Journal of Positive School Psychology http://journalppw.com
2022, Vol. 6, No. 7, 3072-3094

Wastewater Reuse In Monrovia: A Potential For Reducing Urban Water Stress & Promoting Environmental Sustainability

Ansumana Abraham Bility[1] , Fidan Aslanova[2] ., Gözen Elkiran[3]

[1,2]Department of Environmental Science and Engineering, Faculty of Civil and Environmental Engineering, Near East University, Mersin 10 Turkey

[3]Department of Civil Engineering, Faculty of Civil and Environmental Engineering, Near East *

Corresponding email: ansumanaability@gmail.com

Abstract As the world's water crisis heightens due to human-induced climate change and unchecked population growth, nations must adopt smart technologies that reduce the pressure on the planet's finite freshwater resources. Monrovia, the capital of Liberia, is regarded as one of the wettest cities globally, with an average annual precipitation of about 4,624mm. However, this massive capital drain has proved insignificant in making the city water-secured. Due to the low elevation (about 10m) and surface water contamination resulting from routine sea intrusion and the use of surface water bodies as toilets by residents, people rely on groundwater sources like hand-dug wells for drinking, sanitation, and urban garden irrigation. After considerable investment in the renovation of the White Plan Water Plant by donor partners, the facility that should provide water for at least all residents of the capital has an output of less than 30% of the total water demand. As the world races for a sustainable solution to the available freshwater crisis considering the rapid decline in quality and quantity, developing countries, as expected, lag behind their developed counterparts in the area of devising new and efficient technologies that address this problem—considering Liberia's vast hydrological potential, adopting and implementing a water treatment technology as ceramic membrane filtration boasts the country's chances of being water-secure in the short and long run. This paper reviews Liberia's existing water infrastructure, examines the challenges, and proffers evidence-based solutions to address the looming crisis of water insecurity. Membrane water treatment is a method of purifying water by removing impurities that would otherwise be present and carry the potential to cause harm to humans and other forms of life. The tiny pore sizes of the membrane filtration instruments can remove the tiniest substances from effluent, thus, making it safe for reuse in homes. Membrane technology has been effectively employed in centralized and decentralized waste reuse. The final use of treated water determines the degree of water quality and the membrane technique required. Microfiltration (MF) and Ultrafiltration (UF) are often employed to create low suspended particles and turbidity fluids. Membrane Bio-Reactors (MBR) are utilized for direct wastewater treatment since they produce low nutrient effluents. In sophisticated wastewater post-treatment applications like groundwater injection for indirect potable reuse or sensitive industrial uses, nanofiltration and reverse osmosis membranes are employed. This paper proposes the ceramic membrane filtration method due to its cost and energy efficiency in treating effluent. The operation is crossflow, thus making it more environmentally sustainable than other wastewater treatment methods. Crossflow operation, as opposed to the dead-end process, allows for longer filtering cycles since the strain acting on the membrane as the fractionating column flows across it helps to reduce membrane fouling. By-products can be utilized for energy generation as biogas, manure for crop production in agriculture, and landscape irrigation for recreational purposes.

Keywords: Water Stress, Environment, Environmental Sustainability, wastwater treatment technology

1. Introduction

As the world's water crisis heightens due to human-induced climate change and unchecked population growth, nations must adopt smart technologies that reduce the pressure on the planet's finite freshwater resources. Water has been the source of all known human civilizations and remains an indispensable element of life and the attending activities such as food production, industrial activities, energy production, etcetera. Water is essential for life. This priceless resource is in a limited amount even though our potential to grow and demand more is insanely infinite. As reported in a recent United Nations report, clean water is critical for human development; nevertheless, more than 1 billion people globally are said to lack access to safe drinking water, and 2.6 billion lack basic sanitation. Poverty, inequality, and ineffective water management regulations all contribute to this catastrophic scenario (Duong, 2015). The problem is humanity's disregard for non-human entities like plants and animals. The sustenance of the hydrological cycle is vital for the survival of the world's ecosystem, which supports humans and non-human entities.

The world's cities are the most vulnerable to present and future water stress incidences. Cities are increasingly becoming congested by the day. A United Nations project indicates an increase in the global urban population to approximately 6.68 billion by 2050 (Niva, V. et al., 2019; United Nations, 2019). This crisis intensifies even more for cities in the global south due to resource and policy planning fragilities. A decade of research has revealed that water is scarcer in Africa than in Europe, Asia, North America, or Latin America; population growth will lower per capita water availability, and conflict or collaboration may follow as national and international water consumers struggle for a restricted resource.

According to another report by the United Nations, 2.1 billion people will live in cities in the developing world by 2030 (Drechsel et al., 2015). Wastewater or greywater treatment has proven to have great potential in alleviating humanity from the crisis of water shortage in recent decades. Liberia may be one of the wettest countries in the world (World Bank, 2021), access to safe, clean, and quality water for potable and sanitation use remains a challenge (UNICEF, 2017). As Monrovia faces its highest rate of urbanization since its founding, the water crisis will intensify and affect all facets of livelihood. This research reviews thirty scholarly pieces of literature on the use of ceramic membrane filtration in wastewater treatment for portable and other services as a potential for the growing water demand in Monrovia.

1.1 Problem Statement

The world's available freshwater is finite. The growth potential of the human population is infinite.

As we (humans) grow in population, the demand for freshwater to meet our needs grow exponentially. Urban areas are poised to be affected more by these water shortages. Monrovia's population has experienced a steady annual growth of 2.4% since the war ended in 2003 (United Nations- World Population Prospect, 2016). Monrovia city is home to about two million people now. This increase further deepens the woes of inadequate access to safe drinking water and sanitation. According to the Joint Monitoring Project 2017, fewer than ten percent of Liberians have access to securely regulated drinking water and sanitation facilities (UNICEF, 2017; JMP, 2017). Monrovia may be one of the wettest cities globally; the primary portable water source is groundwater. Nearly all surface water bodies are contaminated by regular ocean intrusion and semi-industrial activities, thus making them unsafe for consumption purposes. Greater Monrovia experiences enduring water scarcity during mid-dry seasons (December-February). Residents are seen in long queues to get at least a gallon to their homes for drinking.

1.2 Research Significance

As the world races for a sustainable solution to the available freshwater crisis considering the rapid decline in quality and quantity, developing countries, as expected, lag behind their developed counterparts in the area of devising new and efficient technologies that address this problem—considering Liberia's vast hydrological potential, adopting and implementing a water treatment technology as ceramic membrane filtration boasts the country's chances of being water-secure in the short run. Among the several wastewater treatment methods available, membrane filtration has shown to be one of the most intriguing due to its high efficacy, low cost, and ease of operation (Hongtao et al., 2012). This technological transition will abreast public policymakers with the roadmap for sustainable water reuse in Liberia.

1.3 Research Methodology

To have a full grasp of the subject, a comprehensive literature review was conducted for almost 60 scholarly indexed journals from Google Scholar, Jstor, SpringerLink, and ScienceDirect, to determine the most effective wastewater treatment method for reclaiming polluted or contaminated water. The search was conducted using criteria such as author(s) reputation and subject matter understanding, institution’s profile in wastewater treatment, and journals’ impact factor ranking. Searches were conducted using keywords: wastewater treatment, effluent treatment technology, wastewater reuse in agriculture, and ceramic membrane filtration. The excel spreadsheet was used to do a qualitative content analysis of the 60 published materials to identify gaps.

20 Major Water Source in Monrovia

Monrovia is situated along the coast, on the peninsula of Mesurado, between the Atlantic Ocean and the Mesurado River, the mouth of which provides a vast natural port. Monrovia has a tropical monsoon climate, according to the Köppen climate classification (Am). It is the wettest capital city globally, with an average annual rainfall of 4,624 millimeters (182.0 in). In the context of water security, both quantity and quality matter. However, this massive capital drain has proved insignificant in making the city water-secured. Due to the low elevation (about 10m) and surface water contamination resulting from routine sea intrusion and surface water bodies as toilets by residents, people rely on groundwater sources like hand-dug wells for drinking, sanitation, and urban garden irrigation. The Liberia Water and Sewer Corporation (LWSC) has proven ineffective since the postwar era due to the rapid growth in the urban population and limited budgetary support from the national government. According to the Joint Monitoring Project 2017, fewer than ten percent of Liberians have access to securely regulated drinking water and sanitation facilities (UNICEF, 2017; JMP, 2017).

2.1 Challenges in Ensuring Improved Urban Water and Sanitation in Monrovia

Several factors are responsible for the gross water insecurities in Monrovia, ranging from poor drainage systems to improper waste management. Riverline flooding compounds the problem. Charles et al. (2020) used a two-tailed Student T-test to determine the effect of flooding on groundwater quality in Monrovia during the dry and wet seasons. They observed an increase in pollution levels from the dry to the wet season. All water samples analyzed failed to meet appropriate World Health Organization (WHO) standards for safe drinking water, implying that water samples from these sources are unfit for human consumption. Most of the wells are uncovered. Due to Poor drainage systems, surface runoff collects and dumps uncollected wastes, contaminants, and loose earth materials into the wells. Unmaintained sewage pipes damaged due to the over-crowdedness of the city constantly leak fecal materials into waterways for surface water and contamination of the water table for groundwater sources of water. Assessing urban water sources and qualities in two cities: Port Harcourt, Nigeria, and Monrovia, Liberia, Kumbel et al. found that out of a total of 204 water access points in Monrovia, 57 percent of the samples in Monrovia had E. coli concentrations of less than 1 MPN/100 mL, and 19 percent had concentrations of more than 100 MPN/100 mL (N = 204). More than 200 samples (N = 204) exceeded the standard for nitrate in Liberia, 40 mg/L. Almost all samples (97 percent, N = 204) had low TDS concentrations (less than 500 mg/L) for fluoride. Samples with a low pH (less than 6.5) were found about 80% of the time. These microbes create health problems like cholera outbreaks and hot tub rash for most people living in poor neighborhoods who cannot afford to purchase semi-treated sachet water. Another challenge worthy of mention is the lack of data on 1) urban water quality and quantity, 2) daily water demand and supply, and 3) Data on treated wastewater. The absence of such vital data limits the potential of researchers to make accurate inferences. In most nations, regular statistics on water quality are not gathered. This indicates that over 3 billion people are in danger due to a lack of knowledge about the health of local freshwater ecosystems (UN-Water, 2021).

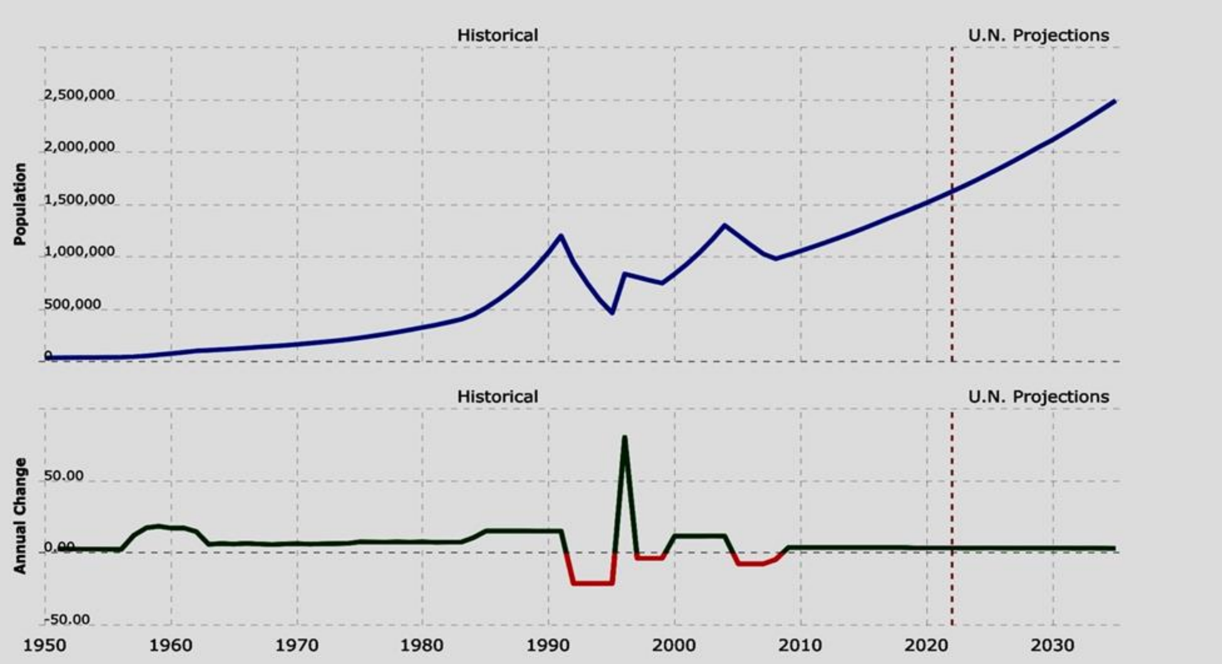


Figure 1 Population growth trend for Monrovia between 2003-2022 *(Source: https://population.un.org/wpp/)*

2.2 Wastewater Treatment Plant in Monrovia

There were no records left of the wastewater treatment facility in Monrovia after 14 years of conflict since it had been destroyed and the bulk of the pipes had crumbled. Through financial assistance from the African Development Bank, in addition to funding capacity building for Liberia Water and Sewer Corporation, a rehabilitation of the White Plains plant, which previously supplied only 4.5 million gallons of freshwater per day against a daily demand of 32 million gallons, was commissioned to increase distribution to 16 million gallons per day (Oirere, 2014). Up to the period this research review commenced, there had been no wastewater treatment plant designed and operated by the Liberia Water and Sewer Corporation, LWSC, the primary entity clothed with the responsibility for the collection, treatment, and distribution of potable water to every household within and outside the limits of the capital. The only presence of wastewater treatment sites is mini TFCs operated by mining companies to treat effluent from unstainable mining practices. Most of these treatments are unsafe and the discharge effluents are never tested to ensure environmental health and safety. However, there is enormous resource potential for constructing and operating a wastewater treatment plant in Monrovia. The city is well-drained with high annual precipitation and massive river flow. Treating contaminated wastewater using membrane filtration offers enormous potential for reducing the city’s water stress during the mid-dry season. Up till recently, the White Plant has been under renovation for almost two decades since the end of the war. The World Bank, via its subsidiary the International Development Association (IDA), contributed $30 million in loans and grants to Liberia's Urban Water Supply Project (UWSP) in June 2019 (Takouleu, 2019). A great deal of said money was used to rehabilitate a drinking water plant that provides for less than 20% of total urban dwellers.

Figure 2 New Pump installed at White Plain to boast water supply to Monrovia *(Source: https://www.afrik21.africa/wp-content/uploads/2019/09/shutterstock_1386912593-1-800x400.jpg).*

2.3 Wastewater Treatment

Wastewater is a complex matrix including substantial amounts of particles (total solids 350–1200 mg/l), dissolved and particulate matter (chemical oxygen demand 250–1000 mg/l), microbes (up to 109 number/ml), nutrients, heavy metals, and toxic elements (Warwick et al., 2013). The mixed concentration of different materials makes wastewater reuse a critical subject in ongoing global efforts to curb the growing water insecurities. The direct proportionality of population growth and resource demand clearly explains the rationale for wastewater reclamation. Water being the most essential of resources needed for the continuing of life, safeguarding the finite amount available has become a critical issue for governments, industries, and NGOs alike. The problem is that water demand is rapidly exceeding supply- thus, creating imbalances that result in routine water stress in arid and semi-arid regions of the world. In response to the growing issue of water scarcity exacerbated by population increase and global warming, purified urban wastewater is now commonly reused and regarded as a dependable alternative supply of water (Kummerer, 2015). Reclaimed wastewater through wastewater treatment can be utilized in agriculture irrigation, landscape irrigation, industrial recycling, groundwater recharge, and portable water supply. The capacity to get safe and adequate water supplies is intricately tied to how wastewater is handled and treated (UN Water, 2021). The majority of issues associated with water quality are produced by intensive agriculture, industrial production, mining, and untreated urban runoff and wastewater, among other things (UN Water 2011). Municipal wastewater and sludge include essential resources such as water, organic matter, energy, and nutrients (e.g., nitrogen and phosphorus) that may be recovered for various economically, socially and environmentally beneficial applications. However, due to a lack of worldwide data on these waste flows, the overall quantity of resources recovered for good purposes has not been estimated accurately (Pay et al., 2015.

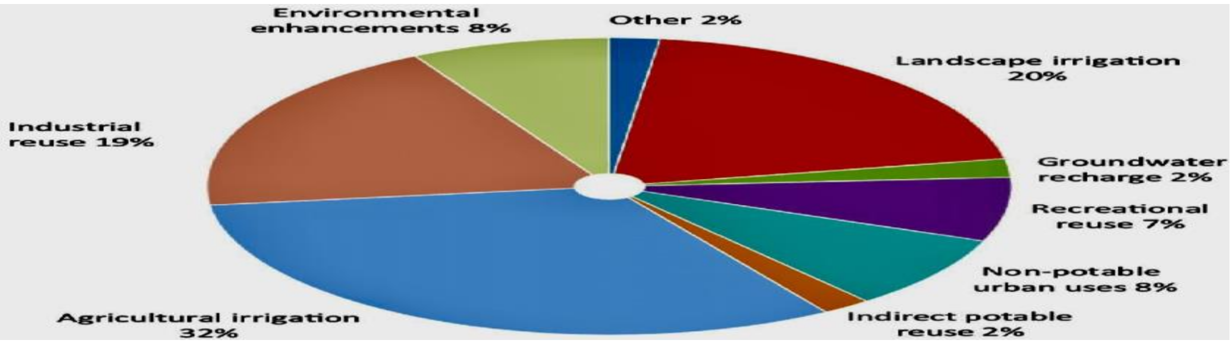
Different methods of wastewater treatment are available. However, the technological cost of the most efficient ones scares away most developing countries. As a result, these countries constitute the highest water-borne disease prevalence. Numerous water-borne illnesses, such as cholera and schistosomiasis, continue to be prevalent in many developing nations, where only a tiny proportion (in some instances less than 5%) of home and urban wastewater is treated before discharge into the environment (UN WWDR, 2017. Of all the resue options for wastewater, agriculture accounts for the most. Wastewater has a high concentration of nutrients. Hence, it has a significant potential for use in agricultural irrigation since it feeds crops with organic carbon, nutrients (NPK), and inorganic micronutrients (Ungureanu et al., 2020).

2.4 Wastewater Reuse

Water used by households (domestic wastewater), industries (industrial wastewater), or agricultural activities is considered wastewater. The United States Environmental Protection Agency (2012), water reuse is the use of treated municipal wastewater. Wastewater comprises dissolved organic and inorganic matters. The composition of typical wastewater is a complex matrix including substantial amounts of particles (total solids 350–1200 mg/l), dissolved and particulate matter (chemical oxygen demand 250–1000 mg/l), microbes (up to 109 number/ml), nutrients, heavy metals, and toxic elements (Warwick et al., 2013). As the finite deposit of global freshwater diminishes in quantity and quality, the need to adopt water reuse technologies has become a human necessity. Water shortage is becoming a concern as the world's population grows and climate change causes more droughts. This situation worsens in arid and semi-arid regions. Social and health concerns, declining agricultural yields, influence on industrial productivity, conflicting land uses, fires, and desertification all pose dangers to these nations if they cannot develop adequate solutions. In certain locations, reusing wastewater is a no-brainer. The capacity to get safe and adequate water supplies is intricately tied to how wastewater is handled and treated (UN Water, 2021). The resources contained in the roughly 330 km3/year of urban wastewater created worldwide would potentially be sufficient to irrigate and fertilize millions of hectares of crops and produce biogas to power millions of houses (Mateo-Sagasta et al., 2015). Continuously improving and lowering the cost of wastewater management enables pollution reduction and clean water supply expansion while fostering sustainable development and assisting in the transition to a circular economy (Jones et al., 2021). Though the treatment and reuse of effluent water have gained significant global attention, acceptability varies across sectors and regions. In most developing countries, wastewater is used without any pre-treatment. Wastewater use is the purposeful or inadvertent use of untreated, partly treated, or mixed wastewater that does not follow a regulatory framework or methodology that ensures the resultant water is safe for the intended use. Treated wastewater can be used in agricultural areas like irrigation water, landscape irrigation, environmental and recreational uses, industrial reuse, domestic use, and portable use.

Several factors drive the use of wastewater across regions. Water reuse results from the restricted water supply in North America (Goyal & Kumar, 2021; Diemer, 2007) and high agricultural demand in South America (Goyal & Kumar, 2021; Jiménez, 2008). Cities, salinization, and climate change are key drivers in Europe. Australian water reuse is driven by industrial, urban, and agricultural requirements and greener technology (Goyal & Kumar, 2021; Po et al., 2003). Water scarcity, water quality degradation, climate change, and food security are driving the reuse of treated water throughout the Middle East, Africa, and Asia (Goyal & Kumar, 2021; Bahri, 2008; Hamoda, 1996; Visvanathan, 2018). In Africa particularly, the wastewater industry remains significantly untapped. This impediment results from several factors ranging from the absence of policy to the lack of technological infrastructure for wastewater treatment. Urbanization is rapidly taking shape on the continent as the UN projects that an additional 2.3 billion people will live in African cities by 2030. This increase in urban population proportionately increases pressure on existing urban infrastructure. Many African cities are structurally unplanned with little or no existing water infrastructure. Most wastewater reused in the developing world is unplanned and poorly managed. Numerous water-borne illnesses, such as cholera and schistosomiasis, continue to be prevalent in a large number of developing nations, where only a very tiny proportion (in some instances less than 5%) of home and urban wastewater is treated prior to discharge into the environment (UN WWDR, 2017). The highest increases in pollution exposure are predicted to occur in low- and lower-middle-income countries, owing to these nations' greater population and economic growth rates, particularly in Africa (UNEP, 2016a), and the absence of wastewater management systems (UN WWDR, 2017). The food manufacturing industry dominates as indicated in Figure 3, in total global freshwater withdrawal and leads in the water reuse sector utilizing more than 30% of total reclaimed water. The surge in the human population will increase food demand considerably, thus leading to increased pressure on available freshwater.

Figure 3: Wastewater Reuse by Sector *(Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FPotential-wastewater-reuse-per-sector-Lautze-et-al-2014-Many-groundwater-aquifers_fig5_351222997&psig=AOvVaw1QpAP9iQOyWIFcjsMSKHJ2&ust=1649588071433000&source=images&cd=vfe&ved=0CAoQjRxqFwoTCJjYlMvohvcCFQAAAAAdAAAAABAD)*



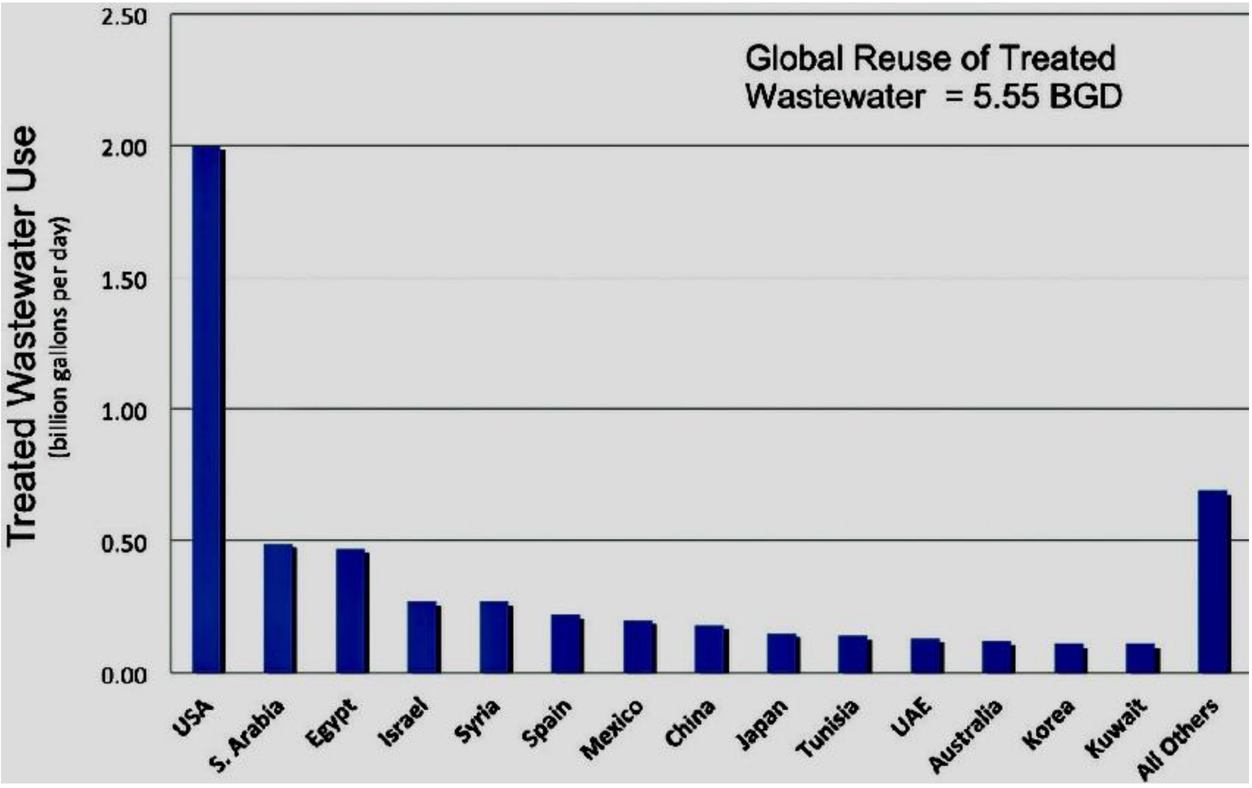


Figure 4: Global Wastewater Reuse By Country Globally
(Source:https://www.researchgate.net/profile/Naeem-Khan-4/publication/326587892/figure/fig6/AS:652181543849985@1532503605353/Reuse-of-wastewater-per-day-in-different-countries-of-the-world.png

As indicated in Figure 4, the most developed societies, such as the United States, with the resource capacity to fund leading innovations in the wastewater industry, tops the list for wastewater use per country, using approximately 2 billion gallons a day.

2.5 Wastewater Reuse for Irrigation Agriculture

As indicated in Figure 3, the sector with the most use of global wastewater is agriculture, utilizing more than 30% of total treated water globally. The global population growth trend will continue to exacerbate the global water crisis by increasing the demand for water for food production. Farmers are increasingly interested in non-traditional water resources, mostly wastewater, for a variety of reasons, including the high nutritional content of wastewater and the scarcity of conventional water supplies. Wastewater, when used appropriately, may be a useful source of both water and nutrients, helping in water and food security, and improved livelihoods. Despite the accompanying health and environmental dangers, wastewater is widely utilized as an affordable alternative for conventional irrigation water, sustaining livelihoods and adding substantial value to agriculture in urban and periurban regions (Ivan, 2018). Since its formation, Liberia has operated, though apparently, as an agrarian economy. Agriculture, including forestry, is the principal source of income for more than 60% of Liberia's population and accounted for 31% of Liberia's actual gross domestic product in 2020. It offers nourishment for a large number of families engaged in the cultivation of cassava, rubber, rice, oil palm, cocoa, or sugarcane. Rice and cassava are the two staples consumed in Liberia. However, due to the country's over-dependence on rainfed agriculture, productivity has been decima since the prewar era. Though blessed with abundant water resources, stretching across its shores, farmers rely almost entirely on rainfed agriculture for crop production. The routine interchange of the rainy and dry seasons makes rice a perennial crop. Tapping the country's vast surface water potential through wastewater reuse offers a greater chance of reducing input, creating local food security, and enhancing economic growth. The table below shows the cultivation of rice in Liberia and the sector's over-dependence on rainfed cultivation.

Table 1: Cultivation of different varieties of rice in Liberia under different ecological conditions (https://www.fao.org/3/Y4347E/y4347e12.htm)

Variety Name	Ecology	Growth duration (days)
IR 5	Rainfed lowland	135-140
ITA 212	Rainfed lowland	130-135
ITA 222	Rainfed lowland	130-135
ITA 306	Rainfed lowland	110-115
KUATI KUNDOR	Rainfed lowland	NA
MAHSURI	Rainfed lowland	125
ROK 10	Rainfed lowland	140-150
ROK 14	Rainfed lowland	
ROK 3	Rainfed lowland	125-135
SUAKOKO 12	Rainfed lowland	
SUAKOKO 8	Rainfed lowland	140-145
ROK 5	Tidal wetland	140-145
IDESSA 6	Upland	110-120
IRAT 133	Upland	115-125
LAC 23	Upland	135-140
MOROBEKAN	Upland	145
OS 6	Upland	130-135
WAB 32 80	Upland	NA
WAB 56 125	Upland	NA
WAB 56 50	Upland	NA
WAB 56-104	Upland	

WAB 56-50	Upland	
WAB 96-1-1	Upland	
WABIS 18	Upland	NA
WABIS 550	Upland	NA
WABSOKA	Upland	NA

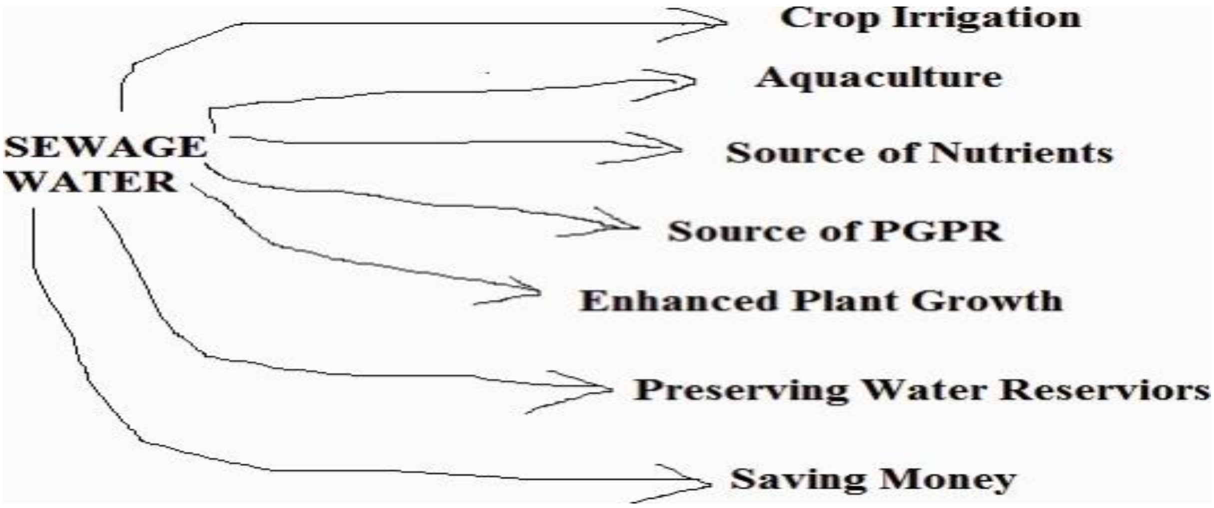


Figure 5: schematic of benefits of using treated sewage water in irrigation (Source: https://www.researchgate.net/profile/Naeem-Khan-4/publication/326587892/figure/fig2/AS:652181543874560@1532503605018/Impacts-of-sewage-water-irrigation-on-plants-and-freshwater-reservoirs.png)

Wastewater carries a huge nutritional potential for plant growth, as illustrated in Figure 5. PGPRs, otherwise known as Plant Growth-Promoting Rhizobacteria, have treatment microbes that enhance crop growth. Effective resource utilization is key to aggregate economic growth and development for a low-income country like Liberia. Wastewater treatment guarantees cash-saving and preservation of vital reservoirs.

3.0 Available Technologies for Wastewater Treatment

As the global freshwater crisis compounds, the wastewater industry grows dramatically in correspondence. According to the World Economic Forum, the worldwide water, and wastewater treatment market was valued at 263.07 billion U.S. dollars in 2020 and is expected to reach a value of over 500 billion U.S. dollars by 2028, growing at a compound annual growth rate (CAGR) of 7.3 percent between 2021 and 2028 (Global Water & Wastewater Treatment Market Size 2020 | Statista, n.d.). This remarkable swell in market size for the wastewater sector can be squarely attributed to the huge operational cost of treatments plants and the technological advances accompanying the growth. These technologies have evolved to meet the growing water demands of humanity. The use of a specific technology is dependent on the type of wastewater (Industrial, municipal, or agricultural) and the intended area of reuse after treatment. Decontamination entails processes and activities that use physical, chemical, and/or biological methods to remove solids from effluents, including colloids, organic matter, nutrients, and soluble pollutants (metals, organics, and other contaminants). Insomuch the sector is experiencing rapid growth, low-income countries still lag in developing and operating cost-effective wastewater treatment plants to ensure water security. Selecting the appropriate technology poses another challenge to most countries aspiring to venture into this industry. National, regional, and municipal policymakers have difficulty in selecting suitable wastewater treatment technologies that support sustainable growth (Kalbar et al., 2012). Each treatment method is constrained by its own set of restrictions, including cost, feasibility, efficiency, practicability, dependability, environmental effect, sludge generation, operating difficulties, pre-treatment needs, and the development of potentially harmful byproducts (Crini & Lichtfouse, 2018).

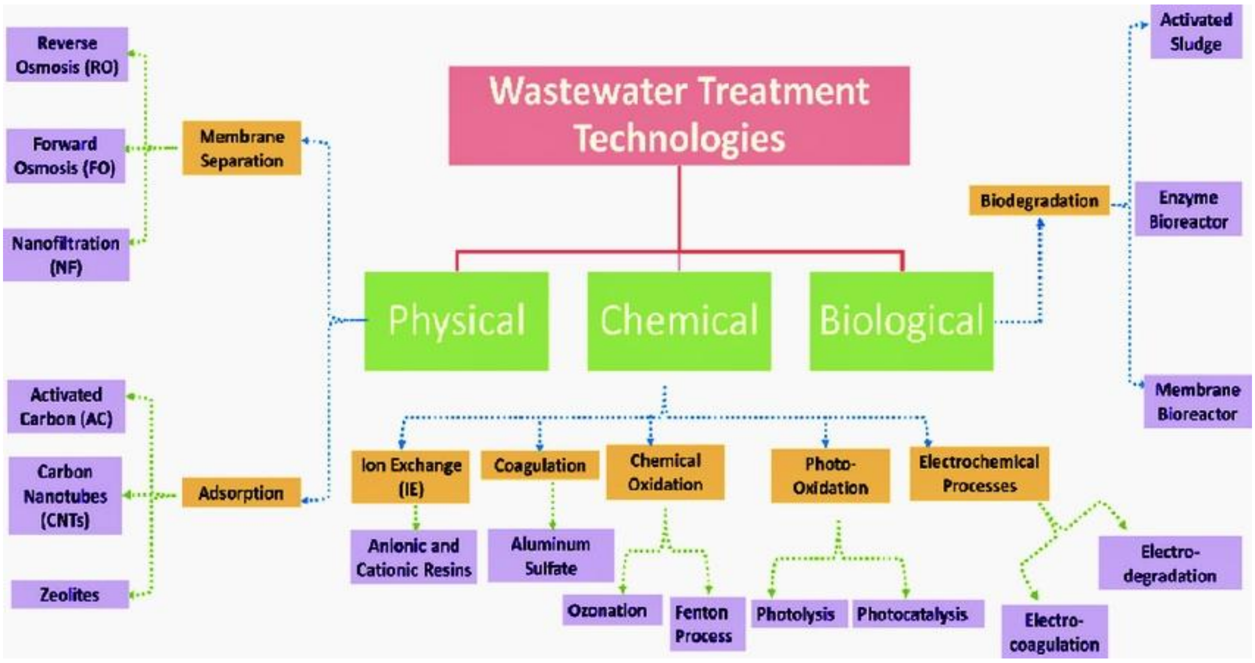


Figure 6: Schematic of Available Wastewater Treatment Technologies(Source: *https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FClassification-of-wastewater-treatment-technologies_fig1_343791923&psig=AOvVaw3WeIuZC9cfZXASiHhLxWlQ&ust=164959*)

3.1 Membrane Filtration in Wastewater Treatment

As the name depicts, membrane filtration utilizes membrane-like materials that allow the passage of some materials while blocking others. The membranes are mimicked after animals' bladders like pigs and fish guts. The human body and much of nature rely on membrane filtration to accomplish various activities, including controlling the cellular environment and excreting waste materials (Madsen, 2014). Membrane water treatment is a method of purifying water by removing impurities that would otherwise be present and carry the potential to cause harm to humans and other forms of life (Nemeth-Harn, 2020). Membrane filtration has emerged as one of the most promising methods for the improved treatment of secondary effluents, and it is currently being researched by many scholars and policymakers (Zho et al., 2012). When it comes to the treatment of wastewater and resource recovery, membrane filtration has demonstrated tremendous potential, particularly in terms of excellent treated water quality, efficient nutrient recovery, and long-term operation, particularly in situations where biological treatment is not viable (Hube et al., 2018). Membrane filtration in the wastewater treatment industry has become an admired renascence due to its adaptive potential to integrate with other forms of wastewater treatment. While bioelectrochemical systems (BES) are an energy-efficient wastewater treatment method, the effluent still needs additional treatment before being discharged or reused. However, by incorporating membrane filtering into BES, high-quality effluents with other advantages may be achieved (Yaun & He, 2015). Membrane filtration is becoming more popular because it can reduce unnecessary costs (by being energy efficient) and transfer concerns associated with modern technological advancements. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis are some of the membrane filtration methods that have been researched (RO).

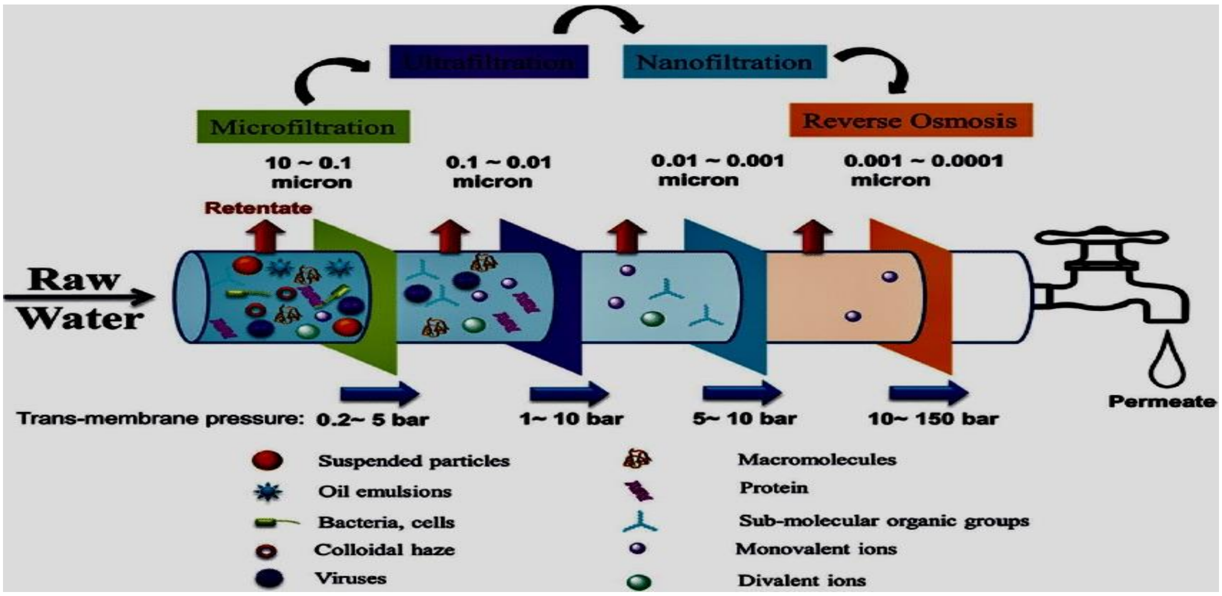


Figure 7: Pore Sizes of Different Membranes *(Source: Retrieved from google image: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure %2)FPressure-driven-membrane-processes-for-water-treatment-technologies-showing-the_fig 2_328882399&psig=AOvVaw0qUHezeaXcn0E5nme3LrJ6&ust=1648640231503000&source =images&cd=vfe&ved=0CAsQjRxqFwoTCOivgtOd6_YCFQAAAAAdAAAAABAJ)*

The tiny pore sizes of the membrane filtration instruments can remove the tiniest substances from effluent, thus, making it safe for reuse in homes. Membrane technology has been effectively employed in centralized and decentralized waste reuse. The final use of treated water determines the degree of water quality and the membrane technique required. Microfiltration (MF) and Ultrafiltration (UF) are often employed to create low suspended particles and turbidity fluids. Membrane Bio-Reactors (MBR) are utilized for direct wastewater treatment since they produce low nutrient effluents. In sophisticated wastewater post-treatment applications like groundwater injection for indirect potable reuse or sensitive industrial uses, nanofiltration and reverse osmosis membranes are employed.

3.2 Ceramic Membrane Filtration

The ceramic membrane filtration method is a water filtration system that produces clean, clear tap water by removing pollutants (bacteria and protozoa such as Cryptosporidium) and turbidity from raw water sources such as river systems and wells (METAWATER). Ceramic membranes can be produced from both aluminum and clay. Aluminum has been the chief raw material for the production of ceramic membranes. However, later research suggests how cost-effective clay can be in the design and operation of ceramic membranes. The use of low-cost ceramic membranes made of kaolin has sparked considerable attention due to their superior mechanical stability, chemical and heat resistance, and, most crucially, their cost-effectiveness in certain circumstances compared to polymeric membranes (Khadijah et al., 2017). The operation is crossflow, thus making it more environmentally sustainable than other wastewater treatment methods. Crossflow operation, as opposed to the dead-end process, allows for longer filtering cycles since the strain acting on the membrane as the fractionating column flows across it helps to reduce membrane fouling (Zsirai et al., 2016). Due to its tiny pore size (not more than 0.1µm), it is classed under the microfiltration category of membrane technology. The way Membranes are carefully thought out, planned, and executed may save capital costs and chemical consumption and need minimum maintenance. Due to their durability to harsh working circumstances and cleaning processes, ceramic MF membranes are progressively replacing organic and polymeric membranes in the drinking water and wastewater treatment sectors (Hakami et al., 2020). In general, ceramic membranes outperform polymeric membranes in mechanical strength, endurance against severe chemical cleaning processes, suitability for hot environments and slurries containing hard suspended materials, and resistance to biological corrosion (Park et al., 2014). Such technologies, as argued, are best suited to harsh weather conditions.

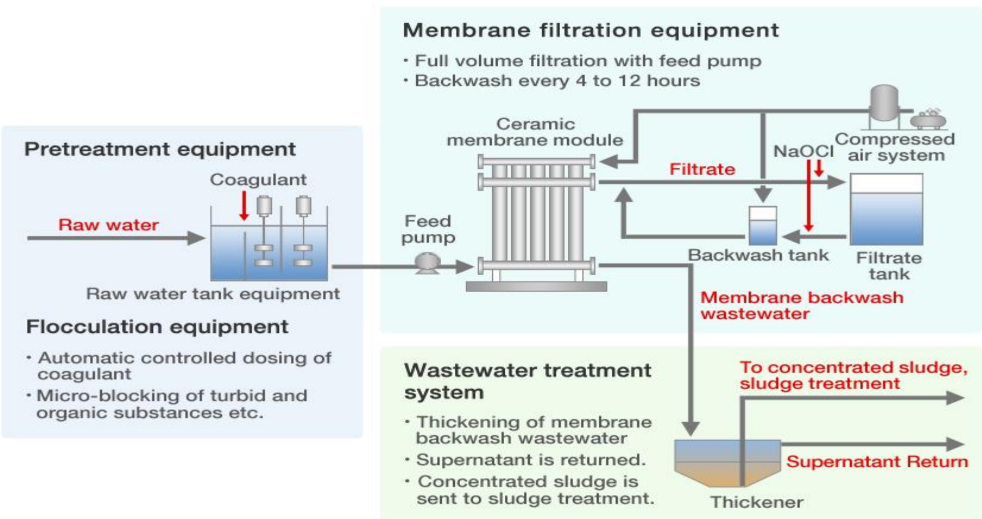


Figure85: A Diagram of The Ceramic Filtration Process in Wastewater Treatment (*Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.metawater.co.jp%2Feng%2Fsolution%2Fproduct%2Fwater%2Fmembrane_clarify%2F&psig=AOvVaw1cPOucvMULYSakGpyM8vbU&ust=1648712574902000&)*

4.0 Discussion

4.1 Liberia's Water Infrastructure and Challenges

Liberia's massive drain in high precipitation and numerous surface water bodies has not translated to making the country water-secured. The Liberia Water and Sewer Corporation (LWSC) has proven ineffective since the postwar era due to the rapid growth in the urban population and limited budgetary support from the national government. Through financial assistance from the African Development Bank, in addition to funding capacity building for Liberia Water and Sewer Corporation, a rehabilitation of the White Plains plant, which previously supplied only 4.5 million gallons of fresh water per day against a daily demand of 32 million gallons, was commissioned to increase distribution to 16 million gallons per day (Oirere, 2014). This leaves a gap of more than half unmet demand for portable water on a daily basis. According to the Joint Monitoring Project 2017, fewer than ten percent of Liberians have access to securely regulated drinking water and sanitation facilities (UNICEF, 2017; JMP, 2017). This figure could be worse given the annual average population growth of 2.5% since the end of the civil war (Figure 1). Charles et al. (2020) used a two-tailed Student T-test to determine the effect of flooding on groundwater quality in Monrovia during the dry and wet seasons. They observed an increase in pollution levels from the dry to the wet season. All water samples analyzed failed to meet appropriate World Health Organization (WHO) standards for safe drinking water, implying that water samples from these sources are unfit for human consumption. Wastewater treatment for consumptive and non-consumptive purposes remain non-existent. Monrovia receives the highest proportion of Liberia's annual rainfall on average (approximately 2700mm). This massive downpour in addition to the stretch of surface water bodies throughout the city offer great potential for water reclamation to ensure water security. **Table 1**, shows liberia's over dependence on rainfed agriculture- something contributing significantly to the low agriculture output of the country. Wastewater water reclamation can ensure water is readily available for urban garden irrigation and other forms of crop production without season.

4.2 Global Trend for Wastewater Treatment and Reuse

The global wastewater industry is fast growing due to increasing pressure on available freshwater resources exacerbated by climate change, population growth, and rapid economic development. According to the World Economic Forum, the worldwide water, and wastewater treatment market was valued at 263.07 billion U.S. dollars in 2020 and is expected to reach a value of over 500 billion U.S. dollars by 2028, growing at a compound annual growth rate (CAGR) of 7.3 percent between 2021 and 2028 (Global Water & Wastewater Treatment Market Size 2020 | Statista, n.d.). Figure 3 depicts the use of reclaimed water by different sectors. The agriculture sector accounts for approximately one thirds of the use of reclaimed or treated wastewater. Landscape irrigation, mostly for recreational purposes, follows with 20%. Liberia's tourism sector remains untapped. Treated wastewater for landscape irrigation can be a starter in this direction. Developed societies like the United States lead way globally in the use of the world's treated 5.5 billion gallons per day (Figure 4) with consumption of 2 billion gallons a day.

4.3 Treatment Technology

There are several technologies available for treating wastewater (**Figure 5**). The organized form of wastewater treatment began in the 19th towards the 20th centuries in Europe and America. These technologies have evolved since introduction. The realization that discharging sewage directly into water bodies create unmeasured environmental hazards triggered the need for constant improvements in the decontamination industry. Membrane filtration (**Figure 6**), has emerged as one of the most promising methods for the improved treatment of secondary effluents, and it is currently being researched by many scholars and policymakers (Zho et al., 2012). The tiny pore sizes of the membrane filtration instruments can remove the tiniest substances from effluent, thus, making it safe for reuse in homes. Membrane technology has been effectively employed in centralized and decentralized waste reuse. The final use of treated water determines the degree of water quality and the membrane technique required. Microfiltration (MF) and Ultrafiltration (UF) are often employed to create low suspended particles and turbidity fluids. Membrane Bio-Reactors (MBR) are utilized for direct wastewater treatment since they produce low nutrient effluents. In sophisticated wastewater post-treatment applications like groundwater injection for indirect potable reuse or sensitive industrial uses, nanofiltration and reverse osmosis membranes are employed. Particularly, for low-income societies, the ceramic membrane filtration (**Figure 7**) offers a lot. The ceramic membrane filtration method is a water filtration system that produces clean, clear tap water by removing pollutants (bacteria and protozoa such as Cryptosporidium) and turbidity from raw water sources such as river systems and wells (METAWATER). Ceramic membranes can be produced from both aluminum and clay. Aluminum has been the chief raw material for the production of ceramic membranes. However, later research suggests how cost-effective clay can be in the design and operation of ceramic membranes. The use of low-cost ceramic membranes made of kaolin has sparked considerable attention due to their superior mechanical stability, chemical and heat resistance, and, most crucially, their cost-effectiveness in certain circumstances compared to polymeric membranes (Khadijah et al., 2017). The operation is crossflow, thus making it more environmentally sustainable than other wastewater treatment methods. Crossflow operation, as opposed to the dead-end process, allows for longer filtering cycles since the strain acting on the membrane as the fractionating column flows across it helps to reduce membrane fouling (Zsirai et al., 2016).

5.0 Conclusion & Recommendation

5.1 Conclusion

The world's available freshwater is finite. The growth potential of the human population is infinite. As we (humans) grow in population, the demand for freshwater to meet our needs grow exponentially. Urban areas are poised to be affected more by these water shortages. Monrovia's population has experienced a steady annual growth of 2.4% since the war ended in 2003 (United Nations- World Population Prospect, 2016). Liberia, like most developing countries, is experiencing rapid urbanization. Monrovia, the nation’s capital, has experienced unprecedented growth from approximately 1 million people in 2000 to almost 2 million in 2020 (United Nations 2019), a growth margin of nearly 100%, doubling its prewar status.

This unplanned urbanization has led to massive decay in existing urban infrastructure and increased the challenge of city managers to create new ones. Several factors are responsible for the gross water insecurities in Monrovia, ranging from poor drainage systems to improper waste management. Riverline flooding compounds the problem.

Charles et al. used a two-tailed Student T-test to determine the effect of flooding on groundwater quality in Monrovia during the dry and wet seasons. They observed an increase in pollution levels from the dry to the wet season. All water samples analyzed failed to meet appropriate World Health Organization (WHO) standards for safe drinking water, implying that water samples from these sources are unfit for human consumption. Most of the wells are uncovered. Due to Poor drainage systems, surface runoff collects and dumps uncollected wastes, contaminants, and loose earth materials into the wells.

Unmaintained sewage pipes damaged due to the over-crowdedness of the city constantly leak fecal materials into waterways for surface water and leach contaminants into the water table for groundwater sources of water. Water remains the most important resource needed to thrive in a sustainable urban ecosystem. Through financial assistance from the African Development Bank, in addition to funding capacity building for LWSC, a rehabilitation of the White Plains plant, which previously supplied only 4.5 million gallons of potable water per day against a daily demand of 32 million gallons, was commissioned to increase distribution to 16 million gallons per day (Oirere, 2014). The city's water demand is growing, depleting groundwater quality and quantity. The only presence of wastewater treatment sites is mini TFCs operated by mining companies to treat effluent from unstainable mining practices. Most of these treatments are unsafe, and the discharge effluents are never tested to ensure environmental health and safety. In response to the growing issue of water scarcity exacerbated by population increase and global warming, purified urban wastewater is now commonly reused and regarded as a dependable alternative supply of water (Kummerer, 2015). Municipal sewage and sludge include essential resources such as water, organic matter, energy, and nutrients (e.g., nitrogen and phosphorus) that may be recovered for various economically, socially, and environmentally beneficial applications. One of the major challenges facing the water sector in Liberia is the absence of available data for decision-making.

5.2 Recommendation

Monrovia's water insecurity is compounding due to rapid urbanization and surface and groundwater pollution. However, there is enormous resource potential for constructing and operating a wastewater treatment plant in Monrovia. The city is well-drained with high annual precipitation and massive river flow. Treating contaminated wastewater using membrane filtration offers enormous potential for reducing the city's water stress during the mid-dry season. Numerous membrane technologies have been successfully used to centralized and decentralized waste reuse. The ultimate use for the treated water is intended to determine the degree of water quality and the membrane method required to reach that aim. Microfiltration (MF) and Ultrafiltration (UF) are often utilized because they can produce exceptionally low suspended solids and turbidity fluids. Due to its capacity to create fluids devoid of effluent nutrients, the Membrane Bio-Reactor (MBR) is utilized for direct wastewater treatment.

Nanofiltration (NF) and reverse osmosis (RO) membranes are used in advanced wastewater post-treatment applications that need a high-quality permeate, such as IPR groundwater injection or sensitive industrial use. The ceramic membrane made from clay could be a cost-effective solution. The usage of low-cost kaolin ceramic membranes has garnered significant interest owing to their better mechanical stability, chemical and heat resistance, and, most importantly, their cost-effectiveness in certain scenarios.

Acknowledgments

Given that research was a review, the researchers incurred no external sources of funding for this research.

Conflict of interest

The researchers declare no conflict of interest for this paper in entirety

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