Environmental changes and integrated water resource management in Liberia (A Review)

Amos Gayflor Zaizay[1], Huseyin Gökçekuş[2], Yousef Kassem[3],

[1] Department of Environmental Education and Management, Faculty of Educational Sciences, Near East University, 99138 Nicosia (via Mersin 10, Turkey), Cyprus.
[2] Department of Civil Engineering, Civil and Environmental Engineering Faculty, Near East University, Energy, Environment, and Water Research Center, Near East University, Cyprus.
[3] Department of Mechanical Engineering, Engineering Faculty, Near East University, Energy, Environment, and Water Research Center, Near East University, Cyprus.

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Abstract: Liberia, known for its high precipitation levels, has significant challenges in maintaining its water resources. These challenges stem from a range of factors, including pollution, inadequate infrastructure, and the impacts of climate change. For data collection, a cross-sectional design was employed. The study revealed that the main sources of water in Liberia include lakes, rivers, streams, precipitation, and groundwater. According to the study, many residential applications of water were identified, including activities such as cooking, energy generation, industrial processes, and other miscellaneous uses. The findings of the research indicate that groundwater serves as the predominant source for drinking, cooking, and sanitation purposes. Additionally, it was observed that there is a lack of comprehensive national programs dedicated to monitoring and ensuring the quality and availability of water resources. To mitigate water pollution and the presence of other harmful substances, the study further proposes the implementation of a waste management and sanitation system at both the community and national levels. This study proposes to research and recommends measures for mitigating climate change's impact on water supplies. The urban infrastructure must possess the capacity to facilitate the equitable distribution of water resources to various entities such as residential areas, office spaces, commercial establishments, and other relevant stakeholders.

Keywords: Climate Change, water management, water resources

INTRODUCTION

Given the ongoing danger posed by environmental shifts, it is imperative to comprehend and effectively address these changes, while also formulating enduring approaches to meet human needs without engendering more environmental issues. The existence of the biosphere on the Earth's surface is integral and unimaginable. Water covers around 70 percent of the Earth's surface. Due to the significant salinity levels present in water, comprising about 97% of the Earth's total water volume, it is rendered unsuitable for human consumption and limited in its use for many other purposes. Merely 1% of the remaining 3% is deemed readily available for human use as fresh water, encompassing rivers, lakes, streams, reservoirs, and groundwater. Two percent of the total amount is contained inside the polar ice sheets and frozen masses. Based on the abundant presence of water on Earth, it may be inferred that water scarcity is not a significant concern. Nevertheless, the global problem of water availability and quality remains a pressing concern for human populations, as well as for animals and plants (Gökçekuş et al., 2022). On the west coast of Africa, you can find the Republic of Liberia which has a total surface area of 111,400 square kilometers, a mere 14,600 square kilometers are occupied by aquatic bodies. Liberia is geographically surrounded by three nations and the Atlantic Ocean. Numerous surface water and groundwater availability make Liberia a water resource-rich country. On average, the nation receives annual precipitation of over 2,500 millimeters. The coastal regions exhibit the highest levels of precipitation, whilst the interior areas, including high plateaus and low mountains, see the lowest amounts. In these regions, the average annual rainfall is roughly 2,030 millimeters (mm). Precipitation occurs consistently throughout the year in the southern region of the nation, while the other areas have two distinct rainy seasons due to the influence of the West African Monsoon. According to Harris et al. (2020), the mean temperature throughout the period of rainfall is recorded as 25 degrees Celsius. Emptying into the Atlantic Ocean from northeast to southwest direction are Liberia's 15 major basins and 23 minor coastal drainages.

All of Liberia's six major rivers originate from the Fouta Djallon Mountain in Guinea with the total rivers of the nation accounting for 56% of the nation's drainage system. The remaining portion is comprised of 11 smaller tributaries and some shorter coastal rivers. The coastal lowlands of the nation include around six-hundred thousand acres of freshwater wetlands, along with fifty-five thousand acres of coastal mangroves. These areas also include three out of the five Ramsar sites designated inside the country. Both Lake Piso and Lake Shepherd are characterized by their brackish nature, making them the two most expansive bodies of water in the region. A significant proportion of the country's population can use groundwater resources. Due to the inherent unpredictability of groundwater supplies, the process of drilling for groundwater in deeper strata, which may potentially provide higher productivity, is characterized by elevated costs and associated risks.

The sedimentary aquifers which are unconsolidated show higher output despite the risk posed by the intrusion of saltwater into the freshwater resources (Winrock International, 2021). Approximately 60% of the population in Liberia faces the challenge of inadequate access to safe and sanitary water, which significantly hinders their ability to engage in essential activities like drinking, and cooking. This pervasive issue poses a substantial obstacle for persons residing throughout the nation. In conjunction with concerns about precipitation levels seen in the nation pose a significant threat to Liberia's water supplies, particularly in terms of potential flooding occurrences during the rainy season. Nonetheless, some places see an elevation in groundwater levels, hence posing a threat of flooding and contamination to urban areas. Moreover, the recent decline in temperature and escalation in precipitation within the Republic of Liberia might potentially exacerbate future challenges faced by the nation (JMP, 2017). The principal goal of this investigation is to examine the water resources in Liberia, precisely concentrating on the effect of climate change on water accessibility. Additionally, the aims of the research include analyzing the integrated water resource management in Liberia's strategy, along with its challenges. Furthermore, the study will examine the use patterns of water resources in Liberia.

METHODS

The research used a cross-sectional research method, with the data collected being categorized as secondary in nature. This research used a variety of resources including maps, tables, graphs, web publications, journal papers, and Microsoft Excel. The researcher used a straightforward sampling method to choose and analyze papers and previous studies that are directly relevant to the integrated water resources of Liberia. The data collected from several sources was subjected to comparative, quantitative, and sequential analysis. The results of this study provide valuable insights for future research endeavors, establishing a foundation for a research agenda focused on integrated water resource management, their use, and the diverse array of available water resources. The research was carried out by the ethical standards of Near East University. There was no falsification or manipulation of data throughout the execution of this research.

RESULTS AND DISCUSSION

To conduct a comprehensive analysis of the environmental shifts and the implementation of integrated water resource management in Liberia, a thorough investigation was undertaken on the various aspects of water resources, including surface and groundwater. Additionally, the study examined the utilization of water resources, the existing policies governing integrated water resource management in Liberia, the influence of climate change on these resources, and the potential health implications associated with water resource management in Liberia.

Surface and groundwater resources review

Figure 1. Major River Basins of Liberia

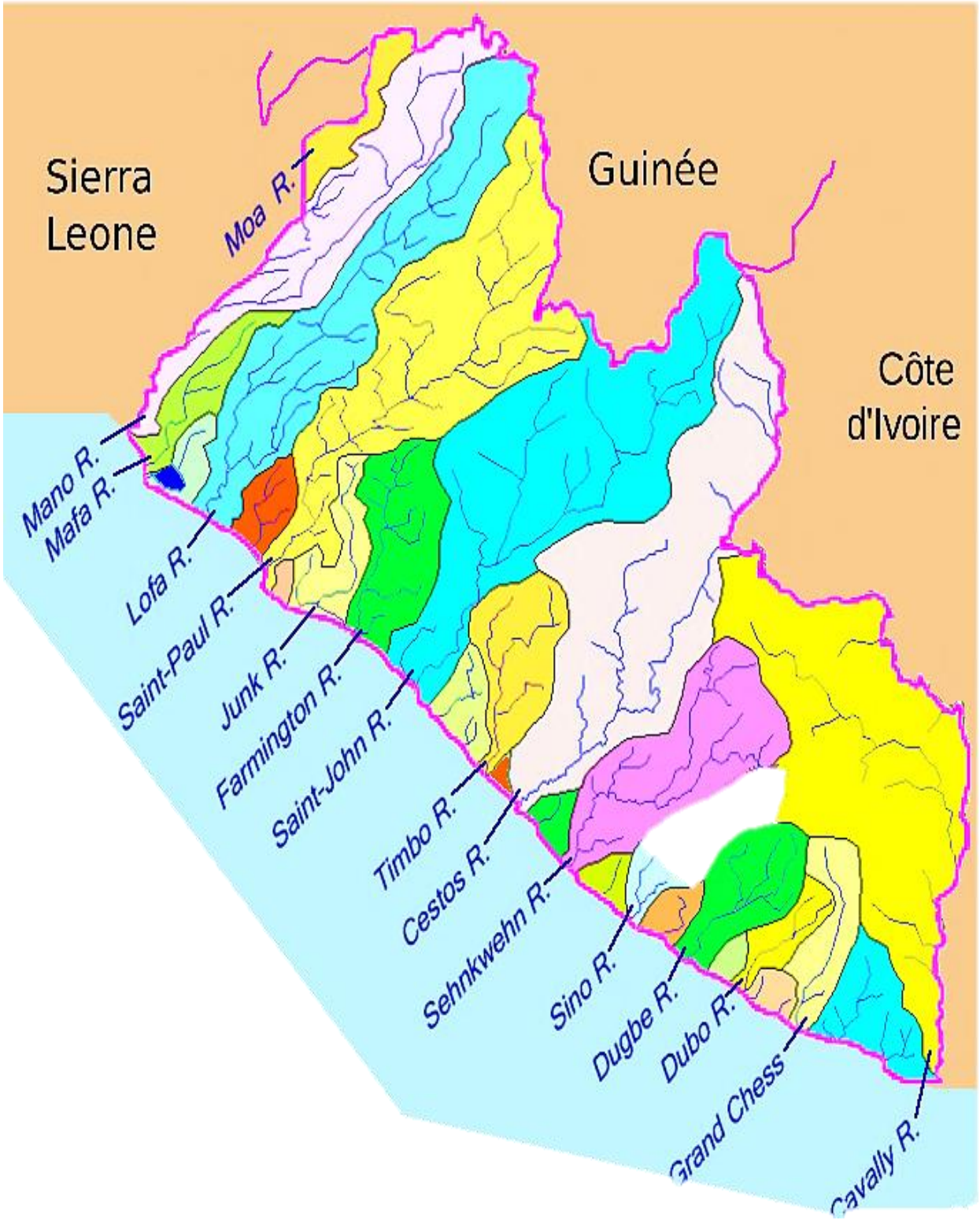


Figure 1 illustrates the geographical distribution of the 15 primary river basins of Liberia, along with their respective locations and their shared outlet, which is the Atlantic Ocean. The 15 primary basins include the Mano, Lofa, St. Paul, St. John, Cavalla, Cestos, Junk, Farmington, Timbo, Sinoe, Dubo, Dugbe, Sehnkwehn, and Grand Chess River. In addition to the aforementioned 15 basins, there are 23 smaller coastline drainages that together discharge their contents into the Atlantic Ocean, following the northeast-to-southwest trajectory. The primary rivers of

Liberia, including the Cavalla, Mano, St. John, Cestos, St. Paul, and Lofa Rivers, have their sources in the Mounts Fouta Djallon region of Guinea. The drainage system of Liberia mostly consists of rivers, which account for 56% of the total drainage.

The remaining area is made up of a few shorter coastal rivers and 11 minor tributaries. Five Ramsar sites exist in Liberia, three of which are located in the country's coastal lowlands. The coastal lowland of Liberia also has more than 600,000 and 50,000 hectares of marshes and mangroves, respectively. Lake Piso and Shepherd are the two biggest lakes of brackish water. Moreover, according to LHS (2016), Lake Piso is the biggest Ramsar site that has been officially recognized in the country. With a capacity of about 239MCM of water from the source river St. Paul, the Mount Coffee dam on the St. Paul River contains the biggest and only significant reservoir in the country. In addition to serving as a significant source of potable water for Monrovia, the dam also generates electricity for use by local government (FAO, 2020).

The main consumers of freshwater resources are cities and businesses. Most rivers face seasonality with little impact except the river on which the Mount Coffee Hydro dam is located (St. Paul River). According to LHS (2016), the St. Paul River experiences an increase to over 1,400 m3/s in September and a decrease in its average flow rate to 50 m3/s during the month of February, due to this drop during the dry season there is a drop in hydropower generation. In general, it is customary for the Dam to operate all four turbines at maximum capacity. However, in periods of reduced precipitation, such as the dry season, it becomes necessary to decrease the output of three turbines as a result of decreased water levels in the reservoir (POYRY, 2012). A major threat posed to surface water is the disposal of solid municipal waste in landfills located in saline marshes next to cities and towns. The rapid expansion of the agro-industrial sector has been identified as a significant contributor to the degradation of watersheds and the deterioration of water quality.

From 2001 to 2018, a significant loss of forest cover amounting to 1.5 million hectares was observed, marking a fourfold increase compared to the deforestation rates of the preceding decade (Butler. 2022). The industrial sector and municipal water systems are the primary users of freshwater. During periods of precipitation and aridity, there are significant fluctuations in river discharge. Except for the unconsolidated sedimentary aquifers near Monrovia's northwest coast, the hard rock aquifers make up the majority of the nation's groundwater. The characteristics of these aquifers are poorly understood however, they show good output and variability in the country's groundwater system. The majority of the wells have a small depth range, often ranging from 5 to 25 meters, and provide limited production outputs. In the case of deeper wells, it is possible to encounter groundwater with greater production rates. However, it is important to note that the process of drilling deep wells is both costly and hazardous, mostly owing to the unpredictable variability of the groundwater supply. According to Gökçekuş et al. (2022), the productivity of unconsolidated sedimentary aquifers is higher along the shoreline, notwithstanding the potential influence of saltwater intrusion on freshwater resources. The understanding of groundwater resources is still limited, despite their significant role as a primary source of drinking water, particularly via the use of hand-dug wells.
Aquifer study is limited in scope, as are analyses of its hydrogeological properties. More than 70% of the population's water demands are satisfied by groundwater, which is the main source of drinking water in both rural and urban areas. The risks connected with pathogenic contamination in groundwater have been greatly increased, particularly within urban areas, due to the increased prevalence of unprotected manually dug wells and inadequate sanitary infrastructure. Additionally, the areas of Robertsport, Voinjama, Monrovia, and Sanniquellie have increased levels of lead due to improper management of solid waste and industrial pollution. When coastal groundwater resources are threatened by causes including coastal erosion, inland storm activity, and rising sea levels, the amount of salt in essential drinking water supplies increases (USAID, 2012).

Table 1. Liberia and median Sub-Saharan Africa water resource data compared

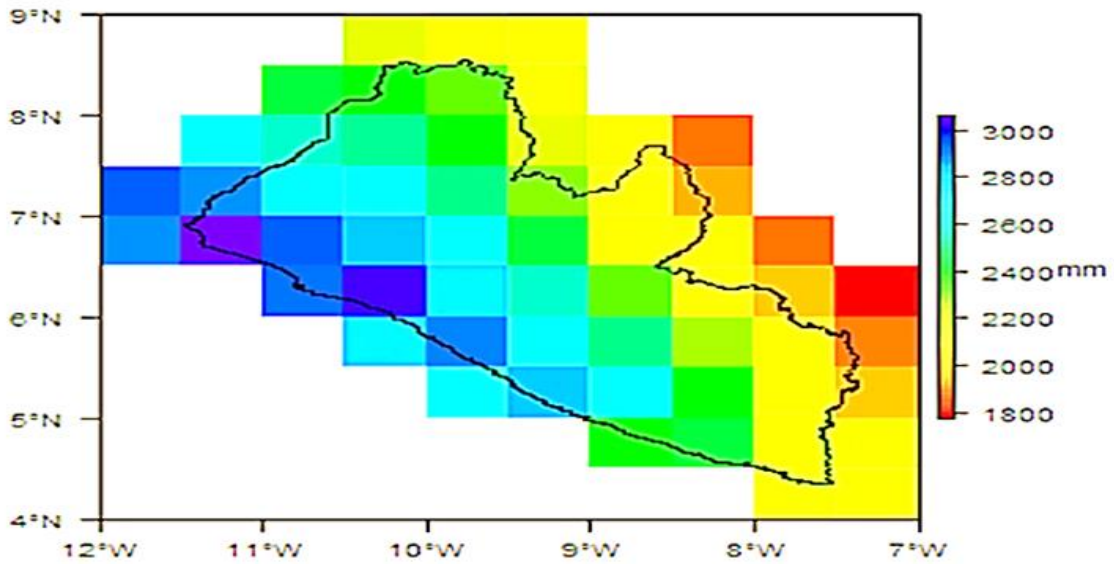
Variables	Year	Republic of Liberia	(Median) Sub-Saharan Africa
Average annual Rainfall (mm/year)	2017	2,391 (mm/year**)**	1,032(mm/year**)**
Renewable Freshwater Total (MCM/year)	2017	232,000 (MCM/year)	38,385 (MCM/year)
Fallen mark Index – Total renewable fresh water per capita (m3/year)	2017	49,028 (m3/year)	2,519 (m3/year)
Renewable surface water total (MCM/year)	2017	232,000 (MCM/year)	36,970 (MCM/year)
Renewable groundwater Total (MCM/year)	2017	45,000 (MCM/year)	7,470 (MCM/year)
Total withdrawal of freshwater (MCM/year)	2002	130.8 (MCM/year)	658 (MCM/year)
Total dam reservoir capacity (MCM)	2015	238.6 (MCM)	7,085 (MCM)
Water Dependency ratio (%)	2017	13.79 %	23%
Variability of Season	2013	2.8	3.15
Environmental Requirements of River Flow (MCM/year)	2017	176,800 (MCM/year)	18,570 (MCM/year)
Water Stress (%) according to SDG6.4.2	2002	0.26%	5.7%

Source: https://winrock.org/wp-content/uploads/2021/08/Liberia_Country_Profile-Final.pdf

According to Table 1, Liberia exhibits a 57% higher annual average rainfall compared to sub-Saharan Africa. Additionally, Liberia possesses 84.5% more total renewable freshwater resources than sub-Saharan Africa. Moreover, when considering the fallen mark index total renewable water resource per capita, Liberia surpasses sub-Saharan Africa by 95%. Furthermore, Liberia's total renewable surface water per year in million cubic meters (MCM) exceeds median sub-Saharan Africa by 86%. Furthermore, the data presented in the table indicates that Liberia possesses a significantly higher annual total renewable groundwater resource of 83.4% per million cubic meters (MCM) compared to the median value for sub-Saharan Africa. Additionally, Liberia exhibits a water resource dependency ratio of 13.76%, which is higher than the median value for sub-Saharan Africa. Moreover, Liberia demonstrates a substantially greater environmental flow requirement for surface water, amounting to 89.5% more than the median value for sub-Saharan Africa. Nevertheless, the data also indicates that the median freshwater extraction in sub-Saharan Africa surpasses that of Liberia by 79.2%. Additionally, the median sub-Saharan Africa region has an average reservoir dam capacity that is 96.7% greater than that of Liberia. Furthermore, it is worth noting that sub-Saharan Africa has a greater level of seasonal variability (with a median value of 3.15) and inter-annual variability (with a median value of 1.55) compared to Liberia, where these values are 2.8 and 0.8, respectively. Finally, by Sustainable Development Goal 6.4.2, Liberia exhibits a water stress percentage of 0.26, which is lower in comparison to the median value seen in sub-Saharan Africa.

Climate Change, Health, and Water Resources

Figure 2 Rainfall Data Map



Source: https://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Liberia

According to Figure 2, Liberia has an average annual precipitation above 2,500 millimeters. The coastal areas, including Robertsport, Monrovia, southern Bomi, Buchanan, Cestos City, and Greenville, get the highest amounts of precipitation, reaching an annual average of 2800-3000mm. Coastal communities such as Barclayville and Harper see comparatively lower annual precipitation levels, ranging from 2200-2400mm, as compared to other coastal cities or regions. Inland regions with elevations ranging from 2200 to 2600 get the least amount of yearly precipitation, whereas high plateaus and low mountains receive an average annual rainfall of roughly 2,030 millimeters (mm).

Precipitation occurs consistently throughout the year in the southern region of the nation, whilst the other areas have two distinct rainy periods owing to the impact of the West African Monsoon. The current increase in the temperature of the nation's climate stands at 0.8 degrees Celsius, and it is anticipated to escalate to a range of 1.4-2.4 degrees Celsius by the conclusion of the century. The United States Agency for International Development (USAID) in 2017 reported that there is evidence to propose that climate change is contributing to the escalation of precipitation patterns. This, in turn, has had a detrimental impact on the occurrence and severity of floods, as well as the prevalence of waterborne illnesses.

Table 2. Flood data of July 17-19 2018 of Montserrado, Margibi, and Grand Bassa County

Date	Types of incidents	County	#of Persons affected	# Of Female	# Of Male	# Of Children	Properties Damaged
17-19/07/2018	**Flood**	**Montserrado**	**33,587**	**14,151**	**11,631**	**7,805**	**261**
17-19/07/2018	**Flood**	**Margibi**	**15,121**	**7,177**	**6,758**	**1,186**	**1,729**

17-19/07/2018	**Flood**	**Grand Bassa**	**2,940**	**1,567**	**1,105**	**268**	**0**
Grand Total			**51,648**	**22,895**	**19,494**	**9,259**	**1,990**

Source: https://reliefweb.int/report/liberia/national-disaster-management-agency-liberia-releases-latest-data-recent-flooding

Table 2 presents the flood data collected over the period of July 17-19, 2018. According to the data presented in the table, it can be understood that the flood most impacted the residents of Montserrado, followed by Margibi and Grand Bassa. The presented data in the Table indicates that women experienced the highest level of impact, followed by males and finally children. The chart also indicates that the extent of property damage in Margibi was much higher compared to Montserrado, which had little property damage, and Grand Bassa, which reported no property loss. According to research done by the World Bank in 2021, it was found that there is a potential for a rise in ocean levels ranging from 0.6 to 1 meter by the end of the present century. A little increase of a single meter in the ocean level would result in the inundation of around 2,000 square kilometers of land, leading to the destruction of mangrove forests and wetland ecosystems. Furthermore, this would necessitate the evacuation of more than 250,000 people.

In some locations inside Monrovia, the phenomenon of increasing sea levels and coastal erosion has already resulted in detrimental effects on infrastructure and the displacement of a significant number of citizens. Furthermore, the populations and ecosystems residing along the shoreface significant threats from coastal erosion and the increase in sea levels.

Liberia has the challenge of rising sea levels as a result of its expansive coastal plains and high population enormity to the coastline. In recent times, there has been a notable escalation in the phenomenon of coastal erosion. As a consequence of the progressive elevation of sea levels, the withdrawal of the coastline in Montserrado County is projected to occur at a rate of up to 20 meters per year (UNDP, 2016). Riverine flooding is a significant challenge across Liberia, with its ramifications exacerbating in recent times (World Bank, 2021).

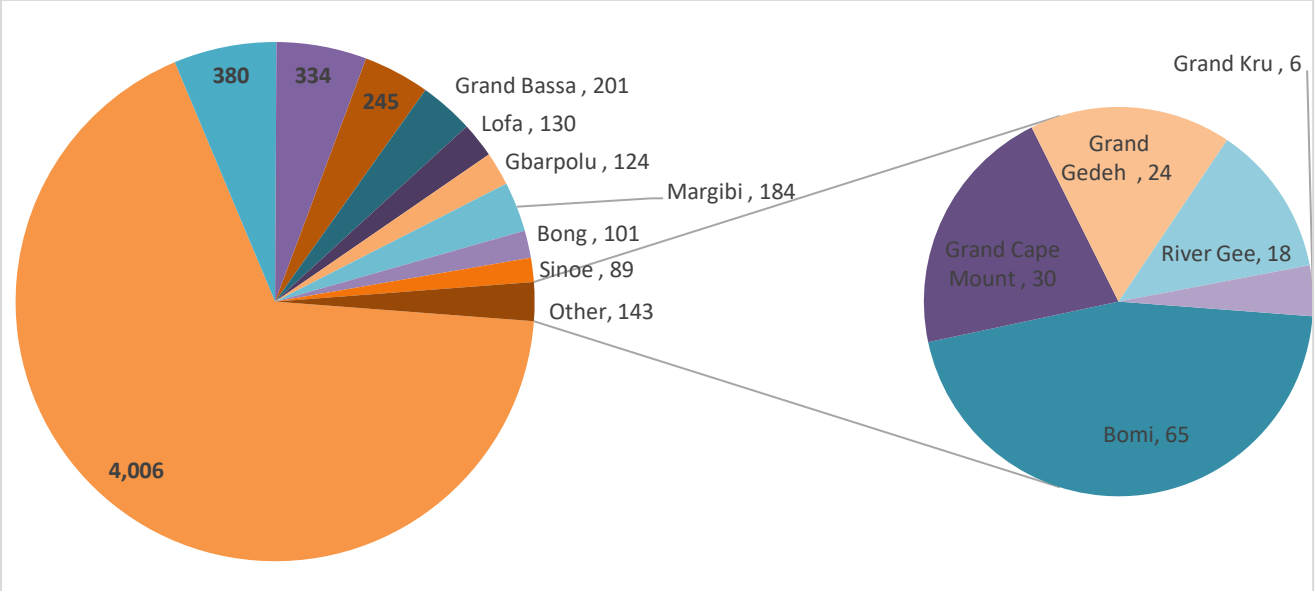
Table 3. Cholera outbreak summary characteristics in Liberia from 2011 to mid-2019

Counties	total cases (%)	Incidence cumulative (per 10,000 inhabit.)
Montserrado	67.5	28.9
Grand Gedeh	0.4	1.7
Maryland	5.6	19.8
Grand Bassa	3.4	7.3
Lofa	2.2	3.9
Gbarpolu	2.1	12.2
Margibi	3.1	7.0
Grand Kru	0.1	0.3
Sinoe	1.5	6.9
River Gee	0.3	2.1

Bomi	1.1	6
Grand Cape Mount	0.5	1.9
Nimba	4.1	4.3
Bong	1.7	2.2
Rivercess	6.4	42.9
Grand Total	100	

Source: https://www.plateformecholera.info/2022-11/CholeraFactsheet_Liberia_2019_Final.pdf

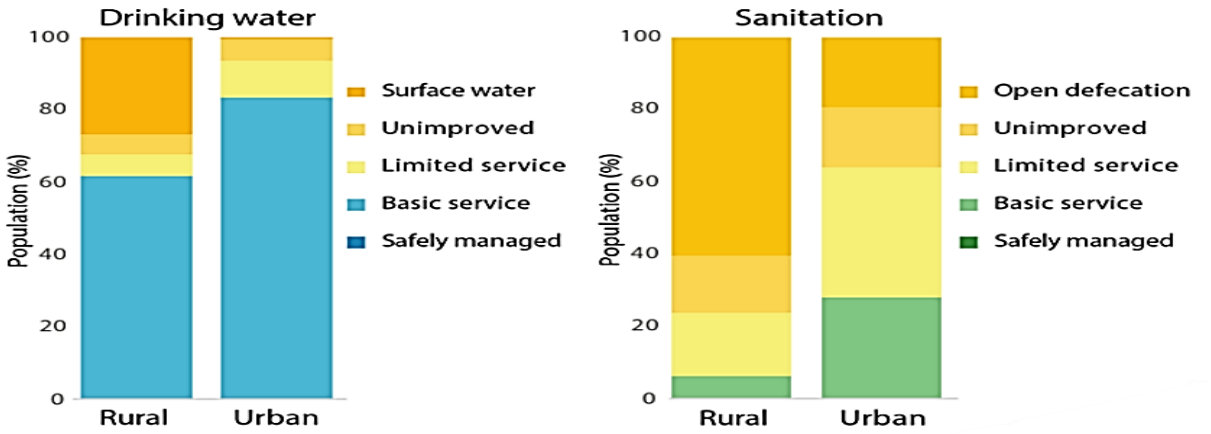
Figure 3. Cholera outbreak summary characteristics in Liberia from 2011 to mid-2019



Source: https://www.plateformecholera.info/2022-11/CholeraFactsheet_Liberia_2019_Final.pdf

According to the data shown in Table 3 and Figure 3, Montserrado County accounted for the highest proportion of probable cholera cases (67.5%) between 2011 and mid-2019. Montserrado County, situated in Liberia, has the distinction of being the most densely populated county in the country. Additionally, it serves as the host of Monrovia, the esteemed national capital. Rivercess County accounted for 6.4% of the total number of probable cholera cases. The county of Maryland had a prevalence rate of 5.6% for all suspected cases of cholera. Nimba County accounted for 4.1% of the total probable cholera cases. During the span of about nine years, it was observed that the remaining counties in Liberia individually accounted for fewer than 4% of the total recorded cases of probable cholera. Moreover, research carried out in Liberia by the United Nations Development Program revealed that informal dwellers in urban areas like Monrovia are particularly vulnerable to natural disasters such as floods and public health emergencies, particularly epidemics of cholera. The majority of urban regions are deficient in advanced sewage systems or wastewater treatment facilities. In Monrovia, a considerable portion of the city's population, around 30%, is served by a rather limited sewage system. It is worth noting that the Wastewater Treatment Plant located in Fiamah has been non-operational for almost two decades, as reported by the Liberia Water and Sewer Corporation (LWSC, 2019).

Figure 4. Water and Sanitation Estimate in Liberia 2017



Source: https://www.plateformecholera.info/2022-11/CholeraFactsheet_Liberia_2019_Final.pdf

The data shown in Figure 4 depicts the estimated state of water and sanitation in Liberia for the year 2017, as derived from research done by UNICEF. A comparative analysis was conducted to examine the disparities in drinking water and sanitation between urban and rural areas of Monrovia. According to a survey conducted by UNICEF, it is evident that the provision of properly managed drinking water is lacking for the whole population. The study reveals that just 60% of the rural population has access to basic drinking water services, in contrast to 83% of the urban population. The provided data also demonstrates that there is a disparity in the quality and accessibility of drinking water between the urban and rural residents, with 7% of the rural population having restricted access to better drinking water services in comparison to the urban population. A proportion of 10% and 5% of the population are found to have inadequate access to basic services and lack access to better drinking water, respectively.

The data shown in the image indicates that 26% of the rural population depend on surface water sources, such as lakes, streams, and rivers, for their drinking water. In contrast, just 2% of the urban population utilizes surface water for this purpose. In the context of sanitation, it is observed that the proportion of rural inhabitants with access to fundamental sanitation services is 4%, while the corresponding figure for the urban population is 24%. Furthermore, it is worth noting that the proportion of individuals in rural areas without access to adequate sanitation services and facilities is 16%, whilst the corresponding figure for the urban population of Liberia is 38%. The table illustrates that both the urban and rural populations exhibit a similar proportion of 18% in terms of lacking access to adequate sanitation services and facilities. Finally, the survey further demonstrates that a majority of the rural population, namely 62%, engage in the practice of open defecation, while 20% of the urban population partake in this behavior.

Insufficient waste management practices and inadequate sanitation systems have had adverse impacts on biodiversity and have led to the pollution of important wetland habitats. The issue of limited access to safe drinking water is a subject of worry due to study findings indicating a notable prevalence of microbial contamination, hence diminishing its overall worth and quality. The study carried out in 2011 in the nation's capital city revealed that drilled wells exhibited a prevalence rate of 44 percent for E. Coli, while hand-dug-protected wells exhibited a prevalence rate of 52 percent for E. Coli. Furthermore, all unprotected wells were found to contain E. Coli. The user has entered a numerical value of 45. Prior research done in Monrovia has shown the existence of heightened concentrations of nitrates, perhaps attributable to inadequate sanitation infrastructure. Moreover, the agro-industrial processing procedures often result in the introduction of chemical contaminants into water sources. A range of chemical substances, including sulfuric acid, ammonia, formic acid, and lye, are often used in rubber plantations and processing facilities. Wilson et al. (2017) assert that the absence of wastewater treatment might lead to the detriment of wetland biodiversity and public health. According to a recent study, it has been noted that the concentrations of mercury detected in Cape Mount County and Bong County have beyond the recommended thresholds established

by the World Health Organization (WHO) for water use in close vicinity to small-scale gold mining operations by a factor of 150.

A significant amount of gold extraction has been linked to an increase in cyanide concentrations and a decrease in pH levels. In the years 2015 and 2017, the Lake Piso-Lofa River Basins and the St. John River saw substantial chemical breaches, according to Dorko (2018). As a result of these catastrophes, aquatic life was wiped out, people had to relocate, and drinking water supplies were contaminated. The St. John River Basin, namely in Sien Creek, received an estimated three million gallons of contaminated mining tailings in 2017, according to studies conducted by the Liberian Environmental Protection Agency. For Sayewheh Town to have drinkable water, the presence of this water source is crucial. 1,900 people reported feeling uncomfortable chemically while taking a bath, and those who drank the tainted water developed significant gastrointestinal problems (EPA, 2017).

National Policy and Challenges of Integrated Water Resource Management in Liberia

Table 4. Budgetary appropriation to the Environment and Energy Sector of Liberia from 2017/2018-2021/2022

Variable	Fiscal Year	Sector Appropriation	(Sector %)Total Approve National budget	(Sector %)Total recast National Budget
Environment and Energy Sector	2017/2018	$15.1Million USD	(2.68%) of 563.5 Million USD	(2.8%) of 536.2 Million USD
Environment and Energy Sector	2018/2019	$12.6Million USD	(2.2%) of 570.1 Million USD	(2.3%) of 540.1 Million USD
Environment and Energy Sector	2019/2020	$15.9Million USD	(3.02%) 525.9Million USD	(3.06%) of 518.9 Million USD
Environment and Energy Sector	2020/2021	$12.2Million USD	(2.14%) of 570.1 Million USD	(2.14%) of 570.1 Million USD
Environment and Energy Sector	2021/2022	$35.6Million USD	(4.4%) of 806.5 Million USD	(4.5%) of 786.6 Million USD
Total over the years	USD 91.4 Million Average appropriation over five years USD 18.28 Million		The total average of the approved budget over the five years is 607.2 Million USD and the average sectoral appropriation from said amount is 3.0%	The total average of the recast budget over the five years is 590.4 Million USD and the average sectoral appropriation from said amount is 3.1%

Source: Researcher's Data, http;//www.mfdp.gov.lr

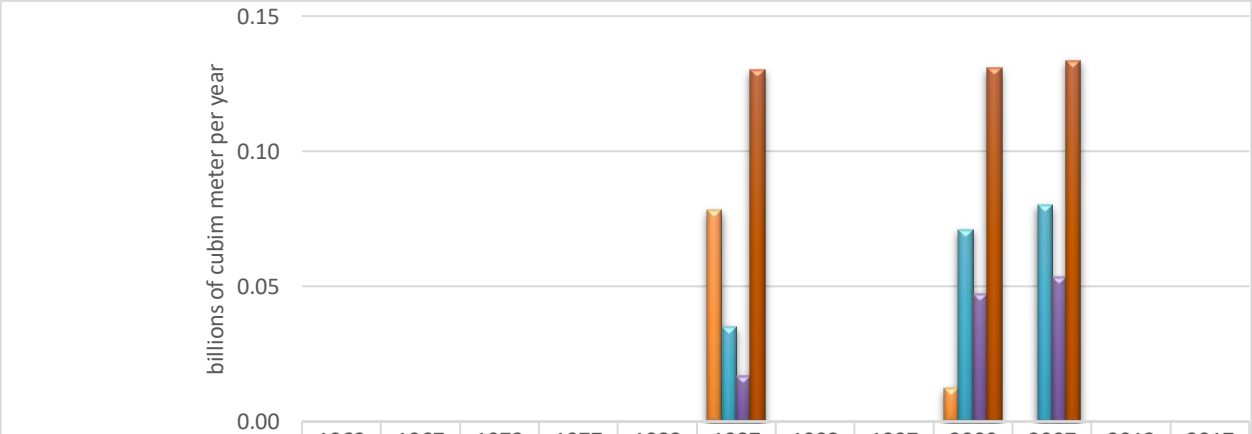
Table 4 presents data on the approved budget of Liberia for the period 2017-2022. The average annual budget allocation during this period amounts to 607.2 million USD, resulting in a cumulative total of 3,036,100,000 USD over the five years. Additionally, the recast budget exhibits an average annual allocation of 590.4 million USD, leading to a cumulative total of 2,951,900,000 USD over the same five-year period. During this specified timeframe, a cumulative amount of 91.4 million average (equivalent to 18.28 million USD) has been allocated to the sector encompassing the Environmental Protection Agency, Ministry of Land Mines and Energy, Liberia Water and Sewer Corporation, Forestry Development Agency, Liberia Electricity Corporation, Forestry Training Institute, and the Rural Renewable Energy Agency. The allocation of an average of 3.0 percent of the budget to the Environment and Energy sector for the specified time indicates insufficient financing for these institutions and the effective governance of Liberia's water resources. The ministries get less than 4 percent of their funding from the national

budget, with the majority of financial assistance coming from donors. Significantly, our research results demonstrate that the term "brain drain" is identified as a significant concern for the business sector under the national Integrated Water Resources Management (IWRM) Policy. The absence of important financial and technical knowledge has wide-ranging implications, leading to an escalation in the risks associated with floods and water pollution, particularly in the city of Monrovia. Monrovia, like several other cities, has challenges stemming from insufficient urban planning, zoning regulations, and policy implementation. The policy of Integrated Water Resource Management in Liberia stipulates the need for the enhancement of both public and private water research institutes to improve the use, protection, and management of water resources. To ensure the provision of accurate and reliable data, it is imperative to provide sufficient financial resources to the meteorological division of the Ministry of Lands, Mines, and Energy, as well as the Liberian Hydrological Service Bureau. To ensure the provision of timely and reliable data, the Department of Meteorology must get enough funding. The Act governs the regulation, use, safeguarding, and maintainable management of water resources. The Integrated Water Resources Management policy advocates for the systematic and regulated utilization of water resources for various non-domestic activities, including mining, agricultural irrigation, industrial processes, navigation, livestock watering, commercial purposes, hydroelectric energy generation, fishing, recreation involving flora and fauna, and conservation efforts, all while minimizing adverse environmental impacts.

The policy offers an institutional framework that facilitates effective communication and collaboration across several levels of governance, including village-community, national, district, and county levels. Additionally, it promotes cross-sectoral management and encourages investor engagement. This study focuses on the capacities required to effectively organize, create, and prioritize strategies to aid decision-makers in water resources management. Moreover, the Integrated Water Resources Management policy entails the development of a comprehensive strategy and implementation framework aimed at ensuring the long-term provision of water and sanitation services. This involves the integration of existing initiatives, as well as the identification and rectification of disparities and deficiencies, via collaborative efforts with various non-governmental organizations, agencies, local governing bodies, and governmental departments. The water resource management policy is allocated among seven distinct governmental agencies. The establishment of a dedicated ministry for water sanitation and resources, as proposed by the World Bank, aims to consolidate the many capabilities, activities, and financial allocations within the sector into a unified institution.

Liberia's Water Resource Use

Figure 5. Agriculture, Municipal, and industrial water withdrawal (Billions of Cubic meters)



	1962	1967	1972	1977	1982	1987	1992	1997	2000	2007	2012	2017
Agricultural Use						0.078			0.0123			
Municipal Use						0.0351			0.0711	0.0802		
Industrial Use						0.0169			0.0474	0.0534		
Total Yearly Withdrawal						0.13			0.1308	0.1336		

Source: https://www.worldometers.info/water/liberia-water/#water-use

According to Figure 5, the data from 1987 indicates that the largest proportion of water withdrawal, accounting for 60%, was allocated for agricultural uses. Municipal usage accounted for 27% of the total water withdrawal, while industrial use accounted for 13%. In the year 2000, the proportion of water withdrawal allocated for agricultural uses had a reduction of 51%, accounting for 9% of the total water withdrawal during that period. In the year 2000, the predominant purpose for water extraction was municipal use, accounting for 54% of the overall water withdrawal. This was followed by industrial usage, which constituted 36% of the entire demand. In 2007, there was a lack of documented data about water withdrawal for agricultural reasons. However, it was observed that 60% of the total water withdrawal during that year was allocated for municipal use, while the remaining 40% was used for industrial purposes. Liberia now relies on the Monrovia Water Supply System and a network of more than 10,000 hand pump wells, both dug and drilled, to provide its residential water needs. According to the Liberia Water and Sewer Corporation (LWSC) in 2019, the average annual water consumption per home in Liberia is anticipated to be 13 million cubic meters (or 0.013 cubic kilometers), which corresponds to an average of 36 cubic meters per person. The documentation, reporting, and measurement of various withdrawals are not consistently undertaken, hence posing challenges in their aggregation. The Monrovia Water Supply System has a daily water production capacity of 3.5 million gallons. The Monrovia water supply system, together with its secondary wells, is required to extract a total volume of 5.028 cubic kilometers of water annually. According to the LWSC (2019), boreholes and excavation wells can provide a daily water supply of 6,250 liters (or 6.25m^3) during the rainy season and 3,750 liters (or 3.75m^3) during the dry season. Water is furthermore used in the mining and industrial sectors. The quantity of water extracted from Mines by various techniques remains uncertain.

Table 6. Liberia water used for electricity (Dams)

Dam name	Location	Capacity
Firestone Hydropower	Farmington River in Harbel	4 Megawatts
Mount Coffee Dam	St. Paul River is found in Harrisburg/Mount Coffee.	64 Megawatts
Yandohun Dam micro hydropower	Yando River in Yandohun, Lofa County	30 KW
Total Power Output		68.03 Megawatts

Source: Researcher Data

According to Table 5, the Mount Coffee Dam is the most significant hydroelectric facility in Liberia, generating a total of 64 Mega Watts (MW) of energy. In comparison, the Firestone Dam produces 4 MW, while the Yandohun Dam generates 30 Kilowatts (kW) of power. Water is utilized for electricity generation in several projects, namely the Firestone small hydropower project, which has a capacity of 4 MW and is situated on the Farmington River in Harbel. Additionally, the Yandohun Dam micro hydropower project, with a capacity of 30 kW, is located on the Yando River in Yandohun, Lofa County. Lastly, the Mount Coffee hydropower dam, with a capacity of 64 MW, is situated on the St. Paul River in Harrisburg/Mount Coffee. The agricultural system of Liberia relies mostly on rainfall, with minimal use of irrigation water, save for certain activities such as vegetable gardening, swamp rice cultivation, and general agriculture. According to FAO figures, the annual agricultural water extraction in Liberia in 2000 amounted to 60 million cubic meters, accounting for about 55% of the total water withdrawal. It is worth noting that the year 2000 was marked by a period of conflict, during which agricultural activities were severely disrupted. Accordingly, it seems that the water extraction estimates from the year 2000 is outdated (LWSC, 2019).

CONCLUSION

The research found that Liberia has more freshwater and rainfall than sub-Saharan African nations. Liberia has lower stress and water dependence than sub-Saharan Africa. The research also found that urban and rural groundwater quality monitoring is weak. The research also found that poor sanitation, sewage treatment, waste management, floods, insufficient infrastructure, and mining operations pollute surface and groundwater, causing cholera. The survey found that Montserrado, Rivercess, Maryland, and Nimba had the highest cholera cases.

Montserrado, Margibi, and Grand Bassa counties were most hit by the 2017 July 17-19 floods, indicating that urban coastal counties are most in danger. According to the national budget from 2017–2022, government entities or the environmental sector that monitor, regulate, and manage water resources received less than 4% of the national budget. Minimal cooperation between water monitoring and management government entities hinders the implementation of the Integrated Water Resource Management Policy. Finally, the survey found that water is utilized for drinking, cooking, personal hygiene, hydroelectric power production, industry, and agriculture.

RECOMMENDATIONS

Established on the findings of this research, it is important to consider revising the national policy on integrated water resource management. Additionally, it is suggested that a concise framework be developed for the monitoring, treatment, and management of water resources. Consequently, it is essential to provide the responsibility to a single governmental ministry or agency that has enough financial resources. The study further proposes that individuals from Liberia get instruction and training in water quality and management, as well as human resource or capacity development. The report further proposes the implementation of a comprehensive waste management and sanitation system at both the neighborhood and national levels, to mitigate water contamination and other forms of pollution. It is recommended to further investigate the effect of climate change on water resources, as well as explore viable strategies for mitigating its effects. It is advisable to prioritize the development of the city's structural infrastructure to facilitate the efficient distribution of water to residential, commercial, and industrial establishments. In conclusion, it is essential to consider the potential impacts of increasing sea levels and ground-level water when constructing cities. This necessitates the incorporation of unimpeded drainage systems, the preservation of wetlands and mangroves, the establishment of flood reservoirs, and the implementation of water channels to effectively mitigate the risks associated with flooding and related challenges.

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DISCLOSURE STATEMENT

This is to affirm that there are no conflicts of interest between the aforementioned writers and this research work. The authors certify that there are no financial conflicts of interest or close personal ties that might have seemed to have influenced the research presented in this study.

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