International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 03 | Mar 2022 www.irjet.net p-ISSN: 2395-0072

A REVIEW OF LIBERIA'S WATER RESOURCES: THE QUALITY AND MANAGEMENT WITH PARTICULAR FOCUS ON FRESHWATER RESOURCES

Prof. Dr. Hüseyin Gökçekuş [1], Assct Prof. Dr. Yousef Kassem 2, Francis Surfia Dioh[3]

[1]Professor Department of Civil Engineering, Civil and Environmental Engineering Faculty, Near East University, 99138 Nicosia (via Mersin 10, Turkey)
[2]Professor, Department of Mechanical Engineering, Engineering Faculty, Near East University, 99138 Nicosia (via Mersin 10, Turkey), Cyprus
[3]Department of Environmental Engineering, Civil and Engineering Faculty, Near East University, 99138 Nicosia (via Mersin 10, Turkey), Cyprus

---

Abstract - Water quality is a major concern for humanity since it is closely linked to human well-being. Freshwater resources are under increasing pressure in many parts of the world due to overuse and contamination from human activities. Liberia's situation is no exception. This study attempts to investigate freshwater quality in Liberia and to identify freshwater resources management mechanisms and challenges associated with these mechanisms. The methodology used was based on a documentary review in which secondary data was gathered through visiting online libraries and reading published research papers and various books. The data from those separate sources were compared and analyzed. Owing to the lack of primary data, no statistical software was employed for the analysis. Findings from existing studies on the quality of freshwater resources showed that the quality has reduced over the past years and as such it is not at an optimal level, the quality of freshwater has been affected mostly by Coliform bacteria contamination, heavy metal contamination, and fecal indicator bacteria. These contaminations can be attributed to inadequate sanitation systems, flooding, mining activities, and the fast-developing agro-industrial sector. Freshwater resources are being managed through a traditional water management system. Water quality management tasks are shared among several institutions. This mechanism allows total involvement of the line Ministries in addressing water quality and management. However, population growth in urban areas, the inadequacy of human resources capacities, and uncontrolled disposal of waste and water activities fragmented amongst ministries and institutions are challenges associated with freshwater management. There is a need for a comprehensive assessment of the quality of freshwater resources, particularly the physical, chemical, and biological variables is needed, an establishment of a proper sanitation system as well as establishing a single institution for the purpose of handling freshwater management.

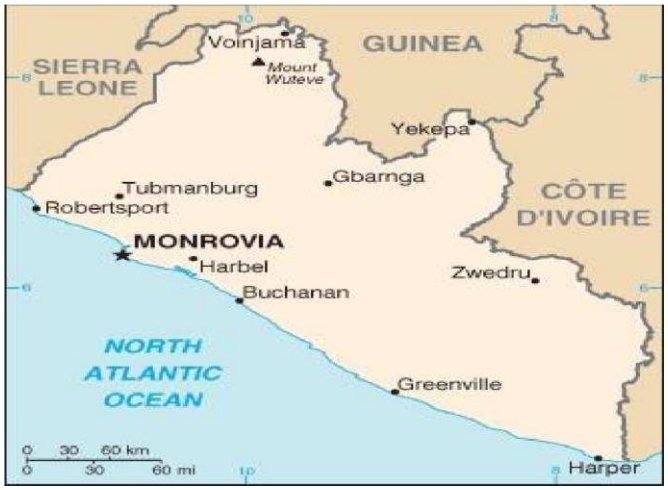
Key Words*: (*freshwater, quality, management, surface water, groundwater, coliform, heavy metals)

1. INTRODUCTION

Water is fundamental for life. Without it, the biosphere that exists on the outer layer of the earth would not be imaginable. Over 70% of the world's surface is covered by water, with 97% of that in the sea, which is unsuitable for human utilization and different uses because of its high salt substance. Of the leftover three percent, 2% is secured in the polar ice covers and icy masses and just a single percent is accessible as new water in waterways, lakes, streams, repositories, and groundwater which is appropriate for human utilization. All living species require a consistent stock of clean water to get by and flourish. Water quality is the main issue for mankind since it is firmly connected to human prosperity. Water quality information are not gathered regularly in a larger part of nations, this implies that north of 3 billion individuals are in danger in light of the fact that the wellbeing of their freshwater biological systems is obscure (United Nations-Water 2021). Of the 89 nations with water quality information, just 52 have data about groundwater, which is hazardous in light of the fact that groundwater regularly addresses the biggest portion of freshwater in a country (UN-Water 2021). Freshwater resources are under expanding tension in many areas of the planet because of abuse and pollution from human exercises. Liberia's situation is no exception.

Liberia is located on Africa's west coast. It has a surface area of 111,400 sq. km, with water covering 14 percent of it. Liberia has a population of about 5 million people and is bordered on the west by Sierra Leone, on the north by Guinea, on the east by Cote d'Ivoire, and on the south by the Atlantic Ocean.

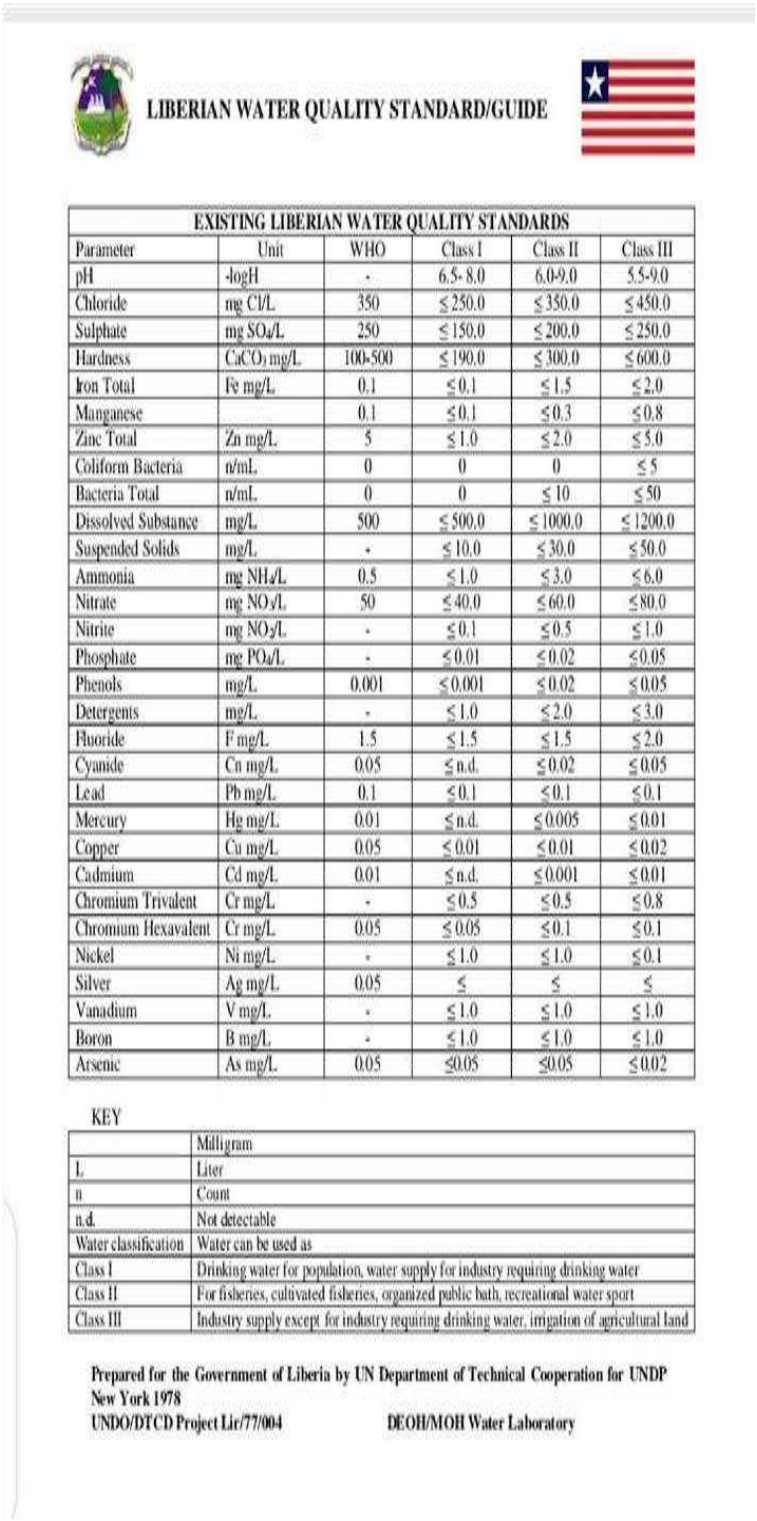
Figure 1 Map of Liberia



Liberia has a tropical climate with two seasons: the wet season, which lasts from May to October, and the dry season, which lasts from November to April. Inland, annual rainfall is 4320mm, and average humidity in the coastal area is 78 percent during the wet season but drops to 30 percent from December to March when the Sahara's Harmattan winds blow. Surface water and wetlands account for roughly 14% of Liberia's total surface area. The national drainage system is divided into 15 river basins. Liberia has a number of significant rivers. The Cavalla River, which runs between Liberia and Cote d'Ivoire, is the longest, while the Mano River runs through Liberia and Sierra Leone. The St. Paul River is the second-longest river in Liberia, supplying the Mt. Coffee hydroelectric facility and providing the majority of Monrovia's raw water. Liberia is home to only two significant lakes. Lake Shepherd in Maryland County and Lake Piso in Grand Cape Mount County are the two largest lakes in the county, with Piso being the larger of the two. Both are located on the Atlantic Ocean, with Lake Piso featuring a large area of wetlands and lowland forest vegetation. Groundwater is generally available and exploitable in most parts of the country; the existence of drilled and hand-dug wells across the length and breadth of Liberia attests to the presence of ample groundwater. However, there has been no systematic mapping and classification of the country's aquifers. Environmental monitoring includes a focus on water quality. When water quality is bad, it has an impact not only on aquatic life but also on the ecosystem. Water quality and management have been a key issue in Liberia since the 14 years of civil war (United States Agency for International Development (USAID 2006). Water bodies have been contaminated due to, inadequate sanitation systems, population increase, flooding, mining activities, and the fast-developing agro-industrial sector. Although there are abundant freshwater resources in Liberia, there are no centralized records of water quality. Water management responsibilities are fragmented among ministries. However, this study seeks to determine the quality of freshwater resources and identify the management mechanism used and challenges associated with these mechanisms

2. Methodology

The study was carried out in Liberia, which is one of the world's developing countries with freshwater quality and management issues. Legal professionals, academicians, government officials from nongovernmental organizations (NGO's), water experts were involved in the study. This study's design was entirely based on secondary data gathered through visiting online libraries and reading published research papers and various books, most importantly published articles in order to bring together knowledge of the quality and management of freshwater resources in Liberia and challenges associated with the management mechanism used. To complement primary data, relevant documents were checked and referenced during the information collection process. The bottom line is that not every literal work is published, and many works are kept off the public record and reserved solely for the use of officers. As a result, the only way to obtain relevant information from these sources was through documentary review, which was extremely effective and resourceful. The data from those separate sources were compared and analyzed. Owing to the lack of primary data, no statistical software was employed for the analysis. However, the existing water quality standard of Liberia which was prepared for the government of Liberia by the United Nations Department of Technical Cooperation was used to analyze these studies done on water quality. The result of the analysis can be used as a direction of a path forward for future research, informing a research agenda measure aspect about the quality and management of freshwater resources and challenges associated with the management mechanism used.



LIBERIAN WATER QUALITY STANDARD/GUIDE

EXISTING LIBERIAN WATER QUALITY STANDARDS					
Parameter	Unit	WHO	Class I	Class II	Class III
pH	-logH	-	6.5- 8.0	6.0-9.0	5.5-9.0
Chloride	mg Cl/L	350	≤250.0	≤350.0	≤450.0
Sulphate	mg SO_4/L	250	≤150.0	≤200.0	≤250.0
Hardness	$CaCO_3$ mg/L	100-500	≤190.0	≤300.0	≤600.0
Iron Total	Fe mg/L	0.1	≤0.1	≤1.5	≤2.0
Manganese		0.1	≤0.1	≤0.3	≤0.8
Zinc Total	Zn mg/L	5	≤1.0	≤2.0	≤5.0
Coliform Bacteria	n/mL	0	0	0	≤5
Bacteria Total	n/mL	0	0	≤10	≤50
Dissolved Substance	mg/L	500	≤500.0	≤1000.0	≤1200.0
Suspended Solids	mg/L	-	≤10.0	≤30.0	≤50.0
Ammonia	mg NH_4/L	0.5	≤1.0	≤3.0	≤6.0
Nitrate	mg NO_3/L	50	≤40.0	≤60.0	≤80.0
Nitrite	mg NO_2/L	-	≤0.1	≤0.5	≤1.0
Phosphate	mg PO_4/L	-	≤0.01	≤0.02	≤0.05
Phenols	mg/L	0.001	≤0.001	≤0.02	≤0.05
Detergents	mg/L	-	≤1.0	≤2.0	≤3.0
Fluoride	F mg/L	1.5	≤1.5	≤1.5	≤2.0
Cyanide	Cn mg/L	0.05	≤n.d.	≤0.02	≤0.05
Lead	Pb mg/L	0.1	≤0.1	≤0.1	≤0.1
Mercury	Hg mg/L	0.01	≤n.d.	≤0.005	≤0.01
Copper	Cu mg/L	0.05	≤0.01	≤0.01	≤0.02
Cadmium	Cd mg/L	0.01	≤n.d.	≤0.001	≤0.01
Chromium Trivalent	Cr mg/L	-	≤0.5	≤0.5	≤0.8
Chromium Hexavalent	Cr mg/L	0.05	≤0.05	≤0.1	≤0.1
Nickel	Ni mg/L	-	≤1.0	≤1.0	≤0.1
Silver	Ag mg/L	0.05	≤	≤	≤
Vanadium	V mg/L	-	≤1.0	≤1.0	≤1.0
Boron	B mg/L	-	≤1.0	≤1.0	≤1.0
Arsenic	As mg/L	0.05	≤0.05	≤0.05	≤0.02

KEY

	Milligram
L	Liter
n	Count
n.d.	Not detectable
Water classification	Water can be used as
Class I	Drinking water for population, water supply for industry requiring drinking water
Class II	For fisheries, cultivated fisheries, organized public bath, recreational water sport
Class III	Industry supply except for industry requiring drinking water, irrigation of agricultural land

Prepared for the Government of Liberia by UN Department of Technical Cooperation for UNDP
New York 1978
UNDO/DTCD Project Lir/77/004 DEOH/MOH Water Laboratory

Figure 2 Liberia water quality standard

3.0 Results and Discussion

This study sought to determine the quality of freshwater resources and identify the management mechanism used and challenges associated with these mechanisms.

3.1 Surface Water Resources in Liberia

Surface water is water in rivers, lakes, or freshwater wetlands. It is naturally replenished by precipitation and loss through discharge to the ocean, evaporation, and subsurface seepage. In Liberia, precipitation is the essential patron of water to surface water bodies, taking care of surface water bodies through run-off, which thus is administered by the consolidated impact of evapotranspiration and precipitation occasions. Liberia's surface water, including wetlands, represents around 14% of the nation's all-out region. Mano, Lofa, St. Paul, Cestos, Cavalla, and St. John waterways are the six significant streams of Liberia that help the watersheds. The Mano and Cavalla bowls are shared by Sierra Leone and the Ivory Coast, separately, while the Lofa, St. Paul, and St. John channel spaces of Guinea. The Border Mountains are the wellspring of a few waterways. St. John, Cestos, and Cavalla Rivers stream from Nimba Mountain; Lofa River streams from Wologizi; Mano River comes from Mano Mountain; and River Nuhn streams from Putu Mountain, bringing about jewel stores on the banks of the Mano, Cestos, St. John, and Lofa Rivers. Liberia has 15 significant waterway basins that channel to the Atlantic Ocean from the upper east toward the southwest. North of 600,000 hectares of freshwater wetlands, 55,000 hectares of beachfront mangroves, and three of Liberia's five Ramsar locales can be found in Liberia's seaside marshes. The two biggest lakes are Lake Piso and Lake Shepherd, with Lake Piso being the country's biggest Ramsar site. Liberia's just eminent repository, the Mount Coffee Dam, holds 239 million cubic meters (MCM) of water from the St. Paul River. The dam is a significant wellspring of drinking water for Monrovia and is utilized to create civil power.

Figure 2 Liberia Rivers Basin

Basin code	Name of principal basin	Total basin area (km^2)	Basin area in Liberia (km^2)	Basin area in Liberia (%)
00	Moa River	19,617	1,730	9
01	Mano River	7,520	5,539	74
02	Mafa River – Lake Piso	2,082	2,082	100
03	Lofa River	10,612	9,189	87
04	St. Paul River	20,281	10,991	54
05	Farmington River	5,249	5,249	100
06	St. John River	16,930	14,363	85
07	Timbo River	3,196	3,196	100
08	Cestos River	12,709	10,389	82
09	Sehnkwehn River	5,659	5,659	100
10	Sinoe River	2,258	2,258	100
11	Dugbe River	2,820	2,820	100
12	Dubo River	1,061	1,061	100
13	Grand Cess (Nuch River)	1,685	1,685	100
14	Po-Joda River	1,042	1,042	100
15	Cavalla River	30,277	12,240	40

Figure3. Liberia Rivers map

3.2 Groundwater Resources of Liberia

Groundwater is freshwater located in the pore space of soils and rocks, it is also water that flows in aquifers below the water table. In Liberia, groundwater is found in aquifers, which are water-bearing rocks with hydraulic properties that allow large amounts of water to be collected through boreholes and dug wells. Groundwater resources are not well understood but it is a principal source of drinking water, particularly through shallow, hand-dug wells. Assessment of aquifers and hydrological characteristics are limited, however, groundwater is the primary source of drinking water in rural and urban areas and is used by 70% of the population. In many rural and peri-urban populations, shallow wells are the principal source of groundwater collection. Groundwater levels are shallow, ranging from less than a meter in coastal locations to a few meters inland. In communities, hand-dug wells are shallow (up to 10-m depths) and completed 1–2 m below the water table. Boreholes (drilled wells) are bored to a depth of 5–100meters. Most city water frameworks were harmed during the civil wars, which constrained many people to get water through shallow, hand-dug wells.

Figure 4 Shallow Hand Dug well

Figure 5 Borehole well

However, Jimoh.R.A RA et al 2016 did an assessment of groundwater in Buchanan County, Liberia using VLF-EM and Electrical resistivity methods, results showed groundwater potential is quite substantial with different degrees of production. Another study Siqueria L et al 2018, identify groundwater potential zone in the crystalline basement rock terrain of Liberia using integrated remote sensing and GIS, results showed that there was significant groundwater within 5kms of all the sites studied. Elster, D et al 2014 investigated the basement complex aquifer system in Lofa County Liberia. Results showed groundwater resources in the basement aquifer can be detected by using standard approaches for sitting boreholes and exploiting from elsewhere based on the basic conceptual model. Furthermore, another study Onafeso OD et al 2016 on hydrogeological deep percolation modeling of groundwater recharge in Voinjama Region, Liberia, showed a sufficient amount of water in the hydrogeological system as well as potential of groundwater recharge that is suitable for exploitation. Ministry of Public Work 2017 conducted water point mapping of over 20000 groundwater sources, to conclude, these previous studies show the potential and availability of groundwater resources in the country however, considering the total land area of the country, a very comprehensive and detailed investigation needs to be conducted for groundwater.

3.3 Freshwater quality in Liberia

Findings from existing studies on the quality of freshwater resources showed that the quality has reduced over the years and as such the quality is not at an optimal level as per the existing water quality standard of Liberia, the quality of freshwater has been affected mostly by Coliform bacteria contamination, heavy metal contamination, and fecal indicator bacteria. These contaminations can be attributed to inadequate sanitation systems, flooding, mining activities, and the fast-developing agro-industrial sector. The water quality standard of Liberia was used to analyze results from previous studies conducted on the subject. It was deduced that the results gathered were in conformity with the water quality standard of Liberia. Below are studies conducted on the quality of freshwater resources in Liberia.

In 2017 the Ministry of Public Works completed a survey of over 20,000 water points throughout all counties. Although

the study offered only limited water quality data pertaining to fecal coliforms and basic chemical indicators, according to WHO standards, 65.9% of the water sites tested were safe from coliforms bacteria contamination, 20.6 percent had intermediate-risk, 10.6 percent had high risk, and 2.9 percent had very high risk, and as such coliform contamination is the main water quality issue. However, addressing E.coli contamination with ongoing efforts of water treatment is needed to address this. Chea Sampson KP et al 2021, conducted a study on the Impact of constructing Septic Tank in close proximity to boreholes (groundwater), Liberia, results showed coliform contamination in four of the five samples taken, other parameters were in the World Health Organization (WHO) permissible limit. Charles JF et al 2020, evaluated the impact of flood on groundwater in hand-dug wells in Monrovia, Liberia, all the samples failed to meet WHO requirements. There were changes in E.coli and fecal contamination between the dry and rainy season and also turbidity, nitrate, lead, and other elements. Duwah YR 2020, did water quality mapping of Lofa River fecal coliforms level were high and also dissolved oxygen level. Another study conducted by Gibson SM 2019, evaluated landfill effects on soil and water sources, Whein town sanitary landfill, Montserrado County, Liberia, results showed that biochemical oxygen demand (BOD) and total dissolved solids (TDS) were higher than WHO permissible limits, heavy metal levels constituted contamination. Kamara M. 2019, assessed heavy metal pollution in soil and surface water in MNG Gold, Kokoya District, Bong County, Liberia, except for Iron, all the other heavy metals were below WHO permissible limit. All the physio-chemical parameters were below the WHO range. James M 2017, did spatial analysis of groundwater sources in Duport road (Shara and Cowfield) and Soul Clinic Diamond Creek Communities, Paynesville Liberia, coliform bacteria were found in 93% of groundwater infrastructures. Another study by Arno 2017 on Geochemical and Microbial Controls of groundwater in northwestern Liberia. E.coli was found in 39% of all groundwater sources tested, nitrate, arsenic, and lead surpassed WHO standards, and all the other parameters were within the acceptable range. Chea SKP et al 2017, did an analysis of selected physical and chemical parameters in drinking water samples collected from Cotton Tree community, Robertsfield Highway, Liberia,ph, turbidity, lead, zinc, and sulfate levels were all below WHO permissible limit and the presence of nitrate, phosphorus, and chromium at a high level. Mc Clain J et al 2017, did a Household water quality and management survey in Paynesville, Greater Monrovia. Results showed that Microbial contamination was introduced to drinking water due to poor water management at home. Furthermore, Abrampah,N.M, et al 2017 investigated improving water, sanitation, and hygiene in health facilities, in Liberia, results showed poor environmental management and as such, an improvement in water treatment, water quality testing, and health care waste management was necessary. Kumpel E, et al 2016, also investigated urban water services in fragile states: Analysis of drinking water sources and quality in Port Harcourt, Nigeria, and Monrovia, Liberia. 57% of the sources contained fecal Indicator Bacteria (FIB) and Nitrate in Liberia. Gleekia AM et 2016, investigated the impacts of iron ore mining on water quality, a comparative study of India and Liberia, results showed the presence of heavy metal contamination of surface and groundwater in the environment. Macpherson N et al 2015, also investigated the Environmental Pollution potential of the Burl Basin of Liberia, results showed that increase in subsistence farming, small-scale mining, logging, settlement construction, waste disposal, climate change, and population growth are threatening the rivers ability to support consumptive uses and the lack of well-defined water quality standard leads to resource exploitation. Farngolo, EM 2014 did a health assessment of mining activities on concession communities in Nimba County, Liberia, results showed Heavy metal (As, Hg, and Pb) contamination in water sources. Runkle KD et al 2013 investigated Public Health Policy options for improving well-water quality in West Point, Liberia, however, the presence of nitrate, nitrites, total coliforms, and E.coli at elevated levels. The author recommended that the installation of community latrines, covered wells with hand pumps or the provision of public water were Policy choices that could improve drinking water quality. According to studies (Dorko, 2018), mining activities have lowered surface water quality, which has been connected to environmental disasters and public health consequences. Mercury levels in drinking water around small-scale gold mining operations were up to 150 times higher than WHO guideline values in recent research (Dorko, 2018) in Cape Mount County and Bong County. Large-scale gold mining has also been linked to lower pH and increased cyanide concentrations (Dorko, 2018). Between 2015 and 2017, two massive chemical spills in the St. John River and Mafa River-Lake Piso Basins destroyed aquatic species, displaced communities, and poisoned drinking water supplies. (Dorko, 2018) The accident in 2017 released an estimated three million gallons of untreated mine tailings into Sien Creek (St. John River Basin), which Sayewheh Town relies on for drinking water (Senkpeni, 2020). Many of the 1,900 people were irritated by chemical irritants when bathing, and drinking the dirty water caused serious stomach problems. River dredging for gold and diamond mining, as well as the use of mercury in gold processing, were outlawed by the Ministry of Mines and Energy (MME) in 2019. Untreated sewage and solid waste are being discharged directly into critical wetlands near cities, damaging them. Wastewater treatment plants and large sewerage networks are rare in most urban areas. A minor sewerage system serves 30% of the population of Monrovia, although the Fiamah Wastewater Treatment Plant has been closed for more than 20 years (LWSC 2019), (AWF 2012). Outside of cities, solid municipal garbage is frequently dumped in makeshift landfills in saline wetlands, posing a hazard to surface water quality. Municipal waste and wastewater have seriously deteriorated the Marshall Wetlands in the Farmington River Basin and the Mesurado Wetlands in Monrovia (St. Paul River-Farmington River coastal drainage area). Water quality and watersheds are being degraded by the fast-developing agro-industrial sector.

Long-term agro-industrial concessions for rubber, palm oil, and logging, which cover more than 25% of the country and are present in all 15 counties, are affecting downstream water quality and biodiversity in freshwater wetlands and coastal mangroves, including Ramsar sites. (Gatter, W 1988), (USAID 2014). The Lofa, St. Paul, Cavalla, Timbo River, and St. John Basins have the most rubber concessions, while the Lofa, St. Paul, Sinoe, and Sehnkwehn Basins have the most palm oil concessions. Logging concessions are primarily located in the Cestos Basin and the higher portions of the Cavalla, Sehnkwehn, Dugbe, Grand Cess, and Dubo Basins (LHS 2016). Microbial contamination poses a wide range of dangers, according to limited drinking water quality studies. E. coli was discovered in all unprotected wells, 52 percent of protected hand-dug wells, and 44 percent of drilled wells in a 2011 investigation of groundwater quality in Monrovia. Similar investigations in Monrovia discovered significant levels of nitrates, which are most likely the result of inadequate sanitation. (Uhl 2011) Poor solid waste management and industrial pollution have also resulted in high levels of lead in Monrovia, Robertsport, Voinjama, and Sanniquellie. (USAID, 2012).

All the studies mentioned supra showed how freshwater quality has been reduced, most especially by coliform bacteria contamination, heavy metal contamination, and fecal indicator bacteria. These contaminations can be attributed to, inadequate sanitation systems, flooding, mining activities, and the fast-developing agro-industrial sector.

3.4 Freshwater Management in Liberia

Freshwater quality and management have been a key issue in Liberia since the 14 years of civil war. In Liberia, freshwater is being managed through a traditional water management system, wherein water quality monitoring tasks are shared among several institutions. This mechanism allows total involvement of the following institutions in addressing water quality and management. The National Water Resources and Sanitation Board (NWRSB) is in charge of water resources and sanitation. In 1980, the National Water Resources and Sanitation Board was established in response to the necessity for a coordinated strategy for water development. The Chairman was the Ministry of Lands, Mines, and Energy, and the Secretariat was the Liberian Hydrological Services. The board worked on coordinating all activities related to the development of water resources, reviewing sectoral rules, and creating Water Legislation and Policy. Although the board has ceased operations, it has not been formally dissolved. The Liberian Hydrological Service (LHS) Bureau serves as the Secretariat for the Ministry of Lands, Mines, and Energy, which is responsible for the general management of water resources and the issuance of water licenses. The Secretariat also coordinates the gathering and storage of hydrological data. It offers technical assistance to other government agencies and basic information on all elements of water resource development, including water quality concerns. Prior to the start of the civil war, the Ministry had monitored over 40 hydrometric networks through the Liberian Hydrological Service. The Liberia Hydrological Service is responsible for surface and groundwater quality and monitoring, however, water quality assessments that are comprehensive are scarce. In 1990, the hydro-meteorological network in Liberia completely broke down. Since 2010, with support from the Norwegian Water Resources and Energy Directorate (NVE), there were seven Liberians Liberia Hydrological Service staff that went under intensive hydro-meteorological training, and they are operating the hydro-meteorological network in Liberia since 2012. Both the Ministry of Health and Social Welfare (MOHSW) and the Ministry of Public Works (MPW) monitor the quality of drinking water. Ministry of Health and Social Welfare is responsible for water quality examinations, particularly for household water supply. The ministry establishes water quality and environmental health standards. The Environmental Protection Agency (EPA) is in charge of controlling and monitoring industrial effluent discharge, as well as coordinating environmental legislation across multiple ministries and developing water quality standards depending on water use. Despite the fact that most standards are still in the draft stage, the Liberia Environmental Protection Agency has adopted World Health Organization standards as interim drinking water quality standards until national standards are finalized. The Mano River Union (MRU) was originally established as a bilateral association between Liberia and Sierra Leone to manage the Mano River. However, The Mano River Union membership has grown to include Cote d'Ivoire and Guinea, and the organization now deals with Transboundary basin management for all rivers shared by its members.

3.5 Challenges Associated with Water Management in Liberia

According to findings challenges of water management in Liberia can be associated with Population growth in urban areas, Inadequacy of human resources capacities, uncontrolled disposal of waste, and water activities fragmented amongst ministries and institutions.

- Increase in population growth in urban areas- The population of Liberia's major cities is rising at an exponential rate, putting a strain on social services such as water supply and sanitation. In many circumstances, population increase puts significant strain on water resources. One of the most significant challenges in water resource management is reversing this tendency.
- The Inadequacy of human resources capacities -The management of water resources is hampered by a lack of suitably skilled water resources practitioners, particularly due to 'brain drain' in third-world nations, like Liberia. There aren't many opportunities for training.
- Water activities fragmented amongst institutions - Traditional water management and water quality

monitoring tasks are shared among several institutions.

- Uncontrolled disposal of waste-The uncontrolled disposal of garbage creates major problems for water resource management. The majority of these wastes are major polluters and drain system bloggers.

4.0 Conclusion

Based on findings from existing studies, it was deduced that freshwater quality has reduced over the past years and as such it is not at an optimal level, the quality of freshwater has been affected mostly by Coliform bacteria contamination, heavy metal contamination, and fecal indicator bacteria. These contaminations can be attributed to, inadequate sanitation systems, flooding, mining activities, and the fast-developing agro-industrial sector. Freshwater resources are being managed through a traditional water management system. Water quality management tasks are shared among several institutions. This mechanism allows total involvement of the line Ministries in addressing water quality and management. However, population growth in urban areas, the inadequacy of human resources capacities, and uncontrolled disposal of waste and water activities fragmented amongst ministries and institutions are challenges associated with freshwater management. To conclude, taking into consideration the results from the findings, a comprehensive freshwater quality assessment, particularly the physical, chemical, and biological variables is needed. An establishment of a proper waste disposal system, enforce monitoring of mining activities in concession areas, enforce monitoring of chemicals use in the agro-industrial sector and a single institution should be responsible for freshwater management and enforce monitoring, testing, and treatment of freshwater resources.

Reference

1. Chea, S KP et al 2021, Impact of Constructing Septic tank in close proximity to boreholes (groundwater) the cases of Kesselly Boulevard Community Montserrado County, Liberia. Global Journal for Research Analysis Volume 10 ISSN No. 2277 - 8160 DOI: 10.36106/

2. Charles JF, et al 2020, Evaluation of the impact of flood on groundwater in hand-dug wells in Monrovia, Liberia International Journal of Energy and Water Resources 4, 181–188 https://doi.org/10.1007/s42108-020-00060-x.

3. Duwah YR 2020, Water quality Mapping of Lofa River, (Doctoral dissertation, Indian Institute of Technology, Roorkee). Google Scholar

4. Gibson SM 2019, Evaluation of landfill effects on soil and water sources, Whein Town Sanitary Landfill, Montserrado County Liberia (Doctoral dissertation, University of Ghana). Google Scholar

5.Kamara M 2019, Assessment of heavy metal pollution in soil and surface water in MNG Gold, Kokoya District, Bong County, Liberia, African University of Science and Technology ((Doctoral dissertation). Google Scholar

6. Siqueria L et al 2018, Groundwater potential zone identification in the crystalline basement rock terrain of Liberia using integrated remote sensing and GIS. Revista Brasileira de Geografia Física 11.03 (2018): 988-994.

7. Mc Clain J 2017, spatial analysis of groundwater sources in the Duport (Shara and Cowfield) and Soul Clinic Diamond Creek Communities, Paynesville City, Republic of Liberia. International Journal of Scientific Research in Science and Technology 3, 1-12.

8. Weiyu Yu et al 2017, Integration of population census and water point mapping data, a case study of Cambodia, Liberia and Tanzania. International journal of hygiene and environmental health. Jul 1; 220(5):888-99.

9. Arno 2017, Geochemical and Microbial Controls of groundwater in Northwestern Liberia. (Doctoral dissertation, University of Nevada, Reno). Google Scholar

10. Chea SKP et al 2017, Analysis of selected physical and chemical parameters in drinking water samples collected from Cotton Tree Community, Robertsfield Highway, Liberia. EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH ISSN 4(2), 268-273 2394-3211.

11. Mc Clain J et al 2017, Household water quality and management survey, Paynesville, Greater Monrovia. International Journal of Scientific Research in Science and Technology. Volume 3 ISSN: 2395-6011.

12. Abrampah, NM et al 2017, Improving water, sanitation and hygiene in health-care facilities, Liberia. Bulletin of the World Health Organization.; 95(7), p.526.

13. Ministry of Public Works 2017, Water Point Mapping in Liberia

14. Jimoh.R.A RA et al 2016, Groundwater assessment in Buchanan County, Liberia using combined VLF-EM and Electrical Resistivity Method. International Journal of Advancement in Earth and Environmental Sciences Vol.4, No.2, 15-23 ISSN 2321 – 9149

15. Onafeso, OD et al 2016, Hydrogeological Deep percolation modelling of groundwater recharge in Voinjama Region, Liberia. Ethiopian Journal of Environmental Studies and Management, 9(6), pp.700-712.

16. Kumpel E et al 2016, urban water services in fragile states; Analysis of drinking water sources and quality in Port Harcourt, Nigeria and Monrovia, Liberia. The American journal of tropical medicine and hygiene, 95(1), p.229.

17. Gleekia AMGD et 2016, Impacts of iron ore mining on water quality, a comparative study of India and Liberia. Conference paper 6th ASIAN MINING CONGRESS (pp. 23-26).

18. N. Macpherson et 2015, Environmental Pollution Potential within the Burl River Basin of Liberia, West Africa. New Water Policy & Practice, 1(2), pp.32-45 Google Scholar

19. Farngolo, EM 2014, Health assessment of mining activities on concession communities in the Nimba County, Republic of Liberia (Doctoral dissertation Department of Community Health, College of Health Sciences, Kwame Nkrumah University of Science and Technology (Ghana) Google Scholar

20. Elster D et al 2014, an investigation of the basement complex aquifer system in Lofa County, Liberia, for the purpose of citing boreholes. Quarterly Journal of Engineering Geology and Hydrogeology, 47(2), pp.159-167.

21. Runkle KD et al 2013, public health policy options for improving well water quality in West Point, Liberia. World Medical & Health Policy, 5(4), pp.304-323.

22. Burt M et 2011, strengthening post-conflict peace building through community water resource management, case studies Congo, Afghanistan and Liberia. Water international, 36(2), pp.232241.

23. Liberia Hydrological Service (LHS)

24. Integrated Water Resource Management Policy of Liberia (2007)

25. United Nations Water (Progress update, water and sanitation for all) 2021

26. Ramsar Convention on wetland management in Liberia (2003)

27. United Nations Environmental Program (Unep) Desk Study on the environment in Liberia, Nairobi (2003)

28. Environmental Management Policy and Law, Republic of Liberia (2003) USAID, Environmental Profile of Liberia (2006)

29. Hall, Jr. et al, A Country report on Water Resources Assessment and Development Plan, 1988

30. Bunadin, J. Water Resources Development activities in Liberia 1987

31. Liberian Water Quality Standard

32. Liberia River Basin Report 2016

33. WHO&UNICEF Joint Monitoring Program 2020

34. Dorko, K. Environmental Impacts of Gold Mining in Liberia: A Case Study of New Liberty and MNG Kokoya Gold Mines; Monrovia, 2018

35. Senkpeni, A. Liberia: Cyanide Polluted Towns In Bong County Sue MNG Gold For US$285 Million In Damages https://frontpageafricaonline.com/ front-slider/liberia-cyanide□pollutedtowns-in-bong-county-sue-mng-gold-for-us285-million-in-damages/

36. Liberia Environmental Protection Agency. Guidelines for the Operation & Monitoring of Drinking Water Production; Monrovia, 2017

37. Liberia Water & Sewer Corporation. The Liberia Urban Water Supply Project: Environmental and Social Impact Assessment; Monrovia, 2019.

38. African Water Facility. Fostering Innovative Sanitation and Hygiene in Monrovia, Liberia; Abidjan, 2012.

39. Japan International Cooperation Agency; Yachiyo Engineering Co., L.; Katachira & Engineers International. The Master Plan Study on Urban Facilities Restoration and Improvement in Monrovia in the Republic of Liberia Final Report Executive Summary; Monrovia, 2009.

40. Gatter, W. The Coastal Wetlands of Liberia: Their Importance for Wintering Water Birds. International Council for Bird Preservation; UCBP: Cambridge, 1988.

41. USAID. Liberia- Environmental Threats and Opportunities; Washington, D.C., 2014. Trimble.

42. Siakor, S. Uncertain Futures: The Impacts of Sime Darby on Communities in Liberia; 2012.

43. Woods, R. Information Sheet on Ramsar Wetlands (RIS).

44. United Nations Mission in Liberia. Human Rights in Liberia's Rubber Plantations: Tapping into the Future; Monrovia, 2006

45. Uhl, V.; Daw, A.; Baron, J. How a City Gets Its Drinking Water A Case Study - Capital City of Monrovia , Liberia; Lambertville, 2011.

46. USAID. Situational Analysis Report: Liberia Municipal Water Project; 2012