

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

5,900

Open access books available

145,000

International authors and editors

180M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Climate and Environmental Risk Action: A Call for Fresh Commitments to Adaptation and Resilience in West African Sub-Region

Bolaji Abdulkadir Usman

Abstract

Problem of capacity to adapt and build resilience against climate and environmental risks has become a major source of concern globally. However, poorer regions and countries where substantial proportions of the people depend more on natural capital are generally more at risk. West Africa is a region known to have experienced major environmental changes in the last half century. Therefore, using evidences from the literature, this chapter examines climate and other environmental problems that have created challenges to agriculture and food security, water resources, health, energy and infrastructural development. We highlight the potential for adaptation and building resilience, while also emphasising the need to develop appropriate adaptation and risk management strategies built on proper understanding of dimensions of exposure and vulnerability. Among other recommendations, this chapter accentuates the need for raising climate and environmental risk awareness among the populace, sustainable management and use of natural resources, development of weather information and early warning systems and stronger transnational cooperation to address climate and other environmental risk impacts.

Keywords: climate, environmental risk, adaptation, resilience, risk impact

1. Introduction

Climate change has emerged as one of the most prominent environmental, economic and social threats facing humanity today. Climate and environmental risks are associated with extreme weather events like drought, flooding, windstorm, rise in sea levels, earthquakes and volcanic eruptions that may result in ecosystem degradation, loss of natural assets, potential trade and supply chain disruptions, reduced productivity, declining welfare and loss of lives and properties. Consequently, across the globe the probable impacts of extreme weather events and other environmental

hazards and the problem of capacity to adapt and build resilience against the impacts, have become a source of great concern. While international organizations, governments, non-governmental organizations (NGOs) and corporations are responding by building environmental factors into economic, social and political structures to strengthen resilience and adapt to changing conditions, these challenges are proving difficult to manage. It has thus been argued that addressing these challenges require introduction of appropriate incentives, taking efficient economic decisions and promoting changes in households and public institutions in order to change habits and behave in an environmentally friendly way [1, 2].

The global socio-economic impacts of climate change are expected to become more substantial as affected regions continue to grow in number and size, and more people and more natural capital would be negatively affected in the near future. Although, all countries of the world are affected by climate change, poorer regions and countries are generally more at risk as their populations often rely more on natural capital and have less financial resources to adapt quickly [3]. Africa is highly exposed to climate and other environmental risks because it has experienced warming trends of between 0.26°C and 0.5°C per decade in the last one century [4]. It is believed that this trend will continue and may significantly increase with much negative implications in the form of considerable increase in temperature, decreasing rainfall and increasing frequency and intensity of tropical storms. The continent is known to contain about half of the world's most risk prone countries and it is experiencing increasing number of disasters. The number of reported disasters resulting from natural hazards has particularly increased on the continent over the last three decades, with floods, epidemics and drought being most prominent [5]. Climate change, poor urban planning, environmental degradation and fragility, poverty, inequality and conflicts have been found to be the main disaster drivers on the continent. The impact on the human population are in form of increase in exposure to water stress, decline in production of staple food crops and increase in poverty and conflicts due to loss of livelihoods [1, 5, 6].

As a result of increasing climatic variability and human activities, West Africa and particularly the Sahel region, has experienced major environmental changes within the last half century. The Sahel is regarded as the region that experienced the greatest rainfall anomalies in the world during the last century [7]. Observations have shown general warming across West Africa since the 1960s, increase in incidence of warm spells and decrease in incidence of cold days. Overall decrease in annual rainfall has also been observed since the 1960s, while the arid zones have experienced more prolonged droughts since the 1970s [7, 8]. Although, projected climatic models for West Africa differ based on the assumptions, most agree on overall warming trend across the region, with average temperature rise of 0.5% per decade. There is also general consensus on an overall decline in precipitation across the region of 0.5–40% by 2025, and average sea level rise of 0.5–1.0 m by 2100 [8].

Devastating droughts, changes in seasons, reduced and unpredictable rainfall and flash floods have negatively affected local community livelihoods and resulted in population displacements. As a result of these climatic and humanitarian crises, West Africa is now viewed as a region of poverty, conflict and human insecurity [9]. Many parts of West Africa face chronic variability of rainfall and strong pressure on arable land. The situation is made more critical by the fact that agriculture and livestock which depend heavily on the ecosystem creates about 60% of household incomes. Furthermore, due to increasing population the people are forced to adopt

unsustainable practices in order to survive. This makes the environment more vulnerable to degradation and increase in fragility of marginal areas [9]. This paper was conceived to explore climate and environmental risks and the potential for raising adaptive capacity and resilience in West Africa. Against this backdrop the specific objectives are to: investigate the climate and environmental risks; examine the dimensions of vulnerabilities and impacts; determine the adaptation and resilience opportunities; and propose policy options to be adopted to raise adaptive capacity and resilience in the sub-region.

The remaining part of this paper is subdivided into five sections. The section succeeding this introduction focuses on definition and clarification of major concepts relevant to this paper. The next section highlights the main climate and environmental risks in West Africa, while also emphasising the vulnerability of the human population. Using evidences from literature, the succeeding section presents climate and environmental risk impacts and potential for action in major sectors. The next section outlines strategies that can be targeted towards raising adaptive capacity and resilience in West Africa. The concluding section summarizes the key findings and suggests areas for future research.

2. Conceptual clarifications

2.1 Risk

Risk is the combination of the likelihood or probability of an event and its consequences. However, risk could be defined from either the natural hazard based approach or the vulnerability based approach. In the hazard based approach the likelihood is seen in relation to the hazard, in which situation risk is seen as the likelihood of a hazard and its consequences. This is also called event risk. Alternatively, using the vulnerability based approach; the likelihood is attached to the consequences whereby risk is the likelihood of exceeding a given level of damage, otherwise known as outcome risk [10, 11]. Nevertheless, in both cases risk is explicitly or implicitly associated with a “trigger” event or hazard and impacts defined by the characteristics of the exposed system [11]. Risk does not only depend on climate and other environmental events (hazards) but is also determined by exposure and vulnerability to the hazard [12]. Hazard is broadly defined as a process or occurrence of natural origin or due to human action with potential to cause injury, loss of life or other health impacts, damage to property, disruption of social and economic wellbeing or degradation of the environment [10, 13]. Natural hazards are mostly associated with potentially destructive natural processes and phenomena like earthquakes, floods or windstorms and so on [14].

2.2 Vulnerability

Vulnerability is generally defined as the likelihood that a person or group of people will be exposed to and adversely affected by a hazard [15]. As it relates to climate change, vulnerability is defined as the degree of susceptibility of a system to the adverse effect of climate variability and extremes. It is the likelihood that assets (people, buildings, farmlands and so on) would be destroyed or damaged when exposed to hazard [14]. Vulnerability is a function of three constituents which are exposure, sensitivity and adaptive capacity [16, 17], which are important for

establishing the level of vulnerability of a system to climate change and also provide necessary information for evaluating and reducing climate threats [18, 19].

Exposure is described as the inventory of elements or location, attributes and value of assets that could be affected in an area in which hazard events may occur [12, 13]. Therefore, if people and economic assets are not situated in (exposed to) potentially perilous situation, issue of disaster risk will not exist. Hence, while it is possible to be exposed but not vulnerable (if there is enough means to modify the environment and behaviour to mitigate potential loss), vulnerability to extreme event requires exposure [12]. Sensitivity refers to the degree (extent) to which people, property and other assets could be harmed by exposure to hazard. In other words it indicates the potential for adverse impacts [20]. Indicators of exposure include increasing temperature, windstorms, sea level rise and drought, while sensitivity to hazard depends on geographic and socio-economic conditions like natural environmental condition, demographic conditions and level of dependency on natural assets [19].

Adaptive capacity refers to the ability of individuals, group or system to adjust to environmental changes, moderate potential damages, take advantage of opportunities or cope with consequences of event like climatic extremes [21, 22]. In other words, it is the responsiveness to stress in living conditions or shocks associated with extreme conditions. Adaptive capacity encompasses the social and technical skills and strategies of individuals or groups directed towards responding to environmental (or social and economic) changes [22]. For instance, highly managed agricultural and water resources systems in developed countries are expected to be more adaptable than those that are less managed. Adaptive capacity may also be exemplified by ability to shift to alternate land use within an agro system or ability to adopt drought resistant crops [21, 22].

2.3 Adaptation

Adaptation is simply any human action which minimizes the adverse effect of climate change while maximizing its advantages. It is the adjustment carried out in response to actual or expected climatic or other environmental stimuli, which moderates or takes advantage of beneficial opportunities. Adaptation therefore involves changes in attitudes, practices and institutions to reduce or offset probable damages or take advantage of opportunities associated with climate change [21, 23, 24].

The ability of a system to adapt depends on some characteristics of the system consisting of sensitivity, vulnerability, resilience and adaptive capacity, also referred to as the “determinants of adaption” [18, 23]. Adaptation has been classified into different forms. Adaptation could be autonomous or spontaneous, planned, passive, anticipatory or reactive. In addition, adaptation can be short or long term, localized or widespread. Spontaneous adaptations are reactive in nature because they emanate after initial impact has manifested (normally without the intervention of a public agency). Planned adaptation may be anticipatory (when carried out before impacts have manifested) or may also be reactive [18, 24].

2.4 Resilience

Resilience is the degree of shock or change that a system can withstand while still maintaining its structure, basic operations and organizations. It thus describes the

ability of a system (or community) to endure and utilize or even benefit from adversities, shocks or stresses, in both short and long terms. This implies that resilient systems may even benefit from adversities, if they are strong enough [22, 25]. Therefore, a resilient system is expected to possess the ability to anticipate and respond to perilous events, trends or disruptions related to climate or other environmental risks.

At both individual and community levels resilience is usually greater when there is higher level of social infrastructure that facilitates sharing of knowledge and resources in response to shocks and disruption associated with climate and environmental threats. Social safety nets such as mutual assistance within families and communities strengthen people's resilience. In addition, social learning is a major way through which people learn new techniques depending on the prevalent situation in an area [22].

3. Climate and environmental risks in West Africa

Climate change has become a major global challenge, but some geographical regions of the world are more affected than others. Due to socio-economic circumstances and meteorological conditions, African countries are particularly vulnerable to climate and environmental risks. In West Africa, increasing climate variability and human activities has resulted in major environmental changes. Rising temperatures, increasing erratic rainfall pattern and more frequent droughts, degradation and desertification of productive lands, flooding and inundation of coastal areas due to increasing sea level are some of the major environmental problems in the sub-region. These have created challenges to food security and management of land, water and other resources. Most significant is that the last five decades have witnessed recurrent drought episodes that have resulted in serious degradation of natural capital and ecosystems and recurrent food crises within the sub-region [10, 26, 27]. These problems are exacerbated by the rapidly increasing human population. For instance, the human population of West Africa was estimated to be 397 million in 2018 with an annual growth rate of 2.4% since 1980 [10].

These challenges are particularly dire for rural communities in the sub-region, where crop cultivation, livestock rearing and fishery which are highly dependent on climate, are the main sources of livelihood. Rural environmental degradation and increasing population and poverty are escalating the stress on environmental resources and has become a major driver of rural-urban population drift. The rate of urbanization in West Africa is over 4% per year, with 43% of the population living in cities, and this is projected to increase to 63% by the year 2050 [10, 26]. The combined effects of high level of poverty and high reliance on rain-fed agriculture and poor access to resources and services have resulted in high vulnerability to climate and environmental risks in the sub-region. Various studies [26, 28–30] have found that poverty, low level of technology, poor access to health care services and general infrastructural deficiencies among other factors are closely linked to disaster vulnerability in West African countries, and that repeated exposure to stress further exacerbates poverty in the region. Environmental degradation is a major contributing factor for conflict and food insecurity. Degradation or depletion of natural resources and population pressure are known to trigger competition for scarce resources such as arable land and water, which often results in tension and conflict [28].

4. Climate and environmental risk impact and potential for action in key sectors

4.1 Agriculture and food security

4.1.1 Vulnerabilities and impacts

Farming and other rural livelihood activities in West Africa are highly vulnerable to the impacts of climate change. For instance, drought, floods, windstorms and epidemics have been identified as the main climate and environmental risks the people are exposed to in Burkina Faso, Niger, Ghana, Nigeria and Benin [26, 28–30]. Drought often causes widespread crop failures, particularly where rain-fed agriculture is the dominant farming practice. Furthermore, successive floods and drought greatly reduce the ability to store food for future use, with great negative impacts on food security [29]. Decrease in land productivity and crop yields has become a threat to the survival of large number of people and livelihoods in in the region. The environmental stressors like drought have combined with anthropogenic factors like destruction of forest cover and increasing use of intensive cultivation to result in decline in soil fertility and associated decline in ecological resilience [31].

For example, food insecurity was reported to be very high in northern Ghana, as 60% of the rural households have insufficient food during four months of the year. Furthermore, as a result of unpredictability of rainfall many farmers have experienced significant decrease in yields, and often find it difficult to know when to plant [26]. In Burkina Faso where agriculture employs almost 90% of the active population smallholder rain-fed agriculture is the mainstay of the economy, the country is also characterizes by chronic food insecurity with many households finding it difficult to satisfy their food needs [28, 29]. Similarly, in Niger the trend of increasing temperatures, decreasing rainfall coupled with increasing land degradation has emerged as the main challenge to agricultural productivity and food security. In addition, increasing population pressure has pushed agricultural expansion into marginal lands, further increasing environmental degradation [29, 32].

Most other countries in the sub-region also face similar situations. For example, Togo which has about 70% of the working population in agriculture is also highly vulnerable to natural disasters in the form of drought, flooding and windstorms. The country experienced three major droughts and eight major riverine flooding events from 1900 to 2020, with a combined total of over one million people affected

Natural hazard	Subtype	Event count	Total deaths	Total affected	Total damage (‘000 USD)
Drought	Drought	10	0	550,000	500
Epidemic	Bacterial disease	3	1032	11,610	0
	Viral disease	2	84	560	0
Flood		8	72	547,695	0
Storm		1	0	15	200

Source: World Bank [30].

Table 1.
Natural disasters in Togo, 1900–2020.

(**Table 1**). It is projected that increasing temperatures would affect productivity of key crops like coffee, cocoa and maize and also increase the prevalence of pest and diseases in the country. The last four decades in particular have witnessed many floods that have devastated large areas of cultivated lands [30].

4.1.2 Adaptation and resilience options

Some adaptation options for crop production include adoption and promotion of conservation agriculture, agroforestry, water management, cultivar development, fertilizer efficiency, changes in planting dates, restoration of degraded lands and seasonal weather and climate services [10, 33–36]. For instance, agroforestry (integrating trees with crops) has many advantages if carried out correctly. The trees serve as ‘nutrient pumps’ by helping to bring nutrients that are too deep for crops, while their leaves also serve as mulch that might suppress some weed growth and also protect the soil from intense heat. In addition, the litter will be transformed to organic matter while the trees also contribute to adaptation by helping to screen the crops from strong winds [35].

There is also a lot of potential for improving water management in form of irrigation and water harvesting. For instance, it has been estimated that out of the 75.5 million hectares of arable land available in the region, only 1.2% (917,000 ha) benefit from irrigation, while only 0.8% (635,000 ha) could be said to be under effective use [10]. However, it has been argued that it may be more beneficial to focus more on small scale private irrigation as against large scale public irrigation. This will ensure more efficient management and distribution of water [35, 36]. For example, farmer-managed irrigation in Mali and valley bottom irrigation in northern Nigeria and Niger have been found to very successful [37]. Great potential also exist for integrating aquaculture into irrigated plots so as to increase food production in the sub-region. For instance, many West African countries including Nigeria, Mali and Senegal among others have the essential resources required to produce large quantities of fish in irrigation schemes. In particular, rice-fish farming can be successfully adopted and implemented in many areas of West Africa [38–40]. There are also opportunities for the development and adoption of new varieties of cultivars. Introduction of varieties of cultivars that can withstand higher temperatures and varieties that are resilient to drought, pest, weeds, flooding and salinity will go a long way in ensuring higher adaptation and resilience to climate hazards.

Adoption of integrated soil fertility management, changing of planting dates and provision of seasonal weather and climates services are also important adaptation options. For instance, ensuring the application of the right type and quantity of fertilizer at the right time will guarantee efficient use by crops while minimizing emissions. Promotion of integrated soil fertility management will also ensure enhancement of soil organic matter and improve nutrient efficiency [35]. For example, adaptation options like late sowing, fertilizer use and increased planting density have been suggested for sorghum while promising effect of rainfall harvesting technique has been found in maize cultivation in West Africa [36]. Provision of weather and climate information services will raise adaptive capacity by helping farmers to plan their planting and make projection about rainfall distribution patterns and temperature variation. For instance, evidences from Ghana and Senegal have shown the importance of providing reliable information on weather and climate-smart agricultural practices through radio and mobile phone services to farmers [35].

4.2 Water resources

4.2.1 Vulnerabilities and impacts

Climate change, population pressure and economic development are posing major challenges to water resources management in West African countries. Inadequate access to water supply and frequent droughts and floods disrupts the livelihoods of the people. Flooding results in siltation and sedimentation of rivers and lakes, and pollution of surface waters. It may also create ecological condition for invasive species that may further change ecosystem structure and function. For instance, disruption of ecosystem structure may alter biological cycle of fish production in an area [41].

Droughts are associated with drying wells, fall in water body levels, rise in pollutant loads and general aggravation of water stress [29]. In the last five decades, West African rivers have experienced overall decline in water supply and it has been projected that river flows will decline by 20–40% by 2050 [29]. Reduced river flows are expected to encourage the spread of toxic water plants such as hyacinth. When this is combined with rising temperatures, it will cause further decline in water quality and encourage the spread of water borne diseases like malaria. Increased water stress will also aggravate other health conditions. For instance, diarrhoea is a major cause of childhood mortality in West Africa [30].

In addition, increase in water stress implies that people, particularly women and children would have to travel farther to access water for domestic uses, reducing their ability to engage in economic activities [29]. Already, three West African countries namely, Nigeria, Niger and Burkina Faso already belong to the group of 37 “hotspot” countries with largest number of children living in areas of high or extremely high water vulnerability [42]. Poor access to water normally increases vulnerability, considering the fact that access to water is essential for maintaining good health and the ability to cope with other stresses [31].

Along the coastal areas, rising sea levels and increasing sea surges will worsen the problems of salt water intrusion into inland freshwater bodies and may cause lakes and lagoons to become completely brackish, with serious negative implications on biodiversity, including mangrove population [29]. The importance of mangrove is such that it is known to buffer river basins and also protects water birds and river fish stock against ocean waves and saltwater invasion [41, 43]. For instance, in the

Countries	Submerged surface area (sq. km)	Surface area lost through erosion (sq. km)	Value of property affected (millions of USD)
Senegal	1650	28–44	355–464
The Gambia	46	—	—
Cote de Ivory	471	—	4710
Benin	175	22.5	—
Nigeria	8864	78–145	9003

Source: USAID [41].

Table 2.
Projected general impact of sea level rise by 2100 for selected West African countries.

Niger Delta sea surges and flooding pollutes water aquifers and rivers with sediment [44], with great negative implications on human health and human livelihood. Furthermore, salt intrusion on arable land in coastal areas may lead to loss of productive land. It has also been associated with crop substitution and dependence on one crop as an adaptation measure as observed in Guinea Bissau, which created further food insecurity and made the people more vulnerable to price fluctuations [45]. Many West African countries are vulnerable to the risk posed by sea level rise. **Table 2** show the general impact of projected sea level rise by 2100 for some West African Countries.

Additionally, increase in water shortages will fuel conflicts among communities depending on shared water bodies. Conflict over water resources is already becoming a problem in many areas within the sub-region. For instance, the shrinking of Lake Chad by about 90% is viewed as a major factor in the persistent conflict and violent extremism in the area [46]. The lake is very vital to the economy of the area as the primary supplier of fresh water for bordering communities in Nigeria, Niger, Cameroon and Chad. Climate change has led to increasing competition for land resources in the area resulting in conflicts among communities. The persistent insurgency in area has been linked to failed harvests, loss of livelihood, food insecurity, forced migration and poverty brought about by increasing water stress in the area [7, 46].

4.2.2 Adaptation and resilience options

Human activities and their impacts on water scarcity must be fully considered in drought risk management and policy. For instance, while land degradation reduces soil water holding capacity and increases vulnerability to drought, rehabilitation of degraded lands and enhancement of soil health are known to help create better resilience to drought [37]. Water conservation and supplementation in dry areas, adoption of integrated water storage and small reservoir systems have been successfully implemented in Mali, Ghana and Burkina Faso to improve water supply for agriculture [35]. Furthermore, reforestation schemes in the savannah regions of West Africa have shown evidence of increased river flow and ground water recharge [31].

However, adoption and implementation of integrated water resources management is very vital in adaptation to climate change. This will enable the integration of all aspects of the water system (surface water, underground water, water quality and so on) with all water related sectors (flood control, irrigation, water supply, industrial water and so on) and water use and control practices, to secure quantity and quality of water required for modern society [47]. The success of this approach requires the collection and sharing of relevant water data on quantity of water resources and water allocation (water demand, water intake, seasonal water changes and so on). The implementation involves efficient use of water resources to reduce vulnerability to climate change impacts such as adoption of crops with low water requirements, promotion of water saving irrigation technology (such as drip irrigation), reducing water use and raising public awareness. It also involves promoting groundwater recharge, controlling exploitation, monitoring groundwater levels, conserving groundwater quality, enhancing other sources of water supply (like rainwater harvesting and waste water treatment) and promoting water storage by boosting capacity of water resources development facilities [47, 48].

4.3 Human health

4.3.1 Vulnerabilities and impacts

West African countries are characterised by inadequate health infrastructure, services and access to health care, which make public health highly vulnerable to adverse effect of climate change [9]. Many adverse implications are attributable to projected temperature increase, decreasing rainfall, increased frequency and intensity of tropical rainstorms and increased duration and severity of aridity and drought. Expected health implications will be linked to increased water stress, rise in food shortages, and increased exposure and proliferation of infectious and vector borne diseases and heat related diseases [30]. Temperature and rainfall trends are expected to result in shift in the distribution, timing and severity of climate sensitive diseases like malaria and meningitis [49]. Heat stress and other related risks associated with cardiovascular and respiratory diseases are also expected to be on the rise due to increased heat waves, with children and the elderly in particular more likely to be impacted. Evidences already exist related to rising mortality associated with increasing heat in countries like Burkina Faso and Ghana. Deterioration of air quality due to dust is will also worsen the problem of cardiovascular and respiratory diseases in the region, considering the fact that increase in dust during the harmattan has been observed in countries like Nigeria and Togo [30, 49]. For example, in Nigeria 50% of the deaths related to ischaemic heart diseases, stroke, lung cancer and chronic obstructive pulmonary diseases among adults, and acute lower respiratory infections in children below 5 years in 2012, were attributable to household air infection [50].

Increasing water scarcity will worsen the intensity and spread of waterborne and water wash diseases as people are forced to depend more on unsafe sources of water in the drier areas. Poor water quality is a major threat to human health in West Africa. For example, it has been observed that 34% of the population in the sub-region lack access to safe drinking water, while 73% lack access to basic sanitation [42, 49]. In addition, there is high possibility that the rate and distribution of vector and waterborne diseases will be worsened by the warming temperatures, more frequent intense tropical storms and flooding. Nigeria faces great inland flood risk and it is projected that by 2030 an additional 801,700 people may be at risk of river floods annually due to climate change [50]. For instance, recurrence of cholera and diarrheal diseases are closely linked to heavy rains and flooding which bring contaminated water and sewage into domestic water sources. Poor access to safe water, poor sanitation and hygiene have been associated with high rates of diseases like diarrhoea, pneumonia, trachoma and worm related illnesses [44, 49].

4.3.2 Adaptation and resilience options

Health adaptation options can be considered on a range of probable technological and behavioural changes such as improved surveillance of infectious epidemic diseases, early warning systems for human health, public health and environmental education, institutional coordination and disaster preparedness and so on [51]. A number of adaptation measures are already being implemented in West African countries. Evidences of implementation of health adaptation measures exist in Gambia, Nigeria

Sierra Leone, Ghana and Guinea Bissau among others. For example Gambia is designing Geographic Information System (GIS) health data bases on several communicable diseases. These user friendly GIS data bases offer real time information and remote data on epidemiological diseases. The country also plans to implement vector control programmes through its proposed investment in public education, social mobilization and an array of preventive measures such as encouragement of use of insecticide treated nets and mosquito repellents [51].

Nigeria has an official National health adaptation strategy guiding the implementation of climate change adaptation in the health sector. Part of the actions being implemented include awareness programme concerning serious health issues that would enable community members to take pre-emptive actions against health challenges [50, 51]. The country is also strengthening its seasonal weather forecasting system through the provision of up to date information on extreme events like dry spells, heavy storms and heat waves, and providing health warnings through the analysis and integration of weather and health threshold data [51].

In Sierra Leone, community health education programmes are providing community health education to enable community members to identify and eliminate breeding sites of disease vectors. The country is also engaging community health workers and volunteers to educate the public in areas of stress management and improved community education in areas of food poisoning, personal hygiene and sanitation [51, 52]. Health sector specific messages, of Sierra Leone's climate change communication strategy under the National Adaptation Plan (NAP), are designed to help reduce health risk associated with climate change. For instance, to address the problem of increasing cases of disease outbreaks resulting from poor sanitation and hygiene, and warmer temperatures, emphasis was placed on educating the people on the need to eradicate vector breeding sites and encourage healthy living in safe environment, and the use of clean and safe water [5].

Ghana also has an official national health adaptation strategy which is guiding programmes' implementation on health adaptation to climate change. Various actions have been implemented, focused on building institutional and technical capacities to work on climate change. In addition, efforts have been directed towards incorporating climate information into integrated disease surveillance and response system, including the creation of early warning and response systems for climate related health risks. Furthermore, programmes have also been implemented to raise resilience of health infrastructure in the country [53].

Other opportunities for action in the sub-region have however been identified. For instance, in the case of Nigeria, WHO/UNFCCC emphasised the need for comprehensive health vulnerability and adaptation assessment incorporating relevant stakeholders from all sectors [50]. The organisations also called for the need to build up institutional and technical capacities in relation to climate change and health, and implementation of activities to increase climate resilience of health infrastructure. In Ghana, WHO/UNFCCC identified the urgent need to conduct a national assessment of climate change impact, vulnerability and adaptation for health in the country, and the need to work on estimating the cost of implementing health resilience to climate change [53]. Furthermore, it was noted that the country had no focal point for climate change in the ministry of health (which is very necessary for proper coordination of programmes and activities).

4.4 Energy

4.4.1 Vulnerabilities and impacts

Increasing population, rapid urbanization and economic growth is pushing up the demand for power in West Africa. However, the sub-region falls within Sub-Saharan Africa which is regarded as the most electricity poor area in the world, where the average electricity rate is about 20%. It is projected that with the present population growth rate, about 500 million will be without electricity by 2040 [49, 54]. The severe shortage of energy has constituted a major constraint to livelihoods and economic development in West African countries. For instance, there is no access to electricity for 80% of the population in Niger, Liberia and Burkina Faso and for 40% in Nigeria (over 70 million) and Senegal [49]. Even for those that have grid connection, supply is grossly unreliable and people as a necessity most often rely on private generators, thereby incurring extra costs. Furthermore, it is observed that electricity tariffs in Africa are among the highest in the world [49, 54].

Millions of people in the sub-region still depend on the traditional use of solid biomass for cooking. Even some people who have access to electricity, liquefied petroleum gas (LPG), natural gas or biogas still continue to use biogas due to cultural or affordability reasons. For instance, Nigeria is included among the five countries (with Ethiopia, DR Congo, Tanzania and Kenya) that account for about half of the Sub-Saharan population using solid biomass for cooking. In the rural areas in particular, majority of households do not have access to clean cooking, they depend on fuel wood and often spend substantial part of the day collecting firewood [54].

The natural vegetation has been considerably destroyed or degraded by agricultural expansion and overexploitation for firewood, charcoal and timber. For instance the natural forest in West Africa has reduced by 37% and with even higher losses in countries like Nigeria, Ghana, Guinea and Sierra Leone [49]. Natural forests are expected to experience significant drop in productivity in the near future, due to rising temperatures and evaporation that will like lead to water balance deficits and reduced productivity in forest resources. The effect will be more in the savannah region which is already experiencing increasing scarcity of wood resources [5, 28–30].

However, more challenges for hydropower development in the sub-region have been projected. It is expected that increased evaporation due to rising temperature, more extreme rainfall events, decreased river flow in some areas, more dam construction and extensive land use changes would cause higher incidents of flood damage to dams, more reservoir evaporation and siltation and increase river flow variability [29, 49].

4.4.2 Adaptation and resilience options

While inadequate electricity constitutes a major constraint to development, more than 50% of West Africa's hydropower potential still remains untapped. Therefore, considering the large number of rivers that can be harnessed for generating electricity, there is still a lot of opportunity for further development of hydropower in the sub-region. There is also a great potential for solar energy and wind power in West Africa. Presently, solar energy plays a limited role in the power sector in Africa in general despite the fact that most parts of the continent enjoy an average of over 320 days/year of sunlight. Thus, potential power generation from solar energy is far greater than present electricity demands and even far into the future [55]. Wind

power development is also very limited in West Africa as in other parts of Sub-Saharan Africa, for which the potential is estimated at about 1300 GW. West Africa is considered as one of the areas where the greatest potential for wind power lies in Africa [55].

4.5 Infrastructure

4.5.1 Vulnerabilities and impacts

Basic infrastructural development is generally grossly inadequate in West Africa. Poorly planned settlements, inadequate and poorly constructed roads, dams, bridges, health facilities and so on, creates high vulnerability to weather and environmental risks. There is also disproportionate distribution of infrastructural facilities in favour of urban areas which reduces the accessibility of the rural dwellers to these basic facilities. Massive rural-urban population drift is resulting in rapid urbanization, which is encouraging the spread of informal settlements, particularly in marginal environments like flood plains and other low lying areas, that are highly vulnerable to flooding, sea surges and rising sea level [49, 56]. These extreme weather events are resulting in infrastructure damages (such as for transportation, health, education, energy, water, communication and so on) and disruption of operation. For instance, in the case of transportation rainstorms, flooding, landslides and sea surges disrupts operation and put stress on supply chain capacity and efficiency. Temperature and rainfall trends are further intensifying the problem of inadequate water supply, sanitation and disaster risk management. Flooding during the rainy season and water scarcity during the dry season has become common experience particularly in urban centres in the region. In addition, urban residents in many West African cities now increasingly face health problems associated with urban heat highlands; like heatstroke, cardiovascular and respiratory, diseases, heat exhaustion and dehydration [49].

Coastal cities also face additional problems of sea surges and sea level rise and associated flooding, coastal erosion, inundation and salinization of aquifers. For instance, it is projected that West Africa will likely experience sea level rise of 1 m by 2100, resulting in substantial inundation of many major cities. It is also predicted that by the 2050s annual damages from coastal flooding in the sub-region will be as high as \$11billion [49]. In coastal parts of Nigeria, the filling up of some mangrove wetlands for development is already resulting in flooding in many areas and could be worsened by climate-change related accelerated sea level rise. If this situation continues unchecked, about 75% of the population living within 200 km of the coast that derive livelihoods from coastal and marine ecosystems in the country will be affected [57]. It has also been estimated that if there is 2 m rise in sea level, at least 6 million people will be displaced in Lagos alone, while about 80% of people in the Niger Delta will be affected [56, 58].

4.5.2 Adaptation and resilience options

Climate-resilient infrastructure is expected to be planned, designed, constructed and operated in such a way that it projects, prepares for, and adapts to changing climate conditions. It should also be able to withstand and recover quickly from disruptions resulting from extreme weather and climate conditions [59]. Decisions

taken on the siting, building and operation of infrastructure give the chance to lessen vulnerability to the physical impacts of climate change. Climate resilience of new or existing infrastructure can be increased by reducing its exposure or sensitivity to climate-related hazards through various adaptation options depending on the existing situation. Adaptation response may involve the implementation of civil engineering measures to protect assets or other measures that may simply require altering maintenance routines or information-sharing practices [60].

Many West African nations have realized the importance of adapting infrastructure to climate change. For instance, in order to secure coastal roads and ports from flooding, sea surges and sea erosion, Togo has made it a priority to adapt its coastal zones to climate change. This has resulted in investments in coastal protection and preventive management actions and increased monitoring and management of coastal erosion [30]. In Ghana, a number of infrastructure adaptation priorities have been identified for water, energy and transport sectors. For instance, technical adaptation for the water sector include maintaining, rehabilitating and re-engineering existing water systems like dams and irrigation systems. It also includes designing and implementing structural adaptation measures like retarding basins, road elevation and provision of culverts. For the energy sector adaptation options includes adoption of climate resilient designs for facilities and good site selection for energy infrastructure. Other actions are integration of climate adaptation into design of transport infrastructure (like use of materials that reflect solar radiation to reduce temperature of pavement), sealing of unpaved roads, improved road drainage design and planting and management of vegetation along roads [61].

One of the main adaptation priorities in Liberia is the development of infrastructure to reduce the vulnerability of urban coastal zones from erosion, floods, siltation and degradation [62]. For instance, coastal defence projects completed in 2015 reduced erosion, siltation, and degraded coastal landscapes around the capital, Monrovia and other areas. Furthermore, importance was placed on implementation of design standards and planning codes for roads and other infrastructure to cope with flooding, sea level rise and windstorms [63]. Liberia's national policy and response strategy on climate change accentuated the integration of climate resilience in the infrastructure sector. Also, aside from stressing the need to improve the use of weather and climate information in infrastructure planning and development, the strategy emphasised the importance of subjecting infrastructure projects (such as roads, ports and airports) to climate risk screening as part of the planning process [64].

5. Recommendations and policy options

Reducing vulnerability and increasing resilience to climate and environmental risks requires developing appropriate adaptation and disaster risk management strategies. Achieving this however depends on proper understanding of the dimensions of exposure and vulnerability and adequate valuation of changes in those dimensions [13]. In addition, building resilience requires identifying possible hazards and understanding the vulnerabilities that may affect recovery from such hazards. Risk information is central to good risk management as it provides the necessary details about what, when and where disasters might occur, how severe it could be and who might be affected. Having an appropriate understanding of the situation provides the opportunity for proper adjustment. Improving adaptation and building

resilience require appropriate actions from all actors including communities, governments, NGOs and businesses. Therefore, a number of recommendations on strategies to improve adaption and resilience to climate and environmental risks are provided to guide action at local, national and transnational levels.

5.1 Policy options for local level implementation

1. There is urgent need to raise awareness on climate and environmental risks among the populace. Raising awareness and providing advocacy on climate and environmental risk information is very important in helping people to manage the risk and changes they are facing. Dissemination of information on potential climate and environmental hazards and sharing of knowledge on best practices on climate risk management will play a critical role in improving adaptation and building of resilience. Awareness could be promoted through the formation of climate and environmental risk volunteer corps (CERVC) at community and district levels. The CERVC would be very useful in helping to raise awareness and dissemination of early warning information on climate and environmental risks, and also serve as link between communities and NGOs involved in climate risk actions.
2. Climate and environmental risk should be incorporated into local plans. In addition, development of local community adaptation action plans (LCAAP) should be promoted. This will help in guiding climate and environmental risk action at community level. It will also offer an opportunity for integrating local priorities into regional and national plans.
3. Agricultural extension services should be strengthened and climate-smart agricultural practices, both modern and traditional be encouraged based on the specific environmental conditions in different areas. There is also the need to provide enough personnel, technical equipment and necessary training and re-training that will enable the officials perform efficiently under changing conditions.
4. Individual and communal efforts should be encouraged to promote sustainable management and use of land, water and vegetation resources. In addition, people should be encouraged to form cooperative societies and other local saving and loan associations to improve access to safety nets during crisis periods. Such collective efforts will also help to improve access to inputs like fertilizers, improved seeds and farm chemicals which can be obtained in bulk for distribution. This should be supplemented with government subsidies where possible.

5.2 Policy options for national level implementation

1. National climate and environmental risk assessments should be carried out with emphasis on sectorial and local individualities and priorities, but using the system approach. This approach is necessary because it will help ensure that specific adaptation strategies are not considered in isolation, but as part of wide-ranging concerns that takes cognisance of the interrelatedness and interdependencies within and between all aspects of the environment.

2. Provision of weather and climate information and early warning systems should be introduced where they do not exist and expanded where they are already in operation. In addition to the use of radio services, other technologies like mobile phone services in form of text and voice messages in different local languages can be incorporated. This will ensure regular provision of reliable information on climate and environmental risks, plus possible actions to reduce vulnerabilities. This will also ensure the availability of reliable information on weather and climate-smart agriculture and other adaptation options to the people.
3. National preparedness/contingency/emergency response plans should be formulated and integrated into national development planning and budgeting. This will help expedite action in addressing the impacts of climate change in the different sectors of the economy.
4. Focal points for climate change should be established in all ministries. This will enable proper coordination of programmes and activities in relation to every sector and also ensure easy coordination of actions among ministries and agencies when required.
5. Climate-proofing of infrastructure is very important for building resilience against climate and environmental hazards. Existing transportation, health, education, water, sanitation, waste and other infrastructure should be strengthened to withstand changing conditions. Furthermore, climate change risks should be integrated into the design, operation and management of new infrastructure projects. Technical standards and appropriate legal frameworks incorporating projected climate risks should be introduced and enforced to ensure adherence to such standards in the planning, construction and operation of infrastructural facilities.

5.3 Policy options for transnational level implementation

1. There is need for stronger transnational coordination to address climate change impacts in the sub-region. This could be achieved by mainstreaming climate change adaptation into the numerous ECOWAs policies and programmes. While the improvement of adaptive capacity and resilience to and environmental risks is primarily the responsibility of individual member countries, ECOWAS has an important role to play in developing appropriate policies to regulate actions within the region.
2. Efforts should also be directed at strengthening the numerous sub-regional organizations involved in addressing climate change impacts. These include the various river basin development authorities like the Niger Basin Authority (NBA), Lake Chad Basin Commission (LCBC) and the Organisation for the Development of the Senegal River Basin (OMVS), and other agencies like the West African Science Service Centre on Climate Change Adapted Landuse (WASCAL), Sahel and Sahara Observatory (OSS) and the Permanent Interstate Committee for Drought Control in the Sahel (CILSS). Strengthening these organizations would help to improve adaptation and resilience to climate change across West Africa.

6. Conclusion

In conclusion, the key findings in this research can be summarized as follows:

1. West Africa and in particular the Sahel region has experienced significant environmental change in the last five decades, with great negative implications for agriculture and food security, water resources, human health, energy and infrastructural development;
2. the West African sub-region is susceptible to many climate and environmental risks and the people are highly vulnerable as a result of their social and economic circumstances;
3. great potential exist for raising adaptation and for building resilience in agriculture to ensure food security. Opportunities also exist for improving adaptation and resilience levels in water resources, human health, infrastructure and energy sectors of the economy in the sub-region;
4. achieving sustainable improvement in adaptation and resilience require appropriate actions from multiple stakeholders including communities, governments and NGOs.

This study has therefore provided a foundation for further research. Based on the findings of this research, it is suggested that future research be directed towards:

1. greater understanding of meteorological conditions and generation of necessary climatic data for better prediction and planning;
2. improving adaptive capacity and resilience of under-resourced and marginal population;
3. understanding gender differences in vulnerability in rural and urban areas;
4. the role of public-private partnership in promoting adaptive capacity and resilience.

Funding

This manuscript was not funded by any institution, either public or private.

Conflict of interest

There is no conflict of interests in the preparation of this manuscript.

Code availability

Since the manuscript was based on existing research results, no data/codes are available.

IntechOpen

IntechOpen

Author details

Bolaji Abdulkadir Usman
Faculty of Social Sciences, Department of Geography and Environmental
Management, University of Ilorin, Nigeria

*Address all correspondence to: usman.ba@unilorin.edu.ng

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Nzuma JM, Waithaka M, Mulwa RM, Kyatalimye M, Nelson G. Strategies for Adapting to Climate in Rural Sub-Saharan Africa: A Review of data Sources, Poverty Strategies (PRSPs) and National Adaptation Plan for Agriculture (NAPAs) in ASARECA Member Countries. IFPRI Discussion Paper No. 01013; 2010. Available from: <https://www.ifpri.org/publication/strategies-adapting-climate-change-rural-sub-saharan-africa>
- [2] UNEP. Climate and Environmental Risks and Opportunities in Mexico's Financial System from Diagnosis to Action; 2020. Available from: <http://wedocs.unep.org/handle/20.500.11822/34493>
- [3] Woetzel J, Pinner D, Samandari H, Engel H, Krishnan M, Boland B, Powis C. Climate Risk and Response: Physical Hazards and Socio-Economic Impacts. New York: McKinsey Global Institute; 2020. Available from: <https://www.mckinsey.co/business/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socio-economic-impacts>
- [4] Malhi Y, Wright J. Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical Transactions of the Royal Society of London B*. 2004;**359**:311-329
- [5] U N D R R. Disaster Risk Reduction in Africa: Status Report-2015; 2016. Available from: <https://www.undrr.org/publication/disaster-risk-reduction-africa-status-report-2015>
- [6] Have C. Our World: Africa and Climate Change. Tokyo: United Nations University; 2008. Available from: <https://ourworld.unu.edu/en/africa-and-climate-change>
- [7] Nicholson S. Land surface processes and Sahel climate. *Reviews of Geophysics*. 2000;**2002**(38):117-139
- [8] USAID. Climate Change Adaptation in Western Africa. Washington, DC: USAID; 2012. Available from: https://www.climatelinks.org/sites/default/asset/document/west_africa_adaptation_fact_sheet_jan2012%20%281%29.pdf
- [9] UNCCD. The Global Land Outlook, West Africa Thematic Report. Bonn: UNCCD; 2019 Available from: https://catalogue.unccd.int/1220_GLO_WEST_AFRICA_E.pdf
- [10] Jones R. Managing Climate Change Risks. Organization for Economic Cooperation and Development (OECD), Workshop on Benefits of Climate Policy: Improving Information for Policy Makers 12-13 December, 2003; Paris, France; 2003. Available from: <https://www.oecd.org/env/cc/19519189.pdf>
- [11] European Commission. Climate Risk Assessment: An Introduction [Internet]. 2020. Available from: <https://europa.eu>. [Accessed: December 18, 2021]
- [12] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, et al. Determinants of risk: Exposure and vulnerability. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, et al. editors. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge, UK, and New York, NY: Cambridge University Press; 2012. pp. 65-108 Available from: https://www.ipcc.ch/assets/uploads/2018/03/SREX-Chap2_FINAL-1.pdf

- [13] U N D R R. Understanding Disaster Risk; 2020. Available from: www.preventionweb.net
- [14] G F D R R. Understanding risk in an evolving world: Emerging practices in natural disaster assessment; 2014. Available from: www.gfdr.org
- [15] Cutter SL, Boruff BS, Shirley WL. Social vulnerability to environmental hazards. *Social Science Quarterly*. 2003;**84**(2):243-261
- [16] IPCC. Climate Change 2001: Impacts Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC. New York: Cambridge University Press; 2001
- [17] IPCC. Climate Change 2014: Impacts Adaptation and Vulnerability. Part A: Global and Sectorial Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. New York: Cambridge University Press; 2014
- [18] Olmos S. Vulnerability and Adaptation to Climate Change: Concepts, Issues and Assessment Methods. Climate Change Knowledge Network, Foundation Paper; 2001. Available from: <https://citeseerx.psu.edu/viewdoc/download;sessionid=1FC81C95881D6C9ABEE306E404?doi=10.1.1.119.576&rep=rep1&type=pdf>
- [19] Ludena CE, Yoon SW. Local Vulnerability Indicators and Adaptation to Climate change: A Survey. Inter-American Development Bank (IDB), Climate Change and Sustainable Division, Technical Notes No. 857. IDB; 2015. Available from: <https://publications.iadb.org/publications/english/document/Local-Vulnerability-Indicators-and-Adaptation-to-Climate-Change-A-Survey.pdf>
- [20] Cornell S, Georgiou T, Kulp M, Yarnal B. Coastal Processes, Hazards, and Society. Dimensions2: Sensitivity. Penn State's College of Earth and Mineral Sciences, Open Education Resources; 2021. Available from: <https://www.e-education.psu.edu/earth107/node/733>
- [21] WHO. Chapter 11: Adaptation and Adaptive Capacity to Lessen Health Impacts. Climate Change and Human Health – Risks and Responses. Geneva, 2003: WHO; Available from: <https://www.who.int/globalchange/environment/en/chapter11.pdf>
- [22] InTeGrate. Module 11.1: Resilience, Adaptive Capacity, and Vulnerability. InTeGrate [Internet]. 2018. Available from: https://serc.carleton.edu/integrate/teaching_materials/foof_supply/student_materials/1059. [Accessed: 16 December 2021]
- [23] Usman BA. Vulnerability and adaptation capabilities of the rural poor to climate change challenge in Kwara State, Nigeria. *Lapai Sociological Review*. 2013;**4**(1):142-162
- [24] Burton I, Challenger B, Hug S, Klien RTJ, Yohe G. Adaptation to Climate Change in the Context of Sustainable Development and Equity. Geneva: IPCC; 2018. Available from: <https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap18.pdf>
- [25] United States Department of Health and Human Services National Health Security Strategy. US Department of Health and Human Services; 2009. Available from: <https://www.phe.gov/preparedness/planning/nhss>
- [26] Care International. Adaptation Learning Programme: Climate Change Vulnerability and Adaptive Capacity in

Northern Ghana. Care International/ALP; 2013. Available from: https://careclimatechange.org/wp-content/uploads/2014/08/CVCA_Ghana.pdf

[27] Oguge N, Ayal D, Adeleke I, Silva I. African Handbook on Climate Change Adaptation. Cham: Springer; 2021. Available from: <https://library.oapen.org/handle/20.500.12657/49528>

[28] Simonsson L. Vulnerability Profile of Burkina Faso. Poverty and Vulnerability Programme. Stockholm: Stockholm Environmental Institute (SEI); 2005 Available from: <https://liu.diva-portal.org/smash/get/diva2.225233/FULTEXT01.pdf>

[29] USAID. Climate Vulnerabilities and Development in Burkina Faso and Niger: Background Paper. Washington, DC: USAID; 2012 Available from: <https://www.climatelinks.org/sites/default/files/asset/document/climate%20Vulnerabilities%20and%20Development%20in%20Burkina%20faso%20and%20Niger.pdf>

[30] World Bank. Climate Risk Country Profile: Togo. World Bank Group, Washington, DC; 2021. Available from: https://reliefweb.int/sites/reliefweb.int/resources/15859-WB_Togo%20Country%20Profile-WEB.pdf

[31] Bendandi B, Venier M. Vulnerability and Resilience in West Africa: Understanding Human Mobility in Context of Land Degradation. Global Knowledge Partnership on Migration and Development (KNOMAD), Working Paper No. 25. KNOMAD; 2017. Available from: https://www.knomad.org/sites/default/files/201705/WP%2025_Vulnerability%20resilience%20in%20West%20Africa_1.pdf

[32] UNDP. Africa Adaptation Programme: Niger. New York: UNDP;

2012. Available from: <https://www.undp-aap.org/countries/niger>

[33] FAO. Save and Grow: A Policy maker's Guide to the Sustainable Intensification of Smallholder Crop Production. Rome: FAO; 2011 Available from: <https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1421716/>

[34] FAO. Climate-Smart Agriculture Sourcebook. Rome: FAO; 2013 Available from: <https://www.fao.org/i3325e/i3325e00.htm>

[35] Zougmore R, Partey S, Ouédraogo M, Omitoyin B, Thomas T, Ayantunde A, et al. Toward climate-smart agriculture in West Africa: A review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. Agriculture and Food Security. 2016;5:26. Available from: <https://agricultureandfoodsecurity.biomedcentral.com/track/pdf/10.1186/s40066-016-0075-3.pdf>

[36] Sultan B, Gaetani M. Agriculture in West Africa in the Twenty-First century: Climate Change and Impact Scenarios, and Potentials for Adaptation [Internet]. 2016. Available from: <https://www.frontiersin.org/articles/10.3389/fpls.2016.0126/full>. [Accessed: 17 January 2022]

[37] UNCCD. Science-Policy Interface Land Management and Drought Mitigation. Science Policy Brief. Vol. No. 6. Bonn: UNCCD; 2019. Available from: www.unccd.int

[38] Sanni D, Juanich G. A feasibility study of rice-fish farming in West Africa. In: Halwat M, Van Dam AA, editors. Integrated Irrigation and Aquaculture in West Africa: Concepts, Practices and potentials. Rome: FAO; 2006. pp. 75-78. Available from: <https://www.fao.org/3/a0444e/A0444E08.htm#ch6>

- [39] Peterson J, Kalende M. The potential for irrigation-aquaculture in Mali. In: Halwat M, Van Dam AA, editors. Integrated Irrigation and Aquaculture in West Africa: Concepts, Practices and Potentials. Rome: FAO; 2006. p. 79-94. Available from: <https://www.fao.org/3/a0444e/A0444E09.htm#ch7>
- [40] Peterson J, Kalende M, Sanni D, Ngom M. The potential for integrated irrigation-aquaculture (IIA) in Senegal. In: Halwat M, Van Dam AA, editors. Integrated Irrigation and Aquaculture in West Africa: Concepts, Practices and Potentials. Rome: FAO; 2006. pp. 95-116. Available from: <https://www.fao.org/3/a0444e/A0444E10.htm#ch8>
- [41] USAID. Climate Change and Groundwater Resources in West Africa: Transboundary River Basins. Washington, DC: USAID; 2013 Available from: https://www.climatelinks.org/site/default/files/asset/document/Transboundary%2520River_CLEARED.pdf
- [42] UNICEF. Nearly one third of Nigerian children do not have enough water to meet their daily needs-UNICEF [Internet]. 2021. Available from: <https://unicef.org/nigeria/press-release/nearly-one-third-nigeria-children-not-have-enough-water-meet-their-daily-needs> [Accessed: 12 January 22]
- [43] Wetlands International. Guinea Bissau: Mangroves in frontline against climate change [Internet]. 2010. Available from: <http://www.wetlands.org/?TabId=60&articleType=ArticleView&articleId=2117> [Accessed: 19 December 21]
- [44] New Security Beat. Water Stress, Instability and Violent Extremism in Nigeria [Internet]. 2017. Available from: <https://www.newsecuritybeat.org/2017/08/water-stress-instability-violent-extremism-nigeria/>. [Accessed: 02 November 2022]
- [45] Barry BS, Creeppy EGE, Gacitua-Mario E, Wodon Q. Conflict, Livelihoods, and Poverty in Guinea Bissau. Washington, DC: World Bank; 2007
- [46] Anderson ZK. Water Scarcity and Violent Conflict in Nigeria [Master of Arts thesis]. Monterey, CA, USA: Department of Security Studies (Middle East, South Asia, Sub-Saharan Africa), Naval Postgraduate School; 2019. Available from: https://calhoun.nps.edu/bistream/10945/62803/19jun_Anderson_Zach.pdf?sequence=1&isAllowed=y
- [47] Japan International Cooperation Agency. Handbook on Climate change Adaptation in the Water Sector: A Resilient Approach that integrates water Management and Community Development. JICA Global Environment Department; 2010. 70 p. Available from: www.jica.go.jp
- [48] UN Water. Climate Change and Water: UN-Water Policy Brief. Geneva: UN-Water Technical Advisory Unit; 2019 Available from: <https://www.unwater.org>
- [49] USAID. Factsheet/Climate Risk Profile: West Africa. Washington, DC: USAID; 2018. Available from: https://www.climatelinks.org/sites/default/files/assets/documents/West_Africa_CRP_Find.pdf
- [50] WHO and United Nations Convention on Climate Change (UNFCCC). Climate and Health Country Profile-2015: Nigeria. Geneva: WHO/UNFCCC; 2015. Available from: <https://apps.who.int/iris/handle/10665/208865>
- [51] Nhamo G, Muchuru S. Climate adaptation in the public health sector in Africa: Evidence from United Nations Framework convention on Climate Change National Communications. Jamba – Journal of Disaster Risk Studies.

2019;**11**(1):a644. DOI: 10.4102/jamba.v11i1.644

[52] Government of Sierra Leone. Sierra Leone's Climate Change Communications Strategy under the National Adaptation Plan. Environmental Protection Agency of Sierra Leone (EPA-SL); 2020. Available from: <https://napglobalnetwork.org/wp-content/uploads/2020/10/napgn-en-2020-Sierra-Leone-Climate-Change-Communications-Strategy-under-the-NAP.pdf>

[53] WHO and United Nations Convention on Climate Change (UNFCCC). Climate and health country profile-2015: Ghana. Geneva: WHO/UNFCCC; 2015. Available from: <https://apps.who.int/iris/handle/10665/208862>

[54] International Energy Agency. World Energy Outlook 2016. Paris: IEA; 2016

[55] International Energy Agency. Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa. World Energy Outlook Special Report. Paris: IEA; 2014

[56] Usman BA, Tunde AM. Climate change challenges in Nigeria: Planning for climate resilient cities. Environmental Issues. 2010;**3**(1):101-110

[57] Federal Republic of Nigeria. National Environmental, Economic and Development Study (NEEDS), for Climate Change in Nigeria (Final Draft). Abuja: Federal Ministry of Environment, Special Climate Change Unit; 2010. Available from: <https://unfccc.int/files/adaptation/application/pdf/nigerianneeds.pdf>

[58] Metrotra S, Natenzon CE, Omojola A, Folorunsho R, Gilbride J, Rosenzweig C. Framework for City

Risks Assessment: A paper presented at the fifth urban Symposium, Cities and Climate Change: Responding to an Urgent Agenda, June 28-30, 2009, Marseilles, France; 2009. Available from: <https://go.worldbank.org/p74DFRD0>

[59] OECD. Climate Resilient Infrastructure: Policy Perspectives. OECD Environment Policy Paper No. 14. Organisation for Economic Cooperation and Development (OECD) Environment Directorate, Paris; 2018. Available from: <https://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf>

[60] Vallejo L, Mullan M. Climate Resilient Infrastructure: Getting the Policies Right. Organisation for Economic Cooperation and Development (OECD), Environment Working Paper No. 121. Paris: OECD; 2017. Available from: <https://www.oecdilibrary.org/docserver/02f74d61en.pdf?expires=1633614269&accname=guest&checksum=0070E568BE457B5EFFC415E7202c171>

[61] Government of Ghana. Ghana's Adaptation Strategy and Action Plan for the Infrastructure Sector (Water, Energy and Transport Sectors). Ghana: Environmental Protection Agency (EPA); 2020. Available from: <https://napglobalnetwork.org/wp-content/uploads/2020/06/napgn-en-2020-Ghana's-Adaptation-Strategy-and-Action-Plan-for-the-Infrastructure-Sector.pdf>

[62] USAID. Climate Change Adaptation in Liberia. Washington, DC: USAID; 2012. Available from: https://www.climate-links.org/sites/default/files/asset/document/liberia_adaptation_fact_sheet_jan2012.pdf

[63] UNDP. National Adaptation Plan in Focus: Lessons from Liberia. UNDP-UN

Environment National Adaptation Plan
Global Support Programme (NAP-GSP);
2018. Available from: https://www.idc-climate.org/wpcontent/uploads/2018/07/liberia_nap_country_final_online1.pdf

[64] Republic of Liberia. National Policy
and Response Strategy on Climate
Change. Monrovia: Environmental
Protection Agency of Liberia; 2018.
Available from: https://www.epa.gov/r/sites/default/files/National%20Policy%20and%20Response%20Strategy%20on%20Climate%20Change%20Final%20Document-min_0.pdf