American Journal of Climate Change, 2024, 13, 230-250
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

An Analysis of Liberia's Vulnerability to Climate Change in the Context of Least Developed Countries (LDCs): A Review

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How to cite this paper: Togbah, C. F. (2024). An Analysis of Liberia's Vulnerability to Climate Change in the Context of Least Developed Countries (LDCs): A Review. *American Journal of Climate Change, 13,* 230-250.
https://doi.org/10.4236/ajcc.2024.132013

Received: March 31, 2024
Accepted: June 25, 2024
Published: June 28, 2024

Abstract

Climate change is an alarming global challenge, particularly affecting the least developed countries (LDCs) including Liberia. These countries, located in regions prone to unpredictable temperature and precipitation changes, are facing significant challenges, particularly in climate-sensitive sectors such as mining and agriculture. LDCs need more resilience to adverse climate shocks but have limited capacity for adaptation compared to other developed and developing nations. This paper examines Liberia's susceptibility to climate change as a least developed country, focusing on its exposure, sensitivity, and adaptive capacity. It provides an overview of LDCs and outlines the global distribution of carbon dioxide emissions. The paper also evaluates specific challenges that amplify Liberia's vulnerability and constrain sustainable adaptation, providing insight into climate change's existing and potential effects. The paper emphasizes the urgency of addressing climate impacts on Liberia and calls for concerted local and international efforts for effective and sustainable mitigation efforts. It provides recommendations for policy decisions and calls for further research on climate change mitigation and adaptation.

Keywords

Least Developed Countries, Liberia, Climate Change, Vulnerability, Poverty, Hunger, Disease, Research and Development (R&D), Adaptation

1. Introduction

Climate change poses a significant global challenge that requires a unified effort across all nations, irrespective of economic status. Although different regions experience the impacts of climate change differently, the overall global threat it poses remains undeniable. Least Developed Countries (LDCs) are particularly vulnerable, facing acute challenges like severe weather events that lead to poverty, hunger, and disease (Jaglin et al., 2011). Despite their minimal contribution to global carbon emissions, these LCDs suffer disproportionately from climate effects (Makita, 2024). This review focuses on Liberia, an LDC significantly affected by climate-related issues, emphasizing the need for targeted adaptation strategies and international support (Zhou et al., 2022). There has been evidence in recent decades that changing weather patterns, particularly severe floods, droughts, and sea erosion, are affecting (Paavola, 2008) and exposing millions of people to extreme poverty, hunger, and disease, especially in LCDs (Cummings & Martin, 2020). Rising sea levels and other climatic stressors threaten the very survival of millions of people every year. According to estimates, climate change will harm 860 million people in LDCs by 2060 (Elsayed et al., 2024; Oduro et al., 2024). As unfavorable weather patterns continue to shape the planet's future, many will become environmental refugees in the coming years (Kania et al., 2023). To mitigate the crisis, adequate preparedness for adaptation is crucial (Patt et al., 2010).

Nevertheless, the question of who should pay for these costly climate adaptation mechanisms, especially in countries that are not the main culprits for global emissions, remains unanswered.

Several national adaptation programs of action are among the efforts being carried out by many countries (Cummings & Martin, 2020).

For the most part, adaptation measures call for a comprehensive investment in capacity building, science and technology transfer, and environmental sustainability (Caijuan et al., 2024). National and regional development priorities must incorporate climate change mitigation in development planning (Kania et al., 2023), which most often requires additional resources from the international community or the main culprits for global emissions, including the United States, China, and India, which have a combined greenhouse gas (GHS) emission footprint of 42.6% of the global total (Ogle et al., 2023).

Negotiations among nations should focus on encouraging a push for deeper cuts in global greenhouse gas emissions, and priority countries must undergo supported adaptation programs to maintain stability, which is essential to their survival (Hultman & Bozmoski, 2006). As such, negotiations on sustainable funding pathways, such as the post-Kyoto framework and the Paris Agreement, can urgently help to enhance adaptation initiatives for many countries in need. Liberia is ranked 22 out of 49 countries that are low emitters but exposed to climate change effects. **Table 1** shows the emission distribution by countries globally.

All the provisions in Article 2 of the Paris Agreement, the current most considerable global ambarella agreement for combating climate change, focused on LDCs positions (Bodansky, 2016). The climate-vulnerable parties from the Alliance of Small Island States and the Africa Group have advocated for the agreement to firmly commit parties to reducing the global average temperature to less than 1.5˚C above pre-industrial levels (Clémençon, 2016). This would mean steep emission

Table 1. Total Greenhouse Gas Emissions 2003—Selected Countries—The United States, China, and the European Union countries have the highest carbon emission rates in mega tonnes, with the USA and China ranking 1 and 2, respectively, followed by India and Brazil.

Countries	Mega Tonnes of Carbon	World Ranking	% of the World's Total
USA	1576.9	1	22.27
China	1227.4	2	17.34
EU	1092.6	-	15.43
India	313.4	6	4.43
Brazil	90.7	19	1.28
LDCs	38.1	-	0.54
ASIDS	37.7	-	0.53

reductions by 2050 (Institute for Global Environmental Strategies, 2020).

Nevertheless, there is a school of taught that achieving this goal is a matter of survival for their countries and populations (Abeysinghe & Barakat, 2016) because even if the global community successfully cooperated in accounting for the global average temperature increase to 2˚C, warming and associated risks would not be evenly distributed; they would be highest in regions where weaker and vulnerable countries are located. The final language only asks parties to "pursue efforts" to achieve the 1.5˚C goal (Derwent et al., 2006).

Moreover, this represents a significant normative gain, given that previous rhetoric within and outside the United Nations Framework Convention on Climate Change (UNFCCC) had been dominated by references to 2˚C (Azam, 2021). This more ambitious temperature goal signals urgency for climate action and sets the direction of travel for all commitments under the Paris Agreement (Elsayed et al., 2024). As emphasized above, the agreement needed to clarify the linkages between mitigation, adaptation, and costs for LDCs (Clémençon, 2016).

Although this needs to be better reflected in Article 2 of the Paris Agreement, it does, however, recognize the importance of finance for enabling low-carbon and climate-resilient development pathways, making it a critical provision for less emitting countries because they are expected to contribute to the collective effort to achieve UNFCCC's ultimate objective by developing in a way that does not lead to a rise in concentrations of greenhouse gases in the atmosphere. Still, such an objective has already created another debate. Many believe that keeping certain countries from tapping into rigorous industrialization, something developed nations have done to achieve their development potential to avoid GHG emissions, is unfair and unrealistic. On the other hand, serving as a sink for the current culprits (developed nations) is hypocrisy and would only mean that poor countries will remain trapped in dependency and poverty (Bird, 1980; Browne & Goldtooth, 2016).

1.1. Objectives

The paper aims to:

1) Evaluate Liberia's vulnerability to climate change;

2) Explore the nation's potential for adaptation and effective disaster management;

3) Provide recommendations to support Liberia's long-term resilience to climate change.

1.2. Method

This narrative review used a mixed-method approach to enhance a comprehensive understanding of Liberia's fragility to climate change, specifically within the context of being a least-developed country. The paper's viewpoint was drawn by integrating qualitative and quantitative data, incorporating primary and secondary sources, and involved a comprehensive literature analysis that emphasized climate change's impacts on vulnerable communities. It also considered crucial aspects such as exposure, sensitivity, and adaptive capacity. The technique involved thoroughly examining literature from scholarly papers, reports from the United Nations and other organizations, and the official country's regulations and policies on climate change vulnerability.

2. The Case of Liberia

Liberia (4˚20'N-8˚30'N; 7˚18'W-11˚20'W) is a West African nation bordered by Sierra Leone to the west, Guinea to the north, Côte d'Ivoire (Ivory Coast) to the east, and the Atlantic Ocean to the south. It covers an area of about 111,369 km. Located in the heart of the Upper Guinea Forest on the West Coast of Africa, the country has an abundance of biodiversity and was initially characterized by an uninterrupted, dense tropical rainforest spanning from Guinea to Ghana in the south (Marinelli, 1964).

Liberia experiences a primarily tropical climate characterized by three major geographical bands. The narrow coastal zone spans around 40 kilometers and encompasses tidal streams, small lagoons, and mangrove swamps. The second belt consists of undulating terrain with heights ranging from 60 to 150 meters (200 to 500 feet) (World Atlas, accessed January 10, 2024). The third belt, which encompasses most of Liberia, is characterized by sudden variations in elevation, consisting of a sequence of low mountains and plateaus with a lower density of forest cover. **Figure 1** shows Liberia's geographical features with high forest cover and boarded to the south by the North Atlantic Ocean for about 560 km, which makes it experience a fairly warm temperature throughout the year with very high humidity.

Liberia has achieved substantial economic and developmental advancements since the cessation of its civil war in 2003. However, the nation continues to struggle through recovery. It is exceedingly susceptible to the effects of climate change due to high inequality, unemployment, poverty, and the restricted availability of fundamental amenities like safe and clean water, sanitation, and energy (Yang & St John, 2023).

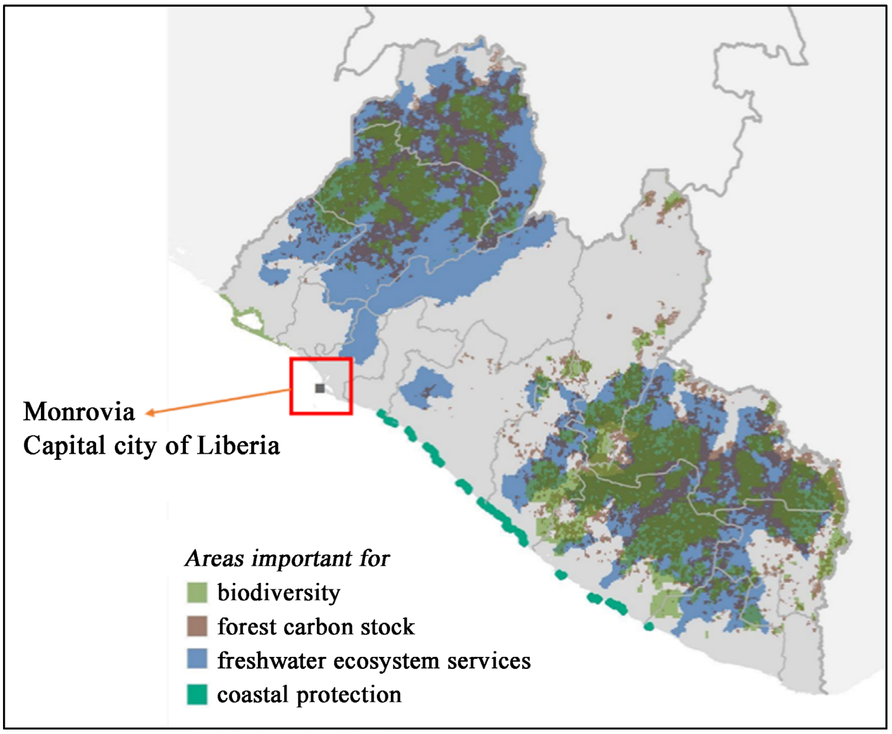


Figure 1. Geographical features map of Liberia.

Liberia's population is estimated to be over 5 million in 2020, and the population growth rate in 2019 was 2.4% (World Bank, 2018a). The current urban population is around 51.6% and is expected to rise to 57.3% and 68.2% by 2030 and 2050, respectively. Based on the 2019 figures, the agriculture sector (including fishing and forestry) holds the largest share of the country's GDP, accounting for 34.2% (Liberia, 2018). The industry sector (including mining, building, power, water, and gas) contributes 12.2% to the GDP. Liberia is highly vulnerable to the impacts of climate change owing to its extreme poverty and reliance on climate-vulnerable industries like agriculture, forestry, fisheries, energy, and mining. Liberia is also highly susceptible to environmental instability (Steady, 2014).

Agriculture, fisheries, and forestry are crucial to achieving Liberia's objectives of promoting economic growth that benefits everyone and reducing poverty. Liberia's substantial dependence on climate-sensitive activities makes it more vulnerable to climate variability and change, likely resulting in increased temperatures, more frequent and intense weather events like heavy rainfall, and rising sea levels. **Figure 2** shows a schematic diagram of vulnerability factors; the bottom box is a summary of the overall constraints' elements that undermine Liberia's adaptive capacity as a least-developed country.

Liberia has recognized urban and coastal expansion, the increase in sea levels, and the potential intrusion of saltwater into coastal regions as crucial aspects of climate change for adaptation strategies (Thirgood, 1965).

In recent years, the coastal community of West Point in the nation's capital, Monrovia, has suffered immense sea erosion and flooding, forcing tens of thousands of inhabitants to evacuate their homes, exposing them to hunger and disease (Thirgood, 1965). Liberia has high levels of inequality, unemployment, and poverty, with low access to essential services such as water, sanitation, and energy. Table 2 highlights the key development indicators with figures from 2018, 2019, and 2020.

A Gross Domestic Product (GDP) of less than $900 and underprovided levels of capital, human, and technological development are defined by the following three criteria:

1) A low-earner benchmark considering a three-year average estimate of the

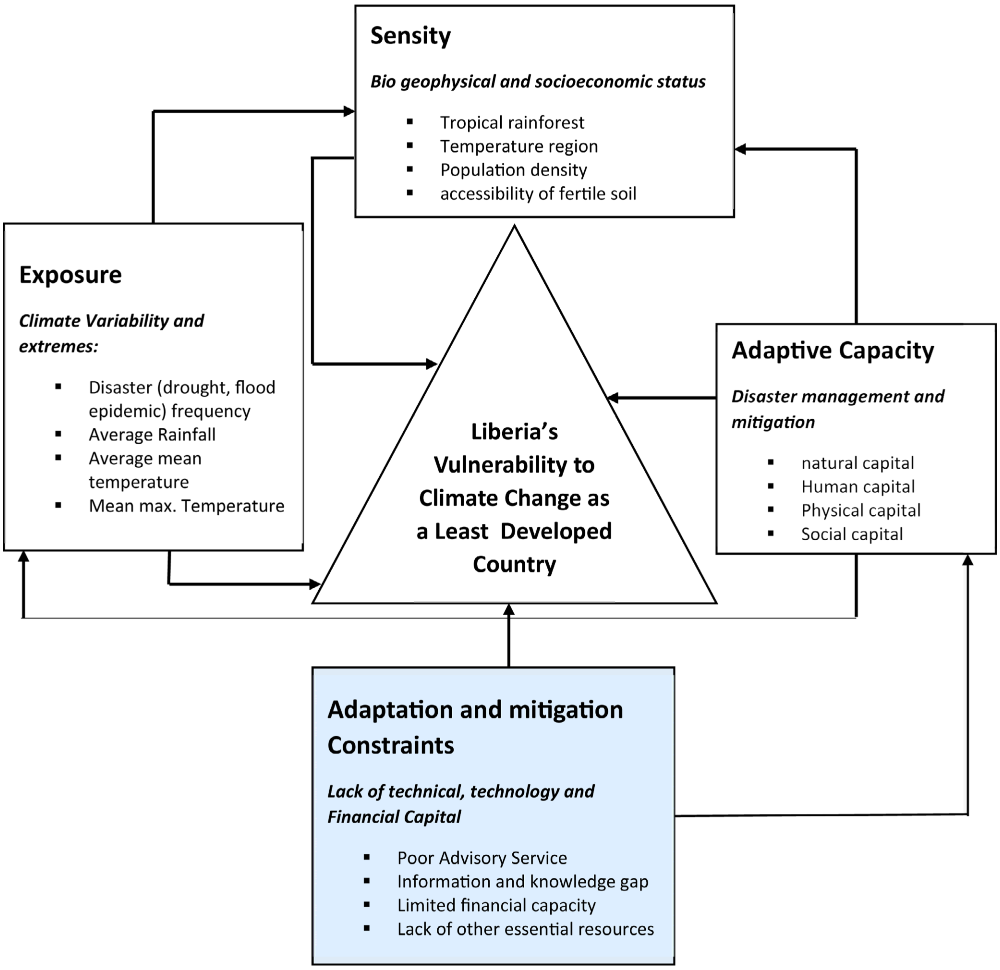


Figure 2. A schematic diagram showing a set of factors and variables affecting exposure, sensitivity, and adaptive capacity and Liberia's overall vulnerability level.

Table 2. Key Development Indicator—shows a summary overview of the Liberia economy and development parameters.

GDP per Capital (US $) (2020)	583.30
% of the population with access to electricity (2019)	27.60%
Population Density (people per sq. km land Area) (2018)	50
Life Expectancy at Birth, Total (Years) (2019)	64.7

gross national income (GNI) per capita (under $750 for inclusion, above $900 for elevation);

2) A human resource weakness criterion involving a composite Human Assets Index (HAI) based on indicators of (a) nutrition, (b) health, (c) education, and (d) adult literacy;

3) An economic vulnerability criterion involving a composite Economic Vulnerability Index (EVI) based on indicators of (a) the instability of agricultural production, (b) the instability of exports of goods and services, (c) the economic importance of non-traditional economic activities, (d) merchandise export concentration, (e) remoteness from world markets, (f) population size, and (g) the share of the population displaced by natural disasters (Bird, 1980). Liberia's gross domestic product per capita in 2023 was 218.2 U.S. dollars (World Bank, 2013).

2.1. Theoretical Framework of Liberia's Vulnerability to Climate Change as a Least Developed Country

As a least developed country, Liberia's economy relies heavily on its natural resources; it has limited financial capacity, its infrastructure and services need to be improved, and it has some of the poorest human development indicators globally. The analysis below provides a comprehensive overview of the factors influencing Liberia's climate venerability as a least-developed country.

2.1.1. Vulnerability

Vulnerability is defined as a function of three elements, namely, exposure to the physical effects of climate change, sensitivity of the natural resource system or dependence of the national economy upon social and economic returns from that sector, and adaptive capacity, which is the extent to which a system enables these potential impacts to be offset (Carrega & Michelot, 2021). To measure vulnerability involves identifying a system's exposure, sensitivity, and adaptive capacity to climate fluctuations and extremes. Thus, Vulnerability (V) = Exposure + Sensitivity (S) − Adaptive Capacity (AC).

2.1.2. Exposure

Exposure describes the usual climate conditions and extraordinary occurrences that serve as the backdrop for a system's operation (Muyambo et al., 2024). It details the characteristics of climate variability and extreme stressors, including the severity, frequency, duration, and scope of hazards (Odersky & Löffler, 2024). This research uses exposure indicators to establish a vulnerability outlook for Liberia, a least developed country. Historical shifts in climate variables and extreme events indicate Liberia's exposure to climate change risks. Factors considered include changes in the average annual temperatures (**Figure 3**), changes in minimum and maximum precipitation (**Figure 3**), and the incidence of extreme events like floods and epidemics from 1980 to 2020. These exposures highlight Liberia's vulnerability to climate change's direct impacts (stimuli).

2.1.3. Sensitivity

Sensitivity refers to how significantly and responsively a system is impacted by climate-related changes, such as stress from climate variations (Guéde et al., 2024). This concept encompasses various aspects, including physical, economic, social, environmental, and cultural factors (Yasunari et al., 2024). Sensitivity is often determined by natural and human characteristics that influence a system's structure (Ge et al., 2024). The effects of climate change on natural ecosystems (biophysical) and socioeconomic factors are typically categorized under sensitivity. Liberia's sensitivity to climate change impacts stems from its reliance on natural resource extraction like mining, agriculture, forestry, and fishery, which heightens sensitivity because these resources are heavily dependent on climate conditions (Pinke et al., 2024).

2.1.4. Adaptive Capacity

Adaptive capacity refers to the ability of a system or country to manage the effects of climate variability and extremes (Chisale et al., 2024). Some recognized factors in global literature for assessing adaptive capacity include human, social, physical, and financial capital. These capitals influence how individuals and communities can access and control resources; however, for a least developed country such as Liberia, these capitals are either very limited or lacking. Measuring vulnerability involves identifying a system's exposure, sensitivity, and adaptive capacity to climate fluctuations and extremes (Fila et al., 2023). The mix of exposure and sensitivity outlines the possible impact. At the same time, adaptive capacity determines how much adverse effects can be mitigated or if benefits can be leveraged from arising opportunities (Sriartha et al., 2023).

2.2. Key Climate Change Impacts on Liberia

As climate variability continues to affect many production sectors, Liberia's agricultural sector (d'Orey, 2020) has experienced rapid land degradation and extreme weather events is more susceptible to climate change because it relies on climate-sensitive crops such as rice and cassava, which are crucial for Liberia's food security (Allen, 2005).

Approximately 74% of Liberian farmers cultivate rice, a staple crop sensitive to humidity, precipitation, and pests. Rising temperatures could make northern latitudes more suitable for rice cultivation, but heavy precipitation can deplete nutrient-rich topsoil and decrease arable land. Primary agricultural commodities like rubber, cacao, and coffee are vulnerable to weather patterns and elevated temperatures. Restoring war-affected cocoa and coffee farms is costly, affecting production and export. The increasing number of wet days and elevated temperatures is anticipated to result in heightened water logging and impose additional strain on existing water infrastructure and sanitation systems. Furthermore, as temperatures increase, the local patterns in daily maximum temperatures provide valuable information about the upper limits for particular crops, which could alter agricultural yields.

The climate crisis is predicted to exacerbate current stressors by increasing the occurrence of pests and diseases. The agriculture sector is projected to experience significant adverse impacts from the heightened occurrence and consequences of droughts and floods resulting from anticipated long-term alterations in precipitation patterns and shifting temperature ranges. The seawater and freshwater fisheries in Liberia, which are essential for the economy and nutrition, are normally negatively impacted by rising sea temperatures, damage to coastal ecosystems such as mangroves and wetlands, and changes in temperature and precipitation patterns that affect the quality and availability of surface water resources (Eicher & Baker, 1992).

Liberia's fragility persists due to other non-climate issues, such as pervasive poverty, significant inequality and unemployment, and restricted availability of crucial utilities (such as water, sanitation, and energy) (World Bank, 2018b). When combined with climate change-related problems, the non-climate elements contribute notable vulnerabilities for Liberia at the national and local levels.

To mitigate the adverse impact of climate change, Liberia needs to expand its energy-generating and environmental monitoring capacities to enhance its ability to withstand the impacts of climate change and achieve its development objectives. Investment research that details the nation's national energy policy, its low-carbon economy, and the national vision for development goals in 2030 can be achieved (World Bank, 2018b). It is necessary to develop and enhance the capabilities of institutions and individuals in renewable energy technology. Additionally, regulations should be formulated to encourage private investment in renewable energy sources, such as expanding hydropower capacity and solar energy. The nation possesses six primary rivers, namely Mano, St. Paul, Lofa, St. John, Cestos, and Cavalla, which exhibit significant capacity for hydroelectric power production. Ensuring the restoration and improvement of current hydropower facilities is a top priority while also providing strong motivation for the nation to construct additional hydropower plants to enhance output capacity.

Liberia must enhance its environmental safeguards and solid waste management to a higher degree (Liberia, 2018). The need for more management and disposal of solid waste, particularly in Monrovia, presents substantial obstacles to controlling water pollution and marine litter. This is especially concerning because the country is on the Atlantic Ocean's coast.

2.2.1. Flooding

One of the most common natural disasters people face in many parts of the world is flooding (Alfieri et al., 2024). Liberia is a member of LCDs and is particularly vulnerable to flood hazards (Lokidor et al., 2023).

In Liberia, it is common knowledge that floods wreak havoc on cities, towns, villages, and their inhabitants (Ziga-Abortta & Kruse, 2023). Every September and October, the Liberia Meteorological Department reliably predicts prolonged rainfall. Communities located low-lying near rivers and streams are disproportionately affected by persistent high rainfall, which in turn causes more severe flooding. Urban floods can also be devastating in places where the drainage systems are lacking or inadequate. Short bursts of heavy rain can cause flash flooding, affecting areas downstream from significant rivers. Flooding can cause devastating impacts on shelters, roads, and surface and groundwater supplies (Zou, 2018).

In recent years, numerous Liberian cities have experienced flooding. According to reports, 1,955 individuals were impacted, and 520 were forced to evacuate their houses when Kru Town experienced flooding on September 1, 2023. Kru Town is a beach fishing community in Robersport City, Western Liberia. Continued heavy rain can cause coastal flooding and property damage (Moller-Jensen et al., 2023). There have been reports that the unpredictable erosion and floods that the Kru Town community has endured for a long time are worsened by the rising sea level and the effects of climate change. Fishing and working as a deckhand are well-known occupations in West Africa. The impact of flooding on families' ability to earn a living is another consequence of the climate crisis (Nyide et al., 2023).

On September 3, 2023, another severe flood involving torrential rains occurred in central Liberia, affecting 795 people. On September 4, 2023, the worst flood Monrovia had ever seen affected 12,450 people in low-lying and flood-prone areas. The flooding of 32 towns in Montserrado County, Monrovia, was a devastating result of the five days of intense, torrential rainfall that started on August 30.

Over the last several decades, floods have affected communities along the St. Paul River, Stockton Creek, the Du Rive, and those in the Mesurado Wetlands with a distributed flood strategy. The catastrophic effects are growing in proportion to the frequency and impacts of severe weather events [23]. **Figure 3**: A drone footage showing a flooded Doe Community leaving several homes in deplorable condition in Monrovia, Liberia's capital city. The flood, which mainly occurred due to prolonged rainfall and inadequate drainage systems, affected

Figure 3. A captured photo of a flooded day in Doe community (KMTV-Liberia).

thousands of residents every year, mainly in the rainy season. However, the irregular pattern in rainfall leaves residents in total doubt about when to expect heavy rain and a temperature rise, making the need to prepare for disaster difficult.

2.2.2. Coastal Erosion

Due to climate change, coastal erosion has been a persistent issue for Liberian villages near the Atlantic Ocean for the past four decades (National Adaptation Plan Global Network, 2023). Liberia is situated on the coast of the Gulf of Guinea, making it susceptible to annual storm surges in the southern Atlantic. These surges cause average tidal increases of more than two meters for a brief period during the dry season, leading to erosion along the coastline (Kargbo & Mico, 2012).

According to regional and global climate estimates, Liberia's sea level will rise by 0.13 to 0.43 meters by 2049 (**Figure 5**) compared to 1980-1999 (World Bank, 2018a). The Special Report on Emissions Scenarios (SARESA) also anticipates an increase of 0.18 m to 0.56 m.

These forecasts of rising sea levels, combined with the increased intensity of storms and potential storm surges, are very likely to accelerate the present catastrophic situation of coastal erosion (Costa et al., 2023).

The International Journal of Scientific and Engineering published research on coastal erosion in Sierra Leone, one of Liberia's neighboring countries 2012. The study found that natural and human-made factors contribute to coastline erosion in Sierra Leone, which borders Liberia (Kargbo & Mico, 2012).

Some factors contributing to the increasing coastal erosion in Liberia include beach deforestation, mangrove tree cutting, and the construction of structures along the waterfront.

Cutting down mangroves to build houses on the shore causes the sea not to flow as it should because it obstructs the movement of the sea. Even though mangroves are naturally positioned on beaches to reduce the coastal effect, they are often cut down for domestic activities and building construction. Along the coast, the sea annihilates whatever stormy barricade it encounters. Thus, it destroys or erodes the coastline, leading to devasting consequences for its inhabitants (Zou, 2018).

Over the years, some interventions have been made to curtail flooding in vulnerable communities (Ziga-Abortta & Kruse, 2023). However, more education and resources are needed to reduce rising coastal erosion and minimize impacts. The Liberian government initiated a US$ 2.9 million Coastal Defense Project, which the United Nations Development Programme (UNDP) finished in 2013. Despite earlier efforts by the government to mitigate certain areas severely affected by erosion, the effects of climate change along Liberia's coast are worsening—**Figure 4** densely populated coastal settlement in Monrovia, Liberia's capital city.

2.2.3. Health

Climate change is expected to impact human health through various channels, including increased climatic hazards like heat waves, droughts, floods, reduced freshwater availability, increased ground-level ozone, and bacterial contamination (Patt et al., 2010). Weak water and sanitation management capacity put Liberia at a significant risk. This could increase mortality and diseases due to unsafe water, sanitation, and hygiene. Climate change is also expected to increase vector-borne diseases like malaria and dengue fever, increasing the health burden in areas without countervailing measures. High temperatures are expected to increase cardiovascular and respiratory diseases, while low temperatures may decrease the disease burden. **Table 3** shows the impact of the rise in sea level on Liberia and the affected sectors and pollution.

Table 3. Impact of sea level rise on Liberia.

	Sea-Level Rise Scenarios									
Total Area (Sq. km.) 111,369	1 m	2 m	3 m	4 m	5 m	1 m	2 m	3 m	4 m	5 m
	Impacted area (in sq.km.)					**% of the country area impacted**				
	100	147	221	319	434	0.09	0.13	0.20	0.29	0.39
Population 5.52 million	**Impacted Population**					**% of the Country's Population Impacted**				
	46,660	89,000	158,594	289,158	360,564	1.6	3.1	5.4	9.9	12.4
GDP 3350	36	36	42	60	60	1.1	1.1	1.3	1.8	1.8
Agriculture Total area (42,027 sq. km.)	2	6	12	28	37	0.005	0.014	1.25	0.067	0.088
Urban Extent Total area (327 sq. km.)	3	9	22	41	53	0.9	2.8	6.7	12.5	16.2
Wetland (593 Sq. km.)	11	20	44	65	89	1.9	3.4	7.4	11.0	15.0

Figure 4. A view of West Point in Monrovia: Rising sea levels significantly impact the township, home to about 75,000 people in Liberia's capital (Web image, accessed February 4, 2024).

2.3. Climate Change Projection for Liberia

While projections for Liberia vary across models depending on assumptions, the majority of climate models suggest the following:

1) Annual temperatures increased from the 1970-99 average of 0.9˚C - 2.6˚C by the 2060s and 1.4˚C - 4.7˚C by the 2090s.

2) There is more rapid warming in Liberia's interior than in coastal areas.

3) Overall, the average annual rainfall and heavy rainfall events will increase, and the sea level will rise by 0.6 - 1.0 m by 2100.

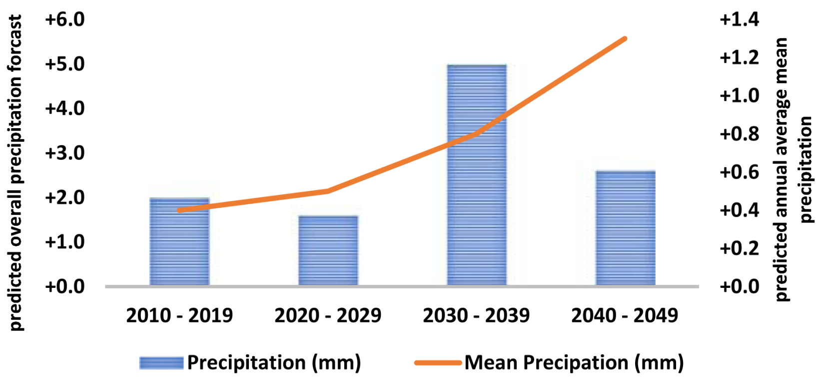
The projected trend for average mean precipitation over the next several decades is upward (Figure 5). According to climate projections, more precipitation will fall in Liberia between 2030 and 2040. Failure to take action to improve mitigation, adaptation, and resilience might lead to the biggest disaster ever. There is still time to take advantage of the sustainable development goals (SDGs), which are set to be accomplished by 2030-the same year Liberia is predicted to see an unprecedented rise in precipitation, a key contributor to flood disasters.

Temperature and Precipitation Patterns

Liberia is in a tropical zone. Its climate is warm and humid most of the year. The rainy season is between May and October each year because of the African monsoon. There are often rains in the other months, except in the dry season, which does not last long and runs from December to February, which is more marked in the north.

Along the coast, rainfall is abundant, exceeding 3000 millimeters (118 inches) annually. In Monrovia's northern part of the coast, rainfall can be as high as 5 meters (16.5 feet) annually. In the interior, rainfall is lower; drops in some areas are below 2000 mm (79 in) per year.

It is winter in the north from December to February, and rains are rare. The



It shows a predicted trend in average mean precipitation between 2010 and 2050, with almost a decade (2030-2039) predicted to have a significant increase in both overall precipitation and average annual mean precipitation.

Shows predicted trend in overall precipitation for the same period. An upward trend on annual average mean precipitation as depicted by the grapy indicates that there will be an increase in rainfall patterns during the next five decades.

Figure 5. Climate Change Projection—shows the predicted precipitation forecast between 2010 and 2050.

sun frequently shines, but some showers are still possible. The temperature is high primarily during the day, around 30/32˚C (86/90˚F), and the humidity remains high, especially along the coast and in the forests of the interior.

However, a dry wind that fills the atmosphere with Harmattan dust sometimes blows from the Saharan desert. Inland hilly regions, especially mountain peaks like Mount Wuteve, which are 1440 meters (4724 feet) high, get cool or cold at night. The temperature rises in March and April, and showers become more frequent. Sometimes, it can get so boiling that the temperature can reach 40˚C (104˚F). The real monsoon starts in May every year and is the beginning of torrential rainfalls, mainly along the coastline. Cloudiness is often observed. The daytime temperatures are lower between June and October, around 30˚C (86˚F) in the middle of July and August, and the rainy front moves northward, so there is a decrease in rainfall, which is more evident in the south. The last month with expected rain is November when the rains have already decreased sharply compared to the previous months. The temperature increases slightly because of the higher number of sunny hours, reaching 30˚C (86˚F) during the day. Figure 6 shows the average temperature and precipitation of Monrovia, the capital of Liberia, on the coast, where rainfall and heat waves are primarily abundant. Critical statistics for natural hazards are illustrated in Figure 7, and Table 4 shows average monthly and annual mean precipitation statistics for the coastal city of Monrovia, respectively.

2.4. Climate Change as a Structural Handicap to Liberia's Development

In Liberia, climate change manifests in various ways, impacting average temperatures, precipitation patterns, storm intensity, and sea levels. Economic sectors like agriculture and mining have long been sensitive to climate conditions, but climate change is set to shift these existing vulnerabilities even more without

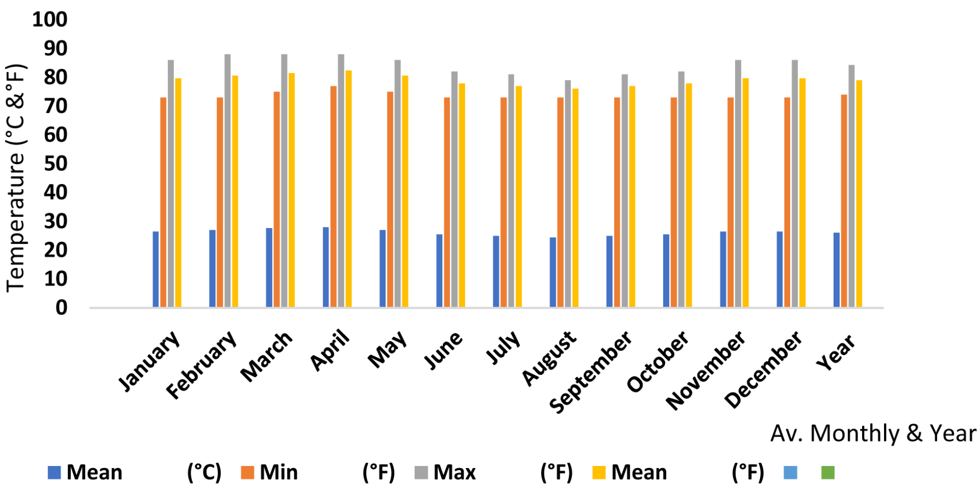


Figure 6. It shows the Average Temperatures in Monrovia. They show a high increase mainly from January to April owing to the dry season and slightly lower in the middle of the year, marking the beginning of the rainy season between April and November.

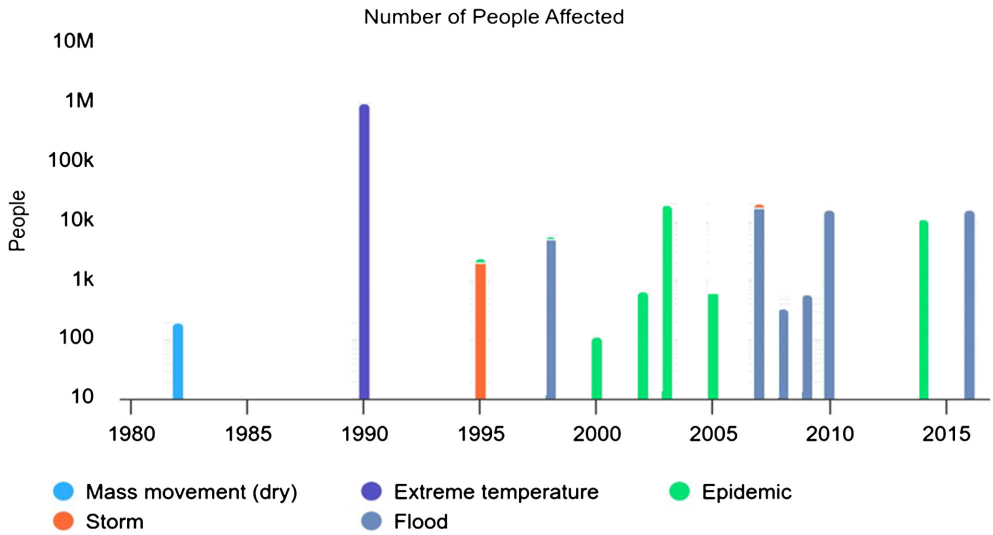


Figure 7. Key Natural Hazard Statistics from 1980-2020-The forecast shows a trend in hazard occurrences directly or indirectly influenced by climate change. A rise in extreme temperatures in 1990 was followed by a sequential flood and epidemic (World Bank, 2021).

Table 4. Average Monthly and Annual Precipitation—The average annual rainfall is 5135 millimeters, with a maximum in June and July, 975 and 995 millimeters, respectively, and a relative decrease in August. The rains are abundant in April and still in November.

Month	Millimeters	Inches	Days
January	30	1.2	4
February	55	2.2	3
March	95	3.7	8
April	215	8.5	12
May	515	20.3	22
June	975	38.4	24
July	995	39.2	21
August	375	14.8	17
September	745	29.3	24
October	770	30.3	22
November	235	9.3	16
December	130	5.1	9
Year	**5135**	**202.2**	**182**

robust adaptation mechanisms. The effects of climate change are already noticeable in many counties in Liberia, especially coastal areas like Montserrado County, and anticipated future shifts in climate patterns pose challenges that many countries, particularly the least developed ones, need to be better equipped to handle. Climate change is increasing Liberia's vulnerability in the following areas: natural disasters, agriculture and food security, health, freshwater, coastal and marine zones, and terrestrial ecosystems and biodiversity, which affect the overall growth of the Liberian economy. These areas are identified as the main areas impacted by climate change in the IPCC.

2.5. The Need for Sustainable Climate Change Adaptation in Liberia

There has been development in climate-related policies for Liberia in recent years to support climate change adaptation planning; however, more work needs to be done if Liberia is capable enough to handle climate variability and impacts (Bodansky, 2016). Adaptation initiatives by Liberia and its development partners, such as the National Adaptation Plan (NAP) framework under the leadership of the Environmental Protection Agency (EPA) and with support from the United Nations Development Programme (UNDP), can help to bolster adaptation and mitigation.

Nonetheless, to achieve a robust adaptation strategy, it is imperative for Liberia to conduct climate sensitivity assessments and risk evaluations on critical sectors, such as coastal zones, agriculture, waste management, forestry, and fisheries, aiming at effectively addressing medium- and long-term adaptation goals. In contrast, Liberia's position as a least developed country presents lingering trepidations over its adaptive capacity in terms of the provision of financial assistance and its long-term viability, which produce uncertainty and ambiguity regarding the complete development and execution of a national adaptation policy (d'Orey, 2020).

Adapting to the consequences of climate change is crucial for Liberia and many other least-developed countries. Research has shown that addressing the adaptation challenge requires focusing on two key areas: improving resistance and lessening exposure (National Adaption Plan Global Network, 2023).

For example, Liberia's national adaptation framework emphasizes a country-driven, gender-sensitive, participatory, and transparent approach involving a collaborative multistakeholder approach, including local communities, youth, women, policymakers, civil society, the commercial sector, and individuals with disabilities. Additionally, Liberia achieves its global climate change goals, such as its Nationally Determined Contributions (Environment Protection Agency Republic of Liberia, 2021), which are measures to address the country's most pressing adaptation needs from 2020 to 2025 (Yang & St John, 2023).

3. Conclusion

This review provides an overview of climate-related vulnerabilities faced by Liberia as a least developed country by exploring and identifying factors and constraints influencing Liberia's exposure, sensitivity, and adaptative capacity to climate change risks. The paper highlights and discusses empirical data on climate impacts in Liberia and lessons from other least-developed nations. This study underscores the urgency of addressing climate change in Liberia and highlights the need for concerted local and international efforts to mitigate its impacts effectively.

It is evidence that Liberia has experienced increasingly varying climate change effects in recent years, including prolonged rain, flooding, and coastal erosion, which have created life-threatening disasters for thousands of vulnerable families, posting significant risks to sustainable development with a long-lasting effect across generations and perpetuates a continuous cycle of poverty and underdevelopment. Moreover, Liberia is particularly susceptible to the impacts of climate change due to several reasons. The country's economy relies heavily on natural resources, has limited budgetary flexibility, has infrastructure and service soften that need to be improved, and has some of the lowest human development indicators globally. Strengthening the capacity of decision-makers and stakeholders to understand and consider climate change issues facing LDCs can help facilitate future development and implementation of appropriate adaptation strategies and disaster preparedness. Therefore, to achieve long-term sustainable development goals and adaptation strategy, Liberia should prioritize programs in sectors prone to climate change, such as agriculture, forestry, and fisheries, and invest in improving its coastal zone management. Additionally, integrating an adaptation plan into its national development agenda is crucial. More scientific climate change research on Liberia is needed to address the knowledge gap on climate change vulnerability, mitigation, and other sustainable development challenges.

4. Recommendations

Based on the findings gathered in this review, extensive, region-specific research and evaluations of climate change impacts, risks, and vulnerabilities are crucial to strengthening Liberia's adaptation potential and disaster management mechanisms and enhancing long-term efforts toward sustainable development and climate resilience. Hence, the following recommendations:

- Investment support and cooperation between Liberia and its development partners in key sectors like forestry, agriculture, energy, health, meteorology, and hydrology can accelerate long-term development and climate resilience.
- Developing robust climate models and weather forecasts to predict temperature and rainfall patterns on a daily or monthly basis and an inter-decadal basis. Furthermore, increasing public awareness regarding the impacts and risks of climate change and adaptation strategies through information broadcasting and outreach initiatives, particularly for vulnerable communities such as coastal settlements and farmers, can help bridge the knowledge gap and enhance mitigation efforts.
- Including indigenous people's needs and effective ways of coping in national development policy and planning, along with improving infrastructure like roads, technology, communication, and sanitation to facilitate the implementation of adaptation strategies, can help people find other ways to

make a living and reduce their reliance on climate-sensitive activities like mining, logging, and fishing.

- Policymakers and other pertinent stakeholders should be trained on local and global climate change science, impacts, and vulnerabilities to support decision- and policy-making. National and local institutions should also be given regulatory, political, and informational frameworks to support national adaptation to climate change and disaster readiness.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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