks and political will to drive the goals among member countries, as well as partnerships with multiple (governmental and non-governmental) partners and well-defined structures for systematic project and policy monitoring, with evaluation procedures that should be uncompromisingly implemented (Figure 9b; [177]).

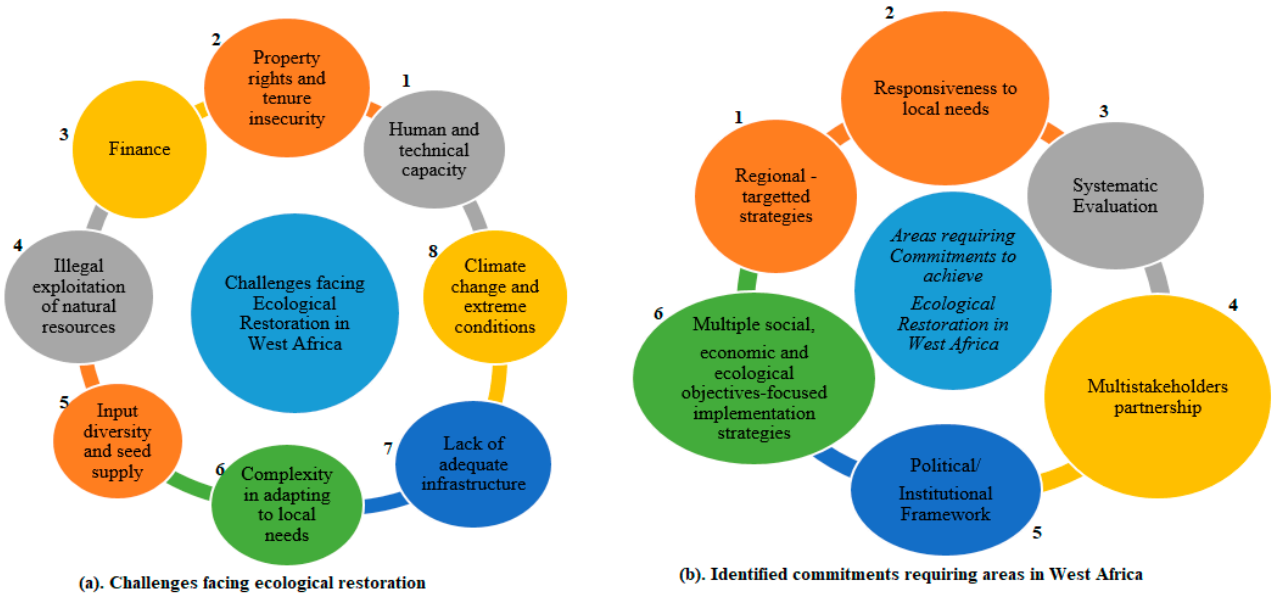


Figure 9. Challenges facing ecological restoration and areas requiring commitments from the governments of West African countries to meet targets for ecological restoration in the sub-region (Data source: [177]).

4.7. Urban Greening and Green Technology

Only 0.7% of West Africa's geographical area is occupied by urban settlement, but there 45% of the country's people are living there, and that number is expected to grow to 67% by 2050, due to a 3.9% annual growth rate [187]. Despite the fact that the governments of West African nations and towns have development master plans to manage city layout and landscaping to handle significant population pressure, their executions have been inadequate. Urban sprawl and infrastructural advancements have caused numerous cities, including Lagos, Kano, Kaduna, Sokoto (Nigeria), Dakar (Senegal), Freetown (Sierra Leone), Abidjan (Cote de I'voire), Accra, Kumasi, and Tema (Ghana), to lose a significant quantity of urban green spaces [188]. As a result, green space now only makes up a small fraction of the landmass of several urban areas. Some of these cities are merging with neighboring cities. Lagos, Nigeria, has extended into cities in the nearby state of Ogun. Parks, gardens, orchards, urban agricultural land, woodlands, etc. have disappeared as a result of this

disappearance in favor of the development of residential and commercial buildings. For instance, a study in Ibadan, Nigeria showed that 0.73 m^2 of green space per person fell short of both the minimal requirements of the World Health Organization (9 m^2) and the United Nations (30 m^2) [189]. New opportunities and difficulties have been presented as a result of the region's current rate of urbanization and awakening to urban greening. The primary types of urban forestry in various West African cities, include green space, designated parks, street trees, and roadside plantations, public green spaces (green parks, botanical gardens and recreational gardens), natural urban forests, among others [188,190]. Other are trees planted to serve as wind breaks, watersheds protection, or as security fence for houses; or planted inside uninhabited lands; or at the seaside. The varieties of tree species planted for landscape improvement, environmental protection, the provision of forest products, and other benefits vary with ecological zones and cultural values of the people.

Many studies have examined green space potential and spatio-temporal changes using field surveys and geographic information systems (GIS) techniques to reveal that trees and urban forestry mostly concentrate around political/administrative or economic seats/capitals in urban centers (191–193). Overall, there is compelling evidence that green infrastructure may significantly enhance both the quality of life and the environment in the expanding cities. Commonly used plant species include *Azadirachta indica, Eucalyptus species, Gmelina arborea* and *Acacia species* predominated the landscape in urban areas of the Guinea and Sudan savannah ecosystems while *Adansonia digitata, Acacia species, Eucalyptus species, and Azadirachta indica* were observed in abundance in the Sahel savannah in strategic locations in the cities. In the tropical rainforest zone, *Terminalia catapa, Gmelina arborea, Tectona grandis, Delonix regia*, and many palm species in urban areas. In the mangrove and swamp forest zones, only a few numbers of species are chosen for urban forestry. Notable examples include the *Rhizophora and Avicennia* species, ornamental palms, and coconut trees. In Lomé, Togo, some of these species can be seen on either side of the road [189–193].

Trees are planted around homes and public buildings, in the West African region are often those that bear tasty fruit, help to reduce excessive temperatures, and absorb air pollutants [188]. Other studies listed commonly planted trees for urban greening to include *Mangifera indica, Carica papaya*, *Psidium guava*, *Cocos nucifera*, *Elaeis guinensis* and *Persia americana* [194,195]. Larinde & Oladele (195) also listed *Irvingia wombulu*, *Chrysophyllum albidum*, *Citrus sinensis* and *Dacryo desedulis*, *Persea americana*, *Citrus* species, *Arto carpusaltilis*, *Spondias mombin*, *Moringa oleifera* and *Treculia Africana* as common urban forest plants. In general, urban green spaces have been linked with role in creating livable, sustainable and resilient cities by lowering air and noise pollution, absorbing precipitation that might otherwise cause flooding, providing a habitat for local wildlife, providing an alternative food source for people, offsetting carbon emissions in the neighborhood, enhancing the aesthetic of the region, and lifting the spirits of those who see it, with advantages for both physical and mental health [196–198]. However, in order to achieve these objectives, the sorts of green spaces created and the tree species that are planted must be suitable for the biophysical setting as well as for the cultures and needs of the local inhabitants [198,199]. The authors concurred that future master plans should include and enforce green space, and that existing cities should find a way to include green space in reconstruction and restoration plans. To instill a sense of good management and protect the present urban vegetation in West African urban cities, several government projects, such as "10 million people–10 million trees," established in 2013 in the Republic of Benin [200], ought to be revisited in most nations.

A multidisciplinary approach must be adopted by researchers to incorporate physical results into social and environmental contexts in order to address complex real-world problems. Authors also recommend training and instruction for technical workers and growers of ornamental plants. Additionally, studies will be required in smaller and less notable urban cities, along agro-climatic zones, and in socio-cultural and socio-economic contexts [201]. To encourage the production of healthy food at a reasonable cost and

enhance biodiversity conservation, strategies must include the planting of native species as well as edible fruit trees in household gardens and other urban spaces [202,203]. Urban green spaces should be planned, established, maintained, and protected with input from all stakeholders, including the public, private, city and town planners, academics, and local residents.

4.8. Smart City

The concept of a smart city (also referred to as a Digital City, Intelligent City or Sustainable City; [204]) is an evolving or a work-in-progress approach to alleviating current and potential urban problems as well as making future urban growth and development sustainable through the application of information and communication technologies (ICT) [204–206]. A smart city uses innovation and technology to make urban environments more inclusive, livable and sustainable [205]. It is a city that is well performing in a future-looking way in terms of living, people, mobility, governance, environment and economy that is built on the smart combination of independent, aware and self-decisive citizens [207]. In general, a smart city is made up of ICT (the digital city components) as an infrastructure to drive the anticipated sustainable management of natural and environmental resources, governance and economy, quality of life, transport, social and human capital [208].

A generalized framework for initiating a smart city for governance, economy, living, mobility, people and environment is defined by Camero & Alba [204] and Alawadhi et al. [205], among others, who identified basic working components of a smart city initiative to include the people and targeted communities, technology as well as policy and governance drive via private–public partnerships (Figure 10). Key actors in a smart city initiative are the government and non-government organizations at all tiers, in integrated capacity for theme-based (ICT, transportation and administration) actions [208].



Figure 10. A working component for a smart city initiative (conceptualized based on [204,205].

In West Africa, Accra (Ghana) with Abuja and Lagos (Nigeria), which were funded by IBM's Smarter Cities Challenge (in 2012, 2013 and 2014, respectively), appeared to be the only settlements with significant focus on smart city development in the sub-region [209]. Abuja and Accra are classified as medium cities (with 0.5–5 million population; [210]) and Lagos as a mega city (with 13 million population; [209]) were strategized to prioritize

'soft' infrastructure developments, with significant private partnerships. Emerging satellite smart cities in West Africa are mainly Eko Atlantic and Centenary in Nigeria and Hope City in Accra [211]. Camero & Alba [204] reported that of the over 4000 publications on smart cities that were indexed in the Web of Science citation report for the period of October 3, 2016–2017, only two countries (Nigeria and Burkina Faso) were represented, an indication that the West African region was poorly represented, and very poor opinion or implementation of the smart city initiative in the sub-region is suggested (Figure 11). One of the studies, which focused on the smart transportation in Burkina Faso [212], demonstrated a mobile-based decision support system for transportation, similar to reported instances in Lagos and Accra [209].

According to Ouoba et al. [212], advanced mobile technological services (including high-end mobile devices and infrastructure, such as 4G/5G networks, Wi-Fi hotspots with high bandwidth) to drive the concept of a smart city are not always available for people in the sub-region. Additionally, Smart Urban Spaces, an infrastructure for common and shareable ICT-based mobile solutions for a smart city project, will be difficult to implement in the West African countries, because the majority of the population may not be able to afford to use the high-end mobile equipment, due to poor status of many West African countries and poor investments in infrastructure of communication. Alawadhi et al. [205] had also identified the lack of staff and budgetary constraints, leadership and management commitment, limited funding and absence of focused policy and commitment as major challenges facing the implementation of a smart city initiative in many developing countries.

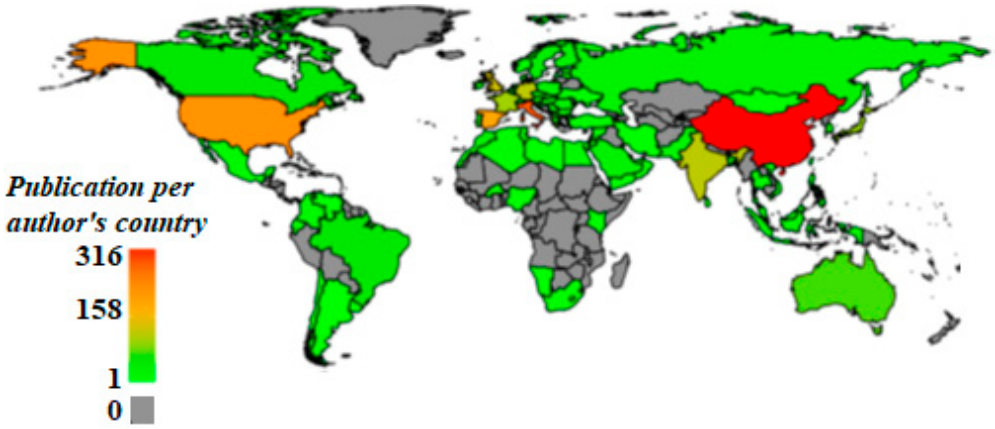


Figure 11. Distribution of publications on smart city by author's country of affiliation [204].

In general, the level of dedication to the smart city initiative in the West African region has been decried [209], with studies offering recommendations, ranging from data-driven conceptualization of the content of a smart city initiative [213] to infrastructure decoupling (a system that requires infrastructure to be changed/replaced, redesigned, removed or transformed and made fit for current population needs, capacity and level) [209]. Infrastructural decoupling is expected to save cost, as it is based on the hypotheses of an infrastructural deficit in African cities, and that building infrastructure is more expensive in African countries than in any other developing countries [214]. Studies also recommended opportunistic and collaborative networking for infrastructure as well as adoption of free and open access technologies, to encourage the regional population to participate in the initiative [207,214].

5. Conclusions

The study reviewed existing literature on the trends of urbanization, the urbanization–climate–pollution nexus and pollution mitigation measures in the West African region. The specific objective was to appraise the trends of urbanization and socio-economic status, as well as the relationship among climate-, urbanization- and pollution-mitigation and -control measures in the sub-region. This was conducted with a view to synthesizing the

urbanization–climate–pollution nexus in West Africa, and provide a better understanding of issues relating to the sustainable development of the region. Findings from the review suggest that the urbanization–climate–pollution nexus in the West African region is complex, and that whereas regional environment has increasingly been urbanized in the recent years, the deplorable conditions of both the physical and human environment have been a major concern in the quest for sustainable development. While the review has reported consistent concerns of pollution, and probably painted a gloomy future of an unsustainable environmental governance, most countries in the region are signatories to protocols and frameworks that are targeted at controlling the negative consequences of physical development. The extent of the impact of governance, population growth, poverty and corruption, which have been reported as the drivers of degradation in developing countries is, however, not yet clear [215–218]. Nonetheless, the higher-than-WHO recommended limits of particulate matter (PM_{10}) in many of the cities in the region illustrate the significant problems that can be attributed to poor enforcement or lax regulations governing the entry of used automobiles into the region. Okorodudu-Fubara [141] attributed poor policy enforcement to political interference or corruption-influenced legislative weakness in parts of the West African region. The main findings in this review suggest the need to improve on the implementation of the institutionalized national and international environmental frameworks in the region for preparedness for the present and future climate uncertainties, as well as contingencies such as the COVID-19 pandemic, and the risk of population explosion. Consequently, the review concludes that although the region's human (population) and natural (vegetation, climate and minerals) resources are potential instruments for strategic productivity and development, the present state of urban infrastructure and preparedness for future population growth and climate change do not project commitments to a sustainable future in the region. Therefore, country- and region-based goal-targeted actions for the strict implementation of relevant sustainable development goals are recommended for the West African region.

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