CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Proposal of Proper Technologies for Purification of Domestic and Drinking Water from River Sanaga for Yaounde City, Cameroon

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled ‘Proposal of Proper Technologies for Purification of Domestic and Drinking Water from River Sanaga for Yaounde city, Cameroon’ independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 14th August 2023

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George Besong BETECK

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Abstract

The recurrent cholera epidemic situation in most urban and rural areas of Cameroon is due to high load of Coliform bacteria in drinking water. This is because the sanitary situation of the country is very poor and there are very limited improved water supply systems in the country. About 30 % of the total population of Cameroon acquire drinking water direct from open sources like rivers, lakes, streams, rain, and unprotected wells. These open water sources are very susceptible to the poor sanitary conditions of their immediate environment. To prevent cholera and other related water borne diseases, Various household water purification technologies were adopted. The type of technology used depends on the income level of the individual household. The aim of this thesis is to review the local household water purification technologies used in Yaounde and to propose a sustainable purification technique for low-income earners particularly in Nang-Eboko Community. In Cameroon about 30 % of the population live below the poverty line of less than $ 1.5 a day. This category of people cannot afford a good quality filter for household water purification technology. Majority of this population used various local techniques including cotton filter, Boiling and chlorine Tablets to purify drinking water. The efficiency of this Cotton filter in purifying raw river water used for drinking was investigated alongside chlorine tablets. A cotton filter with a filtration rate of 3 l/h, was evaluated to have an efficiency in removing total coliform, turbidity, and TDS at 90 %, 97 % and 92 % respectively. While that of chlorine tablets in eliminating coliform was 98.57 % in raw river water and 100 % in filtrated river water. Chlorine tablets was 100 % effective in filtrated water because the turbidity and TDS has been reduced by filtration.

Since WHO recommended zero total coliform unit per 100ml in drinking water, cotton filters will not be a perfect household water purification technology to prevent cholera in Nanga-Eboko. Boiling the water before filtration or using chlorine tablet after filtration will prevent cholera among low-income earner in the community.

Key words: Filtration, Efficiency, Cholera epidemic, Diseases, Hygiene and Sanitation.

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List of the abbreviations used in the thesis.

CAMWATER	Cameroon Water Utility
WHO	World health Organisation
TDS	Total Dissolved Solute
UN	United Nations
RRW	Raw River Water (unfiltered)
FRW	Filtrated River Water
FOA	Food and Agricultural Organization
UNICEF	United Nations Children's Fund
HYSACAM	Hygiene and Sanitation In Cameroon
SUCOCAM	Sugar Cane Society Of Cameroon
SNEC	National Water Society of Cameroon
BOD	Biological Oxygen Demand of Water
COD	Chemical Oxygen Demand of Water
UNEP	United Nations Environmental Protection
SODIS	Solar Water Disinfection
UV	Ultraviolet Light
WFP	World Food Programme

1. Introduction and Literature Review

Water is one of the most abundant natural resources present on the globe, occupying about 73 % of the earth surface. Water exists naturally in three main forms viz: solid, liquid and gas. The liquid form is the most essential because it is the only form needed for biochemical process in all living cells and domestic hygiene. Water constitutes more than 50 % of the total biomass of all living cells and it is almost indispensable in all human domestic activities. Water being a necessity, regular access to improved water source by a household means high living standard in sub-Saharan Africa (Kuitcha et al. 2010; Lea 2014). Despite the abundant of water sources on the earth surface, regular access to the quality and quantity of water that meets the standard for hygiene and sanitation policy of the World Health Organization (WHO) remains a major challenge in the world especially less developed and Developing countries. The quality and quantity of water available for drinking and domestic use determine the prevalence rate of preventive diseases in a community like Dysentery, Poliomyelitis, Hepatitis, Diarrhoea, Cholera, Typhoid, etc (World Health Organization 2018). According to WHO report of 2019, about eighty-three percent of common human diseases on earth are linked to poor water hygienic conditions. About eight hundred and twenty-nine thousand people die every year from water related diseases on the globe. Global progress in improved water management supply was revealed at the end of the Millennium development Goals of the United Nations (UN) in 2015 and the statistic revealed that.

- Approximately five billion people have access to regular purified water at home. Most of this population live in the developed world and some parts in big cities in the developing countries. These countries are shade with thick blue and light Blue colours on Figure 1 below with a regular household water supply coverage range from 80 % to 100 % for thick blue (north America and Europe) while light blue areas range from 50 % to 79 %(Asia, north Africa)
- Less than one and half billion people can access regular purified water from a distance within thirty minutes of walking from their residence home. This category is mostly found in the urban peripheries, and many rural areas in developing countries where there is a common community water supply management system with public Taps or Boreholes. Improved Households water

supply in these areas ranges from 25 % to 49 %. These are mostly countries in latent American and Sub-sahara Africa as shown on figure 1 areas shaded with fade blue colour. Cameroon falls under this category.

- More than two hundred million people need to walk beyond thirty minutes from their homes to access purified water. This category is found only in semi-urban and villages in less developed and developing countries. There is usually a common water source which is managed by the traditional authority or any non-governmental organisation. Presently an estimated population of more than five hundred million people lack access to improved water sources and most of this population comes from sub-Sahara Africa with poverty line below $ 2 a day. The source of water for this category of people includes rivers, lake, wells, and rain. These groups of people are the most vulnerable in the world. They are highly exposed to water borne diseases, malnutrition, hence high death rate. (Rojas & Horcajada 2020). The percentage of improved water supply for household in these countries is less than 25 %. These countries are shown in figure 1 shaded in white colour. These countries include Chad and Central african Republic where drought and civil wars prevent development.

Figure 1. Percentage of improved household regular water supply in different countries in the world (Source: Washdata. 2023).

In 2015 the UN adopted seventeen Sustainable development goals to be achieved by the year 2030 in which water sanitation and hygiene was one of the major concerns. Cameroon being a member of the UN, integrated these goals into the ‘2035 Emergence Plan’. To achieve the ‘2035 Emergence Plan’ for water sanitation and hygiene, the strategy was to quadruple the rate of water supply by adopting feasible and cost-effective technological means of purifying water (Palansooriya et al. 2020). The estimated amount of water expected to be consumed by an individual in Cameroon for both domestic activities and drinking is fifty to one hundred and fifty litters per day. Therefore, a minimum of about four and a half billion cubic meters of improved water supply is needed to satisfy the whole country for a day. But on the contrary more than fifty percent of the population consume less than twenty litter of purified water per day due to lack of access to a nearby improved source or complete absent of one (Tantoh et al. 2020b). Despite the numerous rivers, lakes, streams, springs, and underground aquifers containing incredible volume of fresh water that require minimum energy for purification and distribution technology, only 65.7 % of the entire population in Cameroon have access to regular improved water supply (Valdiviezo Gonzales et al. 2021). Improved Water supply management in Cameroon today is carried out by a parastatal company known by its acronym CAMWATER. Rapid population growth due to high birth rate and rural exodus in major cities like Yaounde, couple with lack of finance, personnels and technological infrastructure, pipe borne water is unable to reach most household and communities at the periphery of the cities. Moreover, the cost of establishing a pipe borne water in a house is too high for an average Cameroonian to afford. There are also some communities with difficult topography which makes it expensive for construction of pipe borne water and lack of energy source needed for water distribution despite the abundant water sources that surround these communities. The most prevailing health problem in Cameroon associated with most communities that depend on surface running water is the cholera epidemic. Since water is an indispensable substance for human health, households and local communities have adopted alternative means of purifying their own water for drinking and domestic use. The method adopted depends on the income level of a household, environmental awareness, and literacy (Mmereki et al. 2017). The common sources in which most of the people acquire fresh water in Yaoundé include rivers, stream, lakes, rain, boreholes, and commercial water supply. The purification techniques range from the conventional sophisticated method to the locally made Cotton Filters (Hanif et al. 2020; Saravanan et al. 2022). Despite the effort made by the Government and citizens to improve water hygiene and sanitation, the recurrent of Cholera epidemic and other water related diseases throughout the territory is still a major cause of death in Cameroon (Chen et al. 2021). According to the Cameroon Ministry of Public Health on the seventh of April 2022, there were ‘twenty-nine death and more than four hundred new cases of Cholera cases were record between 16^{th} to 29^{th} of March 2022 in the cities of Limbe, Kumba, Douala and Yaoundé.

This thesis struggled to answer the question: **Which is the most sustainable household water purification technology to be used by low-income earners in Nanga-Eboko to prevent cholera and other related water borne diseases?**

1.1. Water as a Natural Resource

The part of the earth in which water can be found naturally in any of its forms is refer to as the hydrosphere. There are four reservoirs in the hydrosphere in which water is temporarily stored, and it is transferred from one reservoir to another by various processes including evaporation, transpiration, sublimation, condensation, flow, infiltration, and percolation as represented in figure 2 below. Therefore, the total volume of water found on the globe remains constant. The time a molecule of water spends in one reservoir before moving to another is referred to as residential time. The residential time of water in the atmosphere is the shortest with about ten days maximum while that of an ocean remain the longest with more than thousands of days (Gao et al. 2021).

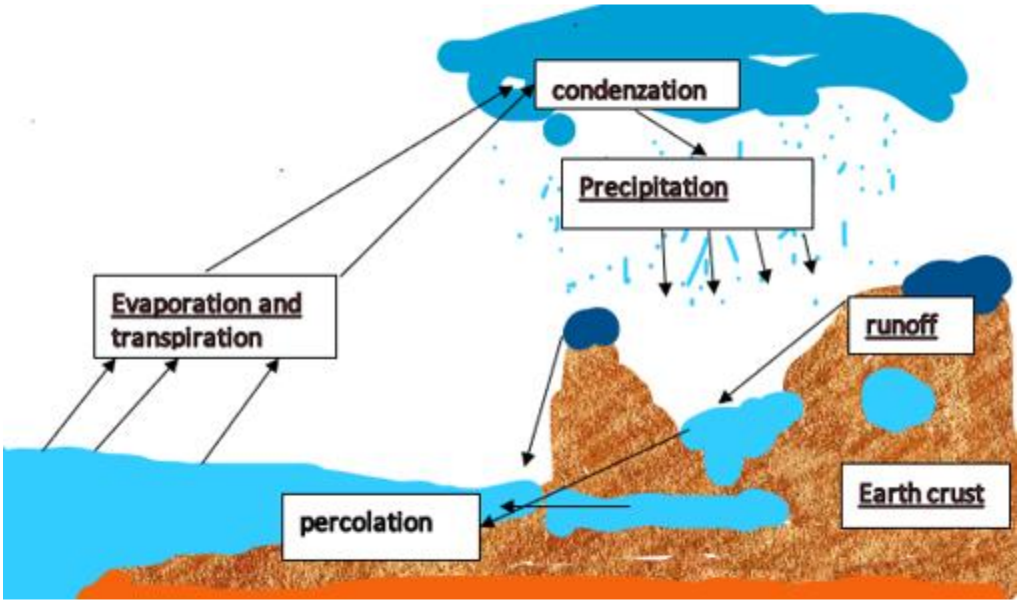

Figure 2. Circulation of water within the hydrosphere (source: Author)

The marine reservoir is the largest, making up to 72 % of the total volume of water on earth with a very high content of salinity which ranges from 2-5ppm. Marine water is usually not good enough for direct domestic use without the desalination process. Although in some minority culture sea water is used for preservation and other spiritual practices in homes. However, the desalinization process of marine water is usually too expensive as it requires high amount of energy and technology (Mohammad Razi et al. 2021). Therefore, purification of marine water for community supply is only common in island countries and those with very high income and technological infrastructures like Japan, America, China etc. Glacier or Ice block is a reservoir containing water in the solid form at the artic, Antarctic poles and alpine mountains. This reservoir stores excessive fresh water found on the earth's surface. The water is released into the seas and other surface running water by melting. The total volume of this reservoir is drastically reducing due to climate change cause by global warming (Wang et al. 2020). Fresh surface running water makes up about 26 % of the earth's total water. It is easily accessible and the most direct usable source of water for domestic and industrial activities (Owamah 2020). The salinity content is less than 0.2 ppm and its purification techniques ranges from simple design to sophisticated design which are usually not expensive as to compare with that of marine water. About 90 % of the world communities water supply have their source of fresh water from a river or lake for purification (Bulta & Micheal 2019). Fresh Underground water usually has a hardness of 0.2-03 ppm it is either confined in aquifers or unconfined in a water table below the ground. This can only be accessible when the water table meets the earth surface and flows as a spring in watershed areas or by the construction of boreholes and wells. It is the most save source of water with very limited chances of pollution. In most rural areas and peri-urban communities in the Sub-Sahara African, Spring and Boreholes are the main reliable sources of water for drinking and domestic activities. (Nya et al. 2021). In Cameroon about 23 percent of rural areas acquires water from Boreholes and Springs for direct drinking without any purification Whilst the twenty percent of the Yaoundé population using Boreholes and Springs all uses various forms of purification before consumption (Kuitcha et al. 2010). However, there is very limited literature to demonstrate that water from Boreholes and Springs in rural areas of Cameroon are safer than those in urban cities. The last reservoir is the atmosphere having the least amount of water in the form of vapour. Water from this Reservoir can only be harvested during condensation and precipitation in the form of Rain, Snow, and Hailstone. It is the most unreliable source of water due to the inconsistency of weather conditions. In Desert areas rainfall can be experienced only in a month for the whole year. On the globe rainfall is more regular at the equator than toward the poles. Ninety-eight percent of the people living in Yaoundé prefer other sources of water for drinking and domestic activities rather than Rainwater. Rainwater is harvested only for agricultural and construction purposes (Fantong et al. 2016). Rainwater lacks mineral ions which make it good for laundry because of its tendency to make soap lather.

1.1.1. Importance of Water

According to scientists, the presence of water on any planet indicates existence of life either in the past or present (Mohammad Razi et al. 2021). Therefore, the abundant of this precious liquid on earth in its various form accounts for the inexhaustible form of life existing. In this regard, it can be concluded that water is an indispensable substance for the existence of life. Water is needed in the body to regulate the osmotic pressure and keep the body healthy whilst providing a suitable medium for biochemical reaction in cell. On an average scale, an adult human being required about three litres of water in the body per day for a healthy life. According to the WHO standard quality water for drinking must be able to promote healthy life of the consumer throughout the life span. To achieve this object, the chemical, physical and microbial properties of water need to be monitored and kept below a non-problematic threshold from source through the various stages of treatment to the consumer(World health Organisation (WHO) 2022). Table 1 below summarises the physio-chemical, and microbial properties of water and compared their accepted limits in drinking water between WHO and Cameroon Ministry of health.

Table 1. Physio-chemical and microbial limits of drinking water for WHO and Cameroon.

parameters	WHO Limit in Drinking water	Cameroon Limit in drinking water
Total Dissolved solute TDS	500mg/l	500mg/l
Turbidity	5mg/l	5 mg/l
pH		6.5-9.5
Lead	0.02mg/l	0.02mg/l
Iron Fe(II) and (III)	0.2mg/l	0.2mg/l
Cupper	0.03mg/l	0.03mg/l
Fluoride	1.5mg/l	1.5mg/l

Nitrate	50mg/l	50mg/l
Chlorine	250mg/l	250mg/l
Nitrite	0.5mg/l	0.5mg/l
Manganese	0.05mg/l	0.05mg/l
Arsenic	0.01mg/l	0.01mg/l
Ammonium	0.3mg/l	0.5mg/l
Calcium	30mg/l	30mg/l
Magnesium	10mg/l	10mg/l
Sodium	150mg/l	200mg/l
Sulphate	200mg/l	250mg/l
Total coliform	0/100ml	2/100ml

The Ministry of public health adopted most of the parameter from WHO except for a few like total coliform count, sodium, sulphate etc.

1.2. General Pollution

Pollution is the release of substances and energy into an environment in a quantity that can cause harm and may lead to disruption of an ecosystem. It arises from both natural and anthropogenic activities. The natural processes that lead to water pollution include volcanic eruption, erosion from agricultural farmlands and bush fire. While the anthropogenic activities included dumping of industrial waste, leachate from Sanitary Landfills, direct defecation, and the use of chemicals for fishing. The natural pollution processes are not usually regular hence self-purification process in an ecosystem take place in time and space which help to maintain the load of pollutants below the threshold along a river (Kuitcha et al. 2010). Before the industrial revolution, pollution has never been a problem to mankind. The desire for high levels of industrialization, urbanization and rapid human population growth has led to excessive production of several pollutants.

The carrying capacity of most inland water bodies in most developing countries with very weak environmental policies has been exceeded (Kringel et al. 2016). This has caused the extinction of many aquatic species and reduces the potability of several inland water bodies, especially in urban areas. Most water bodies are a dumping ground for waste especially in Sub-Saharan Africa (Koji et al. 2017). Figure 3. Below is a typical example where a river course is used as a waste disposal site in Yaounde.

Figure 3. Photo of River Pollution in Yaounde (Google Image)

1.2.1. Major Sources of Water Pollution

Water pollution can be from a non-point source like water run-off after precipitation or a point source from a specific industry, sanitary landfills, septic tanks, and direct dumping of waste into a river course. The various sources included.

1.2.1.1. Agriculture Sources

Agriculture is ranked among the first water consuming sector in the world but in return it generates the largest number of pollutants. Waste dung from range land and fertilizer from crop land always end up in a nearby lake or river as nutrient pollutants (Nitrate and Phosphorus). The presence of these nutrients in a freshwater body causes Eutrophication. The excessive growth of Algae making the water to appear greenish a condition known as Algal Bloom. During the process of Eutrophication, decomposition of organic material by Bacteria uses the dissolved oxygen increasing the biological oxygen demand (BOD) of the water. Other effects of Eutrophication include odour, death of aquatic animals, diseases to human and reduction of the depth of a lake (Mufur et al. 2021). Pesticides used in agriculture is very lethal to aquatic and human life. Most pesticides residues have a very long resident time which make it accumulates along a food chain resulting to health disorder and genetic mutation in the organism at the higher trophic level (McEneff et al. 2014). Most agricultural activities along the Sanaga river are mostly of small scale and extensive agricultural as described on chapter 1.3.0. below. Agricultural pollution is not a major problem during the dry season due to the absent rainfall and fertilizer application on crop land. On like during the rainy season when the river content of nitrate, nitrite, ammonium, and phosphorus increases (El-Sheekh et al. 2014).

1.2.1.2. Industrial Source

According to the united state department of environmental protection, the second major surface water pollutants are from processing industries like the Pharmaceutical, Breweries, Food processing etc. Waste from industries requires an efficient treatment before disposal into a water course. However, most developing countries in Sub-Saharan lack the political will to enforce environmental protection (Egbuikwem et al. 2021).

1.2.1.3. Oil Spillage

This is more common in Oceans and Coastal water where Oil drilling takes place. Oil has a low density than Water therefore it will float on Water. The accidental breakage of offshore Pipes and Drilling tanks will eventually cause Oil spillage which prevents light from reaching the bottom of water and oxygen from dissolving into Water. Other sources of Oil spillage include Water runoff from Garages in nearby cities and direct discharge of waste lubricants into the water. Oil spillage has been the major cause of death in water birds since the beginning of industrial revolution (Leju Celestino Ladu et al. 2018). In Ndian division of Cameroon oil leakage from the rock has rendered the soil unfertile and inland water bodies non potable (Fantong et al. 2016).

1.2.1.4. Radio-active Substances and Heat

These are Point source pollution that usually result from mining industries, radioactive station, military ammunition, and warm water from heavy machine running industries. This is the most detrimental pollutant in an environment because it can lead to genetic mutation, and death of human. Most radioactive stations in the world are highly protected to prevent leakages. Cancer disease is commonly associated with exposure to radioactive particles (Speight 2020).

1.2.1.5. Sanitary Landfills

This is an area where municipal solid waste is buried. Solid waste in a sanitary landfill undergoes gradual decomposition by pressure to release a liquid called Leachate. Leachate flows into underground water or a nearby surface water body by percolation reducing it potability. About sixty percent of underground water pollution in the world originated from sanitary landfills (Defo et al. 2016).

1.2.1.6. Residential Waste

In most cities and rural areas in the world, waste handling at individual homes remains a major challenge to the authorities. Many homes in both urban and rural areas still lack proper hygiene and sanitary facilities for waste disposal. Untreated waste resulting from these residential areas causes huge pollution problems to surface water if not properly handled. According to WHO in 2020 about 80 % of global residential waste are properly managed. While the rest of the unmanaged residential waste is mostly from countries with very low environmental awareness and policies. Studies carried out by WHO in 2015 to 2020 shows that residential waste management is more effective in urban areas than the rural area as shown on figure 4 below.

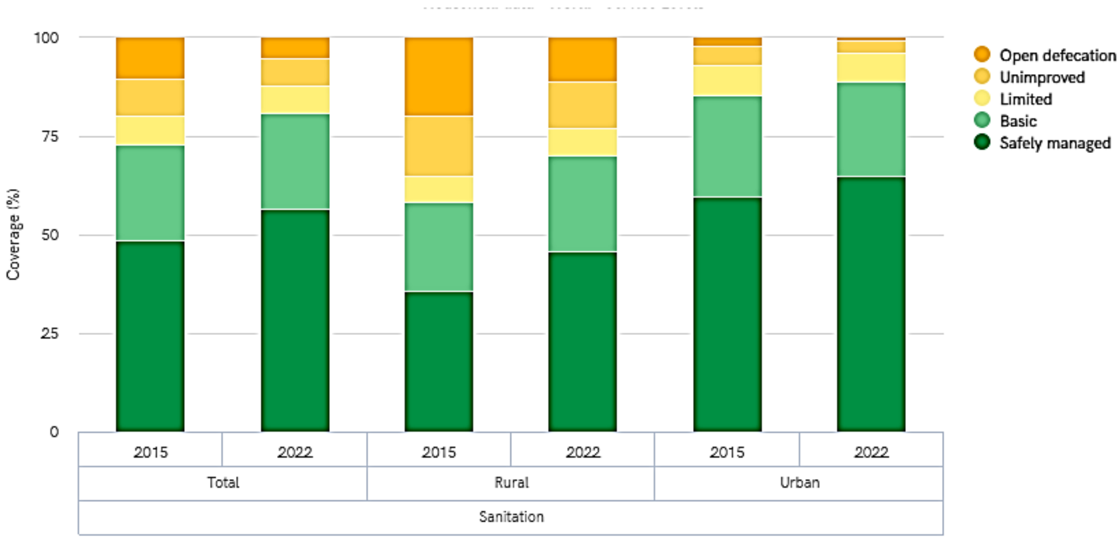

Figure 4. Global Residential Waste management in Rural and Urban areas (Source: WHO, wash Data. 2023)

1.3. Demographic and Economic Activities Along River Sanaga

River Sanaga takes its origin from the Adamawa plateau region and runs about 1000 km passing through the Centre region, Littoral region before entering to the Atlantic Ocean as shown on figure 5 below. It contains many tributaries which makes it the largest with a flow rate of 2200 -3100m/s having many rapids and waterfall (Tantoh & McKay 2021). Human activities along the river side varies with season, cultural practices, and phytogeography.

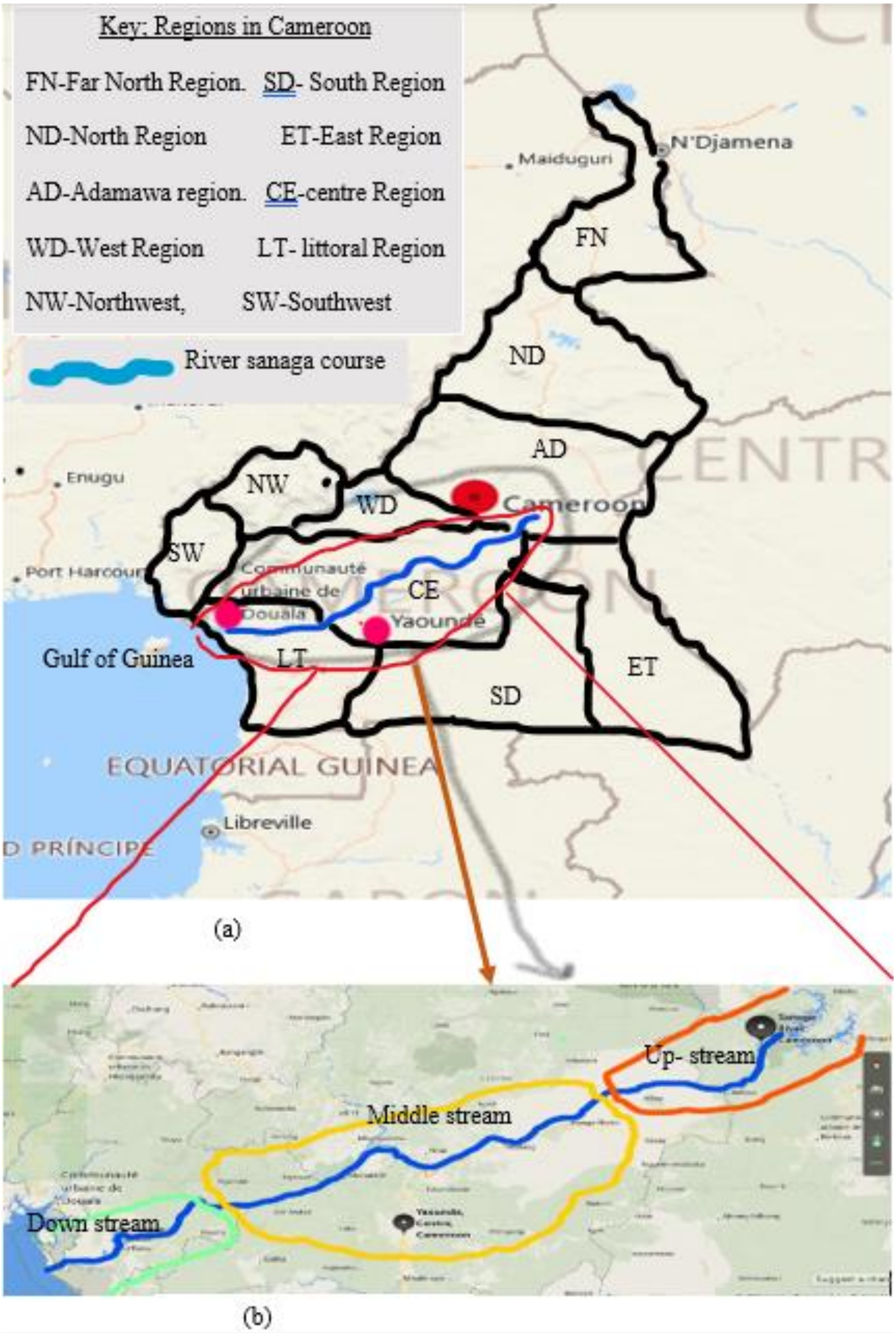

Figure 5a & 5b. The flow of River Sanaga across Cameroon (Author)

The river can be divided into three distinct sections as shown on figure 5b. The upper plateau of Adamawa (upstream section) is found on the active volcanic slopes dominated with savanna vegetation. The tropical humid climate in the upper river side is marked by a rainy season that starts in June and ends in October with annual rainfall of 2000mm per year. The dry season usually begins in November and ends in May with a maximum temperature of forty-five degrees Celsius. This region is sparsely populated, and most of the people are Fulani who practice cattle rearing. Crop cultivation is mainly Rice and Corn which is practiced by peasant farmers with less fertilizer applications. In this part of the river, less attention is given to fishing activities. During the dry seasons the Nomads usually burn the grasses to stimulate growth of fresh grasses for grazing (Bayiha et al. 2017). Therefore, anthropogenic pollution of the upstream is very minimal due to low population density and very few industries. In the Centre region (middle stream section) the river is larger because of many tributaries like River Mbam, Djerem and Lom which empty into it. This area is covered by a rich tropical rain forest with very diverse fauna and flora found on the hilly landscape. The population density is moderate ranging from 25-75 persons per kilometre square. Cultivation of both food crops and cash crops is practice from peasant to plantation. The main food crops include Cassava, Plantains, Corn, Yams, and fruits while Cocoa, Coffee and Banana are the main cash crops. Slash and burn is practiced by peasant farmer who cultivate for their immediate consumption and the excesses is sold to the local markets. Sugar Cane plantations and the processing industry are located around Mbandjock and Oballa. Sand used for most construction work in Yaoundé city come from River Sanaga. Fishing in these areas is rudimentarily practiced by villagers living less than thirty minutes' walk from the river side. There are hydropower dams along the river with the largest found at Song Loulou which produces about 384 mw electricity. In the Centre region most major cities like Yaounde rely on River Sanaga as a source for their water supply systems. The river is an alternative direct source of water for drinking and domestic activities during the dry seasons for local communities living close to it and lacks pipe borne water (Buh et al. 2021). However, the numerous activities along this portion of the river reduces its hygiene and sanitation level.

At the Littoral region (downstream section) the river is broader and gentler where it emptied into the Atlantic Ocean. The vegetation is mostly forest and mangrove with regular rain fall up to 4000mm per annum. Here aquatic activities for commercial purposes are high due to the abundance of sand and various fish species present. The fishermen use various types of vessels ranging from local made to modern boots. Fishes harvested from this region is usually exported to neighbouring countries like Gabon, Nigeria, and Equatorial Guinea (Mohiyaden et al. 2016). The water quality in this portion is very turbid with a high salt content resulting from the sea. Moreover, this is the highest industrialized region in the country which possesses high levels of water pollutants.

1.3.1. Sanitary Conditions Along Sanaga River

Most cities and villages found along River Sanaga do not only extract its natural resources but also dump waste along the course. The limited environmental enforcement policies coupled with unawareness, most waste from residents are dumped either directly or indirectly into River Sanaga as a means of disposal. HYSACAM is the company responsible for collection and treatment of waste in all the cities in Cameroon. It has a calendar of work for collection of waste twice a week in all the accessible areas in the city. In some areas that are inaccessible and during the time the Collection Cans are overwhelmed, the garbage and sewage are emptied into the nearest water runway or a stream which eventually leads to Sanaga River. Other sources of organic pollutant are SUCOCAM, Brasseries and other local breweries which releases warm water from cooling engine (Kuitcha et al. 2010). Chemical pollution is usually either direct by the application of chemicals to catch fish or indirect from run-off coming from sugar cane plantation around Nkoteng and Oballa.

However, the major sanitary issues along the Sanaga River is the high content of the faecal coliform arising from both animals and human Waste (Kometa & Ebot 2012). Figure 6 below is data from WHO which was collected from 2015 to 2022 on household waste management. It revealed that in Cameroon, 60 % urban and 20 % rural residents have basic sustainable facilities and knowledge on household waste management (basic) while 20 % urban and 10 % Rural residents have temporary sanitary facilities that cannot last for long(limited), 18 % urban and 60 % rural resident have sanitary facilities that do not meet the basic standard (unimproved) and the last and worst category is residents without any sanitary facility exist more in the rural area with about 10 % and is less common in the urban cities with only about 2 % (open defecation). The percentage of residents that lacks household sanitary facilities in urban areas are those with limited land access due to urban congestion and land grabbing (washdata,2023).

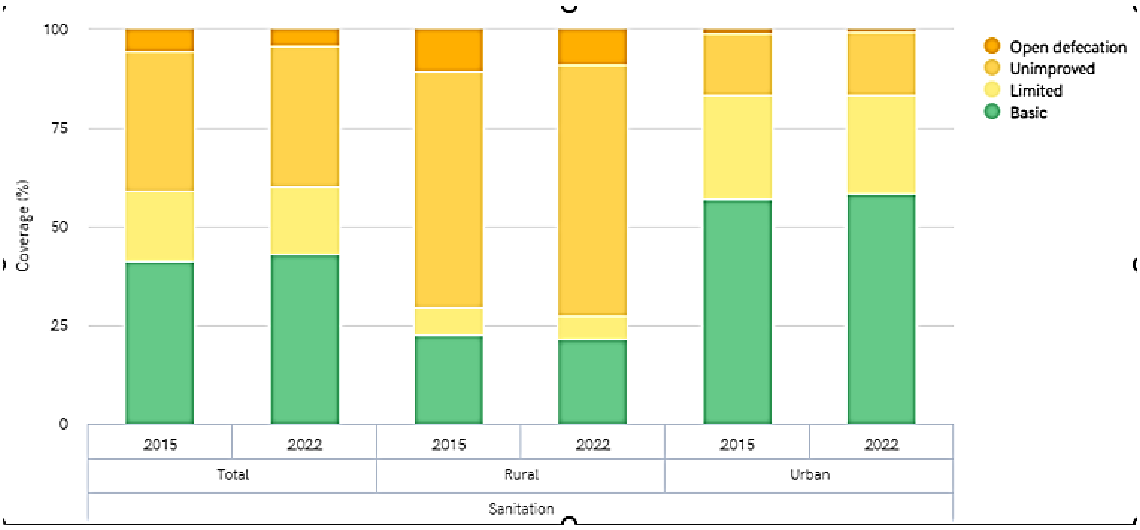

Figure 6. Sanitary Situation in Cameroon from 2015 to 2022 (source: wash data. 2023)

1.4. Common Water Pollutants in Cameroon

A pollutant is any substance or energy that can be detrimental to the environment and individual health at a given threshold of exposure. The table below summarizes the major water pollutants and their health-related effects in human.

Table 2. Summary of Common Drinking Water Pollutants in Cameroon (Author)

Pollutants	Origin	Health Effect in Humans
pesticides	Runoff from agricultural farmland and other agricultural industries. Chemical fishing.	Cancer, liver, and kidney failure.
Hydrocarbons	Waste lubricants from garages and boats.	Abdominal disorder
Nitrates/nitrites/ ammonium	Fertilizers and decay organic matter.	It reduces oxygen carrying capacity of blood.

Phosphates.	Fertilizers, decay organic matter and weathering rocks.	Nervous disorder.
Trace metals.	Weathering rocks	Nervous disorder
Fluoride and chlorides products.	Detergent and other laundry products.	Dysentery and other abdominal disorder.
Micro-organisms.	Organic waste (faeces and other animal dropping)	Diarrhoea, Cholera, dysentery, polio etc.

1.4.1. Measures to Reduce Water Pollution

Pollution has become a major threat to all forms of life on the Globe which is a call for concern. The first important step to reduce cost of water purification is to stop anthropogenic pollution of natural water sources. The United Nations Environmental Protection Agency (UNEP) in 1992 at Rio de Janeiro adopted resolutions 4/21 from agenda 21 in which the ministers of the various member states agreed to strictly implement the strategy of getting a pollution free planet for the well-being of the people. Based on this strategy, a general waste management plan was drafted to be implemented by policymakers of member states to bridge the gap of pollution. In this regard, waste was classified alongside their methods of treatment and disposal to be followed by companies in member states. The effort to combat pollution in different forms included the issuing of certificates for good environmental practice to companies' example ISO 14000, ISO9001 etc. In Cameroon, pollution has never been a political debate, but the Ministry of Environment, Nature Protection and Sustainable Development was created in 2004. This ministry overviews the implementation of the various environmental conventions and treaties in which Cameroon is a signatory example; the Stockholm conference on the environment 1972, world population conference in Mexico 1984 etc. Today, there exist several national and international non-governmental organization (NGO) responsible for promoting environmental protection and awareness in Cameroon, but the result is still far below expectations especially with respect to surface water pollution (Kumi-Larbi et al. 2018).

1.4.2. Water Recycled and Re-used.

Water is a renewable resource, but some reservoirs in some parts of the world diminish faster than it is replenished due to some phenomena like drought caused by climate change. These areas face with severe water constrains adopted several technologies to recycle water to minimizing lost (Mohammadifardi et al. 2018). In this sense a molecule of water can be used several times either for the same purpose or different purposes. The type of technology used for recycling is determined by the purpose and the source of the wastewater. Water recycling can be classified as planned and unplanned. The unplanned is when Wastewater discharged from homes or industries infiltrates through the soil into its original source (Rivers, Lakes, Boreholes) or evaporated into the atmosphere. While the planned recycling is the used of simple or sophisticated technology to purify Wastewater to be used for Irrigation, Drinking water, Food processing, etc. Water recycled or re-used is common mostly with countries in desert regions. Countries with abundant water resources collect and treat wastewater purposely to reduce the biological oxygen demand (BOD) and chemical oxygen demand (COD) before disposal. This is to maintain high levels of public sanitation. However, this is mostly practice in developed countries and some few developing countries with improved sanitary facilities and good environmental policies (Chamizo-Gonzalez et al. 2016).

1.4.3. Collection, Treatment, and Disposal of Waste

The first step to controlling pollution in the world is to properly handle and treat Waste before disposal. In the UN summit of 1992 at Rio de Janeiro, the limit of BOD and COD of Sewage to be disposed into a water body was set to prevent contamination of freshwater body. However, to achieve this goal basic hygiene and sanitation facilities need to be in place for collection of waste at the source and the population needs to be well informed about the dangers of improper disposal (Chamizo-Gonzalez et al. 2016; Mohammadifardi et al. 2018). Since the process of handling and treating waste requires huge finances, human and technological resources, household hygiene and sanitation levels are more feasible in the developed countries than the less developed and developing countries. This was substantiated by statistics carried out by WHO from 2015 to 2020 about sanitary situation in developed countries and developing countries shown on figure 7 and 8 respectively. Open defecation and unimproved sanitary facilities are completely absent in the urban area of the developed countries while about 10 % of unimproved sanitary facilities exist in their rural areas as shown on figure 7 below. The situation is contrary in the developing and less developed countries as demonstrated in figure 8 where open defecation is about 10 % in urban and 30 % in rural area. Basic and safely managed sanitary situations in the developing countries is less than 45 % and 25 % in urban and rural areas respectively.

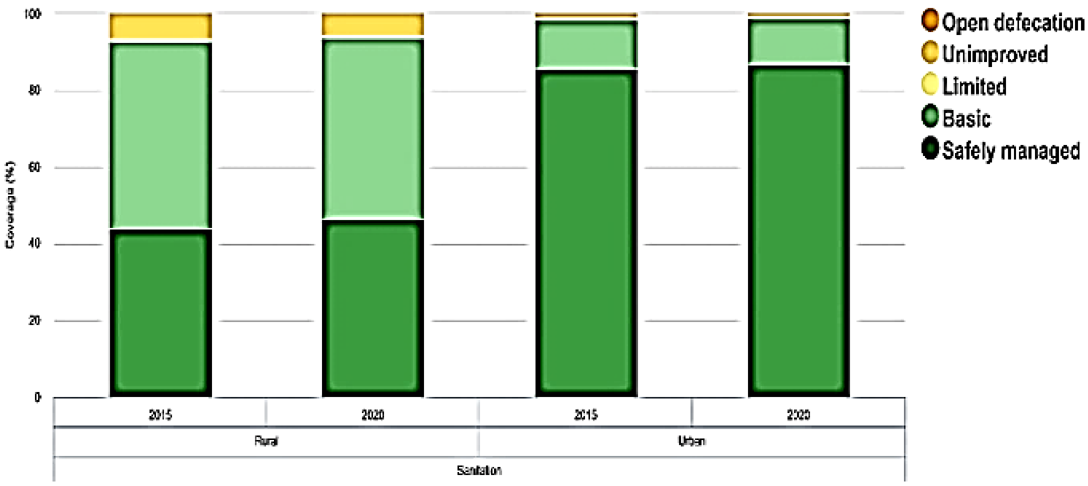

Figure 7. Sanitary situation in the developed countries (source: washdata, 2023)

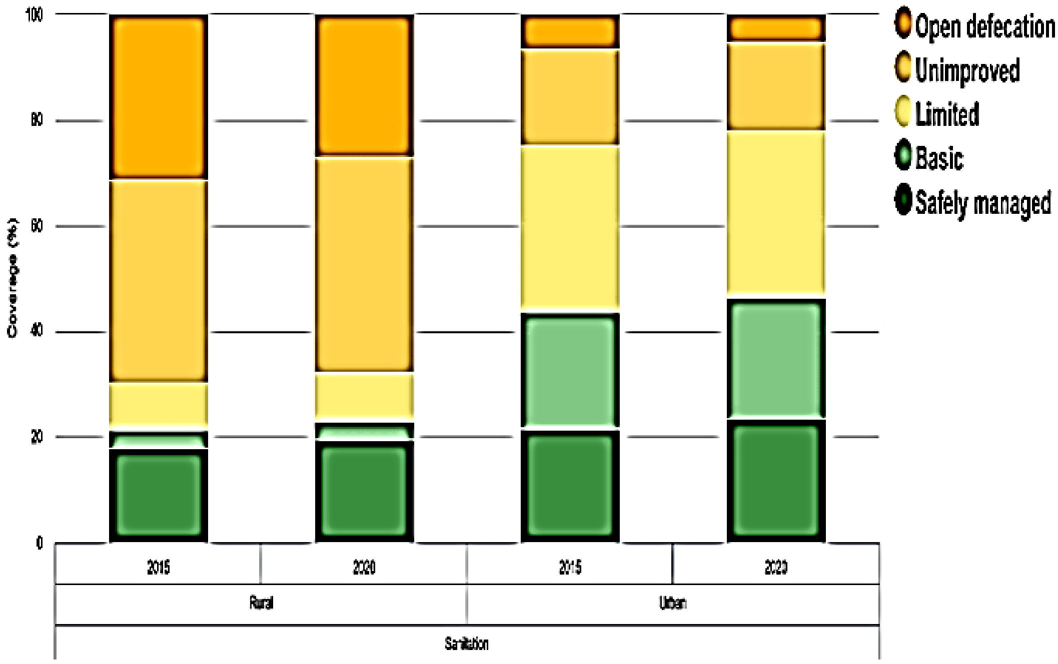

Figure 8. Sanitary situation in Developing Countries (Source: wash data. 2023)

The global effort to improved household hygiene and sanitation has been a top agenda in UN since its creation to reduce diseases and improved livelihood. However, there has been an insignificant progression made in the household sanitary situation of Cameroon in general from the year 2010 till the year 2022 as shown on figure 9 below. According to WHO the percentage increase of household having standard basic sanitary management facilities was 4 % from 2010 to 2022 as indicated by the green portion on figure 9 while the percentage of open defecation drops to about 3 % within the same duration. Therefore, much effort is needed to design a very good sanitary system in the country to collect and treat garbage and sewage mostly in urban areas. This will help reduce the spread of water borne diseases in the country.

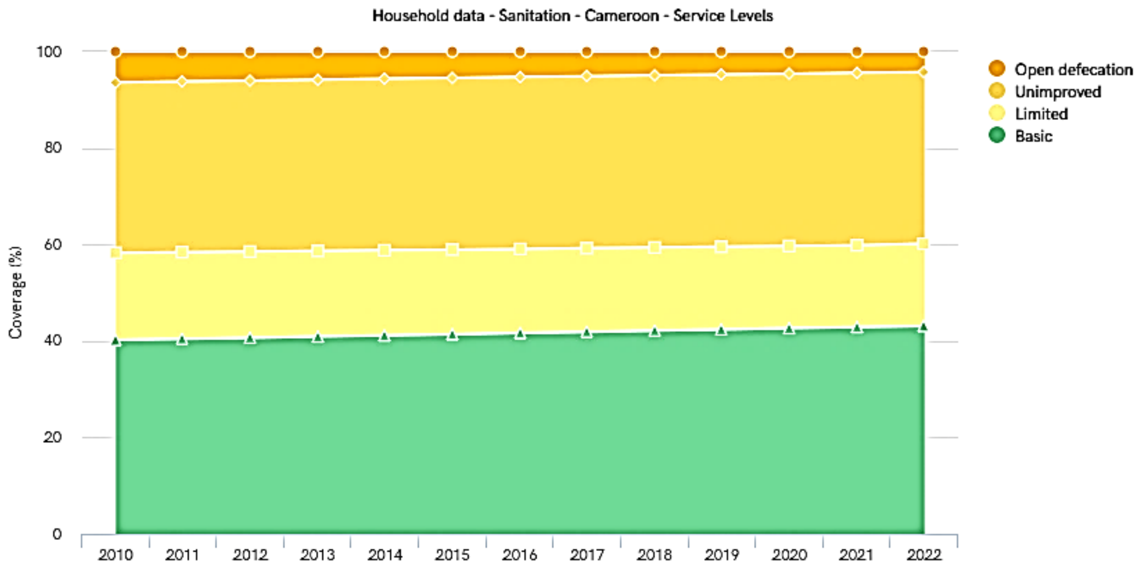

Figure 9. Cameroon sanitary improvement trend from 2010 to 2022. (Source: WHO, wash data. 2023)

In the developed countries, the method of waste collection, treatment and disposal is more organized and complies to the international standards. Figure 11 show how domestic sewage is collected and sorted through the municipal sewer where it is directed into an oxidation pond or stabilization pond. The sludge is directed to a sludge digester tank for oxidation by bacteria to produce biogas which is used for heating. After the fermentation process, the sludge is removed disinfected, dried, and used as manure on cropland (Mohammadifardi et al. 2018). While the effluent is filtered through biological sand bed and the filtrate disinfected before irrigated to farmlands. Garbage is collected using public Trash Cans which are sorted at the collection point. Most solid waste are usually recycled, re-used, or fermented to produce compost and biogas for those that are biodegradable meanwhile other are recycled, re-used, or buried in a sanitary landfill which is regularly monitored by the municipal authorities (Kumar et al. 2017; Abdel-Shafy & Mansour 2018). Figure 10 below summaries the process in which garbage from various domain in a country is managed.

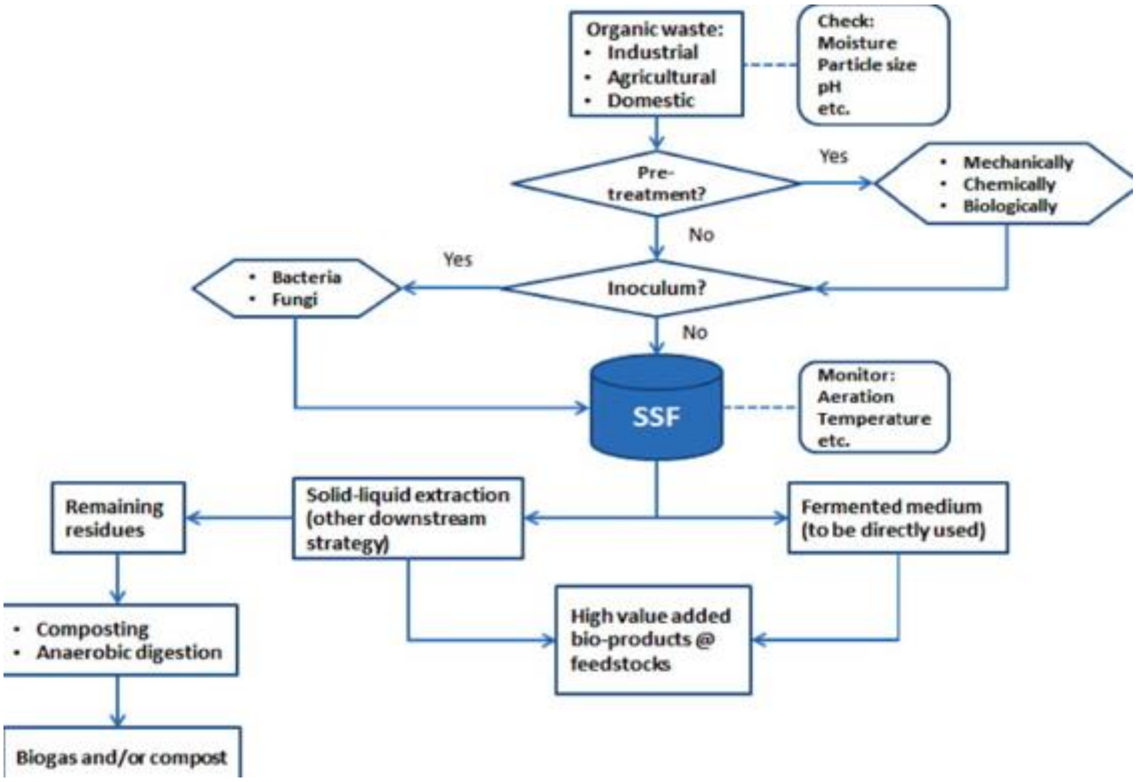

Figure 10. A flow diagram How Garbage are Sorted, Processed to Generate Biogas and Compost (Abdel-Shafy & Mansour 2018)

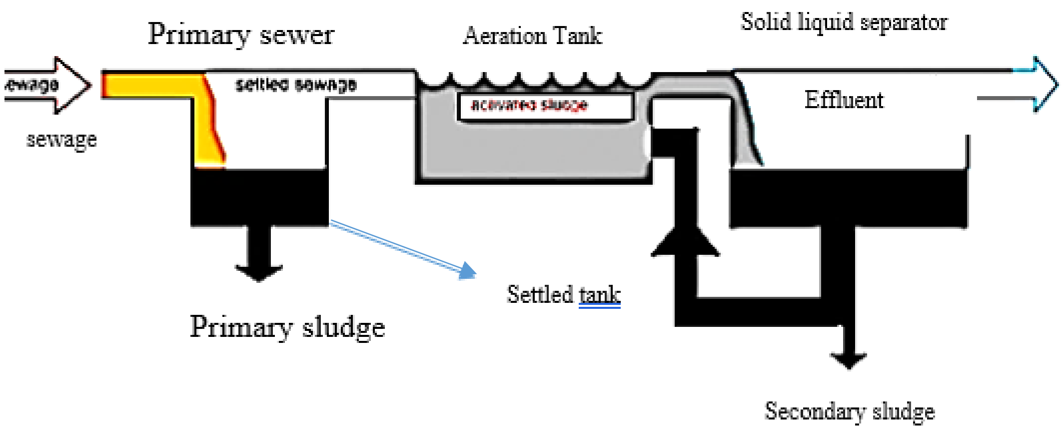

Figure 11. Flow Diagram of Sewage Treatment (Struijs et al. 2016)

Most developing countries in Sub-Sahara Africa used pit latrine, septic tanks, and bucket for their sewage collection. The treatment of sewage is often given a lesser attention as almost 60% of the population do not have a proper sewage system (Mmereki et al. 2016; Abdel-Shafy & Mansour 2018). Since most of those population residing in the rural areas of the developing world are poor and lesser aware of the environmental impact of pollution, their sanitary level is very low (Lemos et al. 2013). The most common method of solid waste treatment is open dumping and incineration in both urban and rural areas (Abdel-Shafy & Mansour 2018). Despite the rapid progressive improvement in hygiene and sanitation trend in other parts of the world from the year 2010 till present day, that of Sub-sahara countries remain slow because of poor economic growth and political instability in the region. There is a need to intensify economic development in the primary sector and promote agricultural education among the youth to reduce poverty. This will help to improve the living standard of the people. This result can only be obtained in collaboration with effort from many environmental NGO and government authorities in this region to promote environmental awareness (El-Sheekh et al. 2014).

1.5. Decentralization and Community Base Water Supply Management in Cameroon

Water supply issues in Cameroon is due to the 'top to bottom' policies of governance that existed before the year 2010 (SNV 2017). It was the sole responsibility of the Ministry of Water Resources and Energy to initiate any project concerning pipe borne water supply for any community in the territory. With the limited finances allocated under this Ministry, pipe borne water supply systems was only established in communities with high political influence (Tantoh & Simatele 2018; World Health Organization 2018). The policy of Decentralization adopted by the government in 2010 has empowered the local authorities to manage their natural resources for the benefit of their communities. With this approach, about seventy percent of rural communities in Cameroon have access to a properly managed source of drinking water (Nyambod & Nazmul 2010; Buh et al. 2021). The policy of decentralization has encouraged social cohesion and active participation of all individuals in the management of natural resources. There are several NGOs and civil societies partnering with many local governments to improve water accessibility alongside hygiene and sanitation.

1.5.1. Water Supply Management Situation in Cameroon.

In 2015 the World Health Organization revised the guideline for good quality drinking water and for domestic use which will help to reduces diseases and mortality rate in the world. These guidelines were adopted by all members states and a strategic safety plan for water resources that aligned to the WHO guidelines was established. The WHO worked in close collaboration with UNICEF to ensure strict implementation of the policies among member states by subsidizing the various government with the technological materials for purification of household water supply especially in schools and rural communities together with health care facilities. (Gara et al. 2018; World Health Organization 2018). In 2014 a household water treatment technology scheme was established with the aim of guiding member states on the selection criteria of purification technology for households drinking water. This scheme was established to ensure affordability of water purification technologies in rural communities and low-income earners at individual level. Hence reducing the amount of enteric pathogens intake to a non-problematic level (Ako et al. 2009). Cameroon like most developing countries, the guideline for safe drinking water was established following that of WHO by the Ministry of Public Health and it was enforced by the Directorate in charge of Prevention of Epidemic and Pandemic Diseases (Nyuydine Wirba et al. 2020). The water supply management system and sanitation were the sole responsibility of the central government from 1967 till 2002 under the parastatal company SNEC. Within this period of function, the company could only make regular water supply to 50% of the population in cities and less than 20% of the rural areas. While the level of sanitation was less than 30% in cities and 4% in rural areas (Arnaud et al. 2008; Ako Ako et al. 2010; Tantoh et al. 2020a) From 1998, the country was marked with a rapid population growth. Hence an increase in water supply demand. There was an ultimate need to expand the regular water network in the cities to reach the peripheries. The lack of finance due to poor managerial aspect of SNEC, the government decided to privatize it in 2002 to a French company known as Cameroon water cooperation. The government later adopted Decentralization and Sectoral Water Supply and Sustainable Development policies which was highly supported by international NGOs and civil society groups in terms of finance and technological support in 2003. This policy was mainly focused more on the accessibility than the quality of regular water supply in rural and urban peripheries using the participatory approach of the local community. In this approach, a local water management committee made of people with limited knowledge on water sanitation was created to handle the maintenance of a community water supply source. Figure 12a, and 12b, below shows a common local potable water source managed by a local authority in Yaoundé. The obtainable objectives of this strategy from 2015 to 2020 is demonstrate on figure 13 show 85 % in urban and 42 % in rural areas for basic purified regular pipe borne water supply which the blue category of the graph(basic). While limited category refers to local community sources like springs and boreholes shown in figure 12a and 12b. the percentage achievement was 10 % in urban and 15 % in the rural area. The category was more acceptable in the rural communities because of one language of communication and social cohesion among which is reduced in cosmopolitan areas (Oumar & Tewari 2013; SNV 2017). About 8 % unban and 30 % rural population used self-managed wells and rainwater for drinking this category is refers to as unimproved on figure 13. The last source of water for drinking in Cameroon is surface water which included streams (figure 12b), rivers and lakes. The percentage of household using surface water in the urban areas is just about 2 % as to 20 % in the rural areas. This is because there are more pipes borne water supply in the urban areas and most surface water are highly polluted (Oumar & Tewari 2013; SNV 2017). The impact of decentralization on basic pipe borne water supply in Cameroon increases significantly from the year 2016 due to subventions from WFP for vulnerable communities in Africa. The percentage trend of basic pipe borne water supply in Cameroon changes from 60 % in 2010 to 70 % in 2022 as shown on figure 14 covered by green colour(basic). Although many households and communities in Cameroon have access to what is considered as potable water in their various communities, cholera epidemic still prevails in most communities in the country. Till date, the major challenge face by the Cameroonian authority is to improve hygiene and sanitation of drinking water to prevent further cholera epidemic and other water borne related diseases.

(a) (b)

Figure 12. Sources of community water Supply in Yaounde (a) spring (b) stream

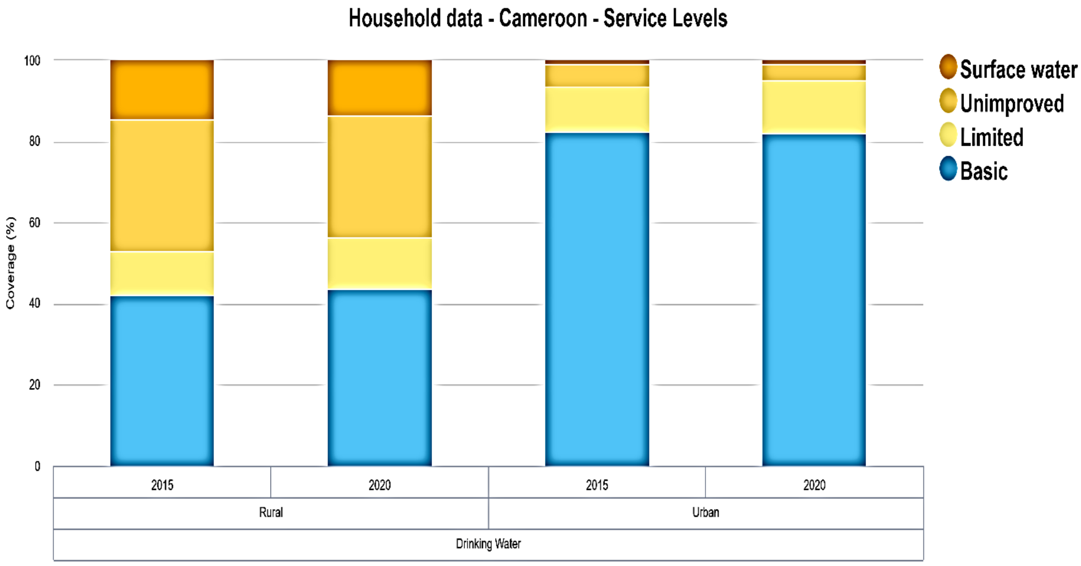

Figure 13. Cameroon household water supply sources in rural and urban areas from 2015 to 2020 (wasdata, 2023)

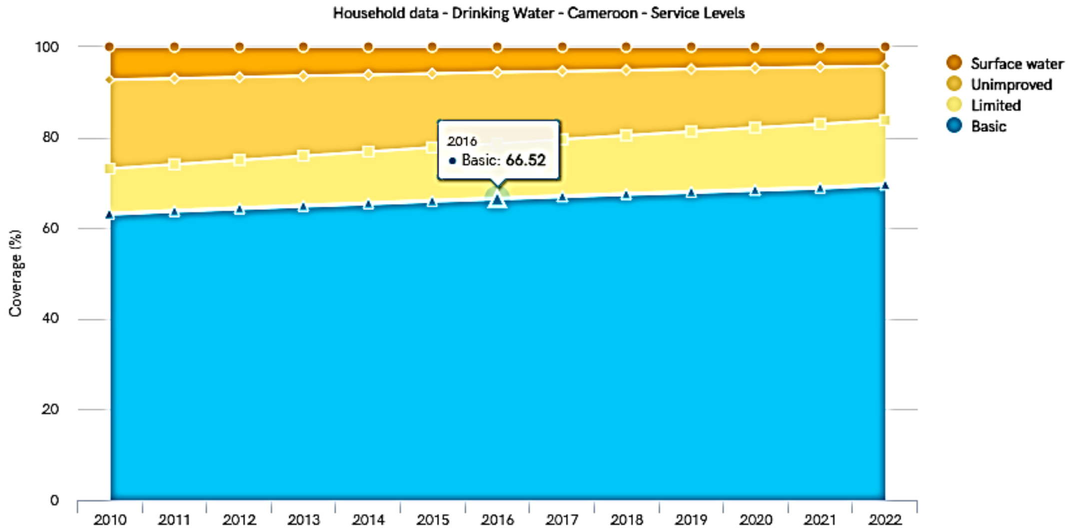

Figure 14. Percentage trend Having Access to basic Improved Water Source in Cameroon from 2010-2022 (wash data, 2023)

1.6. Economic Impact of Water Supply in Cameroon.

From the privatization of SNEC in 2002, public Taps were completely eradicated in most major cities in Cameroon and price of one-cubic meter of water rises from $ 0.3 to $ 0.5. This resulted to water crises in many cities since majority of the population were unable to withstand the price increase. In a respond to this situation, many lower income earners adopted various means of acquiring non pipe borne water for the household. Water scarcity in major cities triggered an economic situation in which many people with business talent took advantage to make profit. Many water vendors proliferated into the major cities in various forms. These vendors can be sole proprietors or corporate bodies. In all the cities in Cameroon its common to see people of all ages on the street selling water in plastic bags, bottles, and gallons. The water can be collected from the Tap, Stream or Borehole treated before selling to the public. The level of treatment and the technology used will depend on the type of vendor. Individual vendors usually used normal ceramic filters in which the purification process has never been certified by any Government authority. While those sold by big companies and corporate bodies were certified by the Ministry of Public Health. However, water purified under a certified process usually has a higher price than others in the local market. The general price of a litre of water from a local vendor can cost a maximum of \$ 0.16. while that from corporate bodies or reputable companies with certified purification standards ranges from \$ 0.14 to \$ 0.82 per litre. Non pipe borne water is transported in numerous commercial ways to consumers and the price for the water depends on the quantity and means of transportation. The first category of transport and the most common in many cities in Cameroon is the Motor Bike (figure 15a). This category employs about seventy percent of the middle-class income earners because of its affordability. Those involved are usually below forty and the maximum quantity a Motor Bike can transport at a time is one hundred litres that cost a maximum of \$ 2.27 depending on the distance from the water sources. The second category is the use of vehicles, usually truck tankers (figure 15b). This is the best method of water transportation in Cameroon but its less common like motor bike and head pot because the cost of a vehicles is to high for an average Cameroonian. This means of transportation is practiced by rich individuals and large commercial water industries. The amount of water transported is usually much and can be supplied to many homes at a time. The transportation cost is usually cheaper since it supplies many clients at a time, but the vehicles cannot reach many areas in the city due to poor roads infrastructures. The last category and most tedious transportation is Head Potting (figure 15c). In most household, children below thirty and women are responsible for fetching water for drinking and domestic activities. In a home without children the individual usually pays for these services to children who usually take advantage to make extra money. The cost is a maximum of \$ 0.82 for twenty little depending on the distance. However, this is the most expensive and unreliable since the quantity supply is very small. This method of water transportation is not encouraged by many non-governmental organizations who are against child labour. This practice is mostly common in sub-urban and rural areas where water is fetched from a stream or any community managed source. Some other drudgery methods include the pushing of Wheelbarrow (figure 15d) and Truck (figure 15e).

Figure 15. Various Means of Transporting Non-Pipe Borne Water to Household in Yaounde

In Yaoundé city, pipe borne water supply system is inconsistent and expensive to established in houses with low income. In this regard, most houses have very large water storage containers for storing water for long periods of time. There are many types of water storage containers in the local markets which vary in size and quality. The size and quality of the storage container depends on the family size and their income level. The most common storage container is dense polyethene plastic containers (figure 16) because of it affordable prices and availability. However, very little literature is known on how a particular storage container may affects the quality of stored water in it. Therefore, the only reason why plastic containers are the most common maybe due to the lower price and availability.

Figure 16. Types of water storage Containers at Home (Google Image)

1.7. Impact of Corruption on Water Supply System in Yaounde.

Corruption is one of the antipatriotic syndromes in Cameroon which has greatly retarded the economy growth in many sectors. In the domain of water supply and management, corruption is practiced from contract award for establishing a pipe borne water supply contract down to the level of monitoring and customer care service. Contractors usually bribe government authorities to win pipe borne water construction projects which are poorly executed due to improper surveillance by the corrupted administrators. The most common type of corruption by the authorities is embezzlement of funds meant for public contracts. Corruption that occurs at the level of management of water supply system includes prices discrimination among customers and inaccurate accountability of income and revenue. Field workers of a water supply company usually connect water to customers in the field without the knowledge of the management. Most consumers on the other hand usually manipulate with the supply system in such a way that their monthly consumption is always lesser than the exact quantity while about twenty percent of these transactions are unknown by the management (Léon & Zins 2020). These poor practices have resulted in lesser revenue generation in the water supply management domain which resulted in its collapse and the privatization of the company in 2002.

1.8. Impact of Climate Change and Global Warming on Water Resources.

In recent decades climate change and global warming has been the major issue on the globe. Seasonal variation with an annual average temperature increases by four degrees Celsius on earth (Speight 2020). The phenomenon has changed the pattern of weather conditions on earth. Since the effect is not the same in all the geographical location on the globe, the areas near the equator experiences frequent rainstorms and floods while those above latitude 23 experiences more drought. In general, the water volume in Lakes and Rivers has reduced due to excessive evaporation while the water table has dropped. The glaciers at the Antarctic, Artic and Alpine mountains have retreated causing a rise in the sea level (Tangan et al. 2018). In Cameroon global warming has greatly changes the length of the dry and rainy season from five and seven months respectively to six months each. In the northern part of the country desertification is encroaching toward the south with less than three months of rainfall. The main permanent water source includes Lake Chad, River Benue, River Chari and Longon other source dry out during the nine-month period of dry seasons (Fantong et al. 2016). This condition has disfavoured crop production which is the main reason most of the people are traditional cattle rearers. In these regions water scarcity is more severe than any other region in Cameroon reason why cholera epidemic is more frequent (WB 2021). In the central part of the country where rain fall is five months water scarcity is not as severe as in the extreme north. There are many permanent water sources that can be used for irrigation, domestic activities and drinking during the dry season. The western part, which is referred to as ‘Grass Field’ is made up of the Northwest and West regions located on high altitude. Although there are many permanent sources of water resources, the undulated nature of the topography makes it difficult for establishing a pipe borne water supply system to reach most communities. However, rainfall is less than five months in a year causing the people to walk for long distances to acquire water for domestic used (Rangel et al. 2003; Alice et al. 2021). Lastly the coastal part of the country is made up of Southwest, Littoral, and South regions. These three regions experience six months of regular rain fall which furnished it with numerous permanent freshwater sources throughout the year. These three regions are among the heaviest industrialized in the country and are characterized by heavy pollution of water sources from both industrial and domestic waste. Although water is readily accessible in major cities of these regions, but the sanitary conditions are very deplorable which is the main reason Cholera incident is the high (Hott et al. 2018). While some fresh water sources in cities like Douala, Kribi and Limbe faces problem with the salt contamination from the Sea during high tides.

1.9. Technological Development in Water Purification for Drinking and Domestic Activities

Water purification is any process used to reduce or eliminate pathogens, turbidity, dissolved solute, and suspended substances from water to increase its potability. Water after purification is referred to as improved because the health-related risk to consumer has been reduced or eliminated. The principles behind any water purification technology may either be physical, chemical, biological or a combination of all. The specific principles adapted to a technology to be used will depend on the type of impurity to be eliminated and the level of pollution. The purpose of water purification may include one or more of the following: medical, pharmaceutical, food processing, drinking, domestic activities, irrigation, disposal, etc. Water purification techniques for the purpose of drinking and domestic activities vary in scales. The technology adopted for the process depends on several factors such as source of water, degree of water impurities, level of income of the country and the capacity of the purifying technology. Water needed for drinking and domestic activity must meet a minimum standard in quality set up by the local government or international organizations (WHO, EU etc.). The standard set by the local government or international body can only be enforced by monitoring the process of purification and technological application. Although the standard usually varies with countries, but majority of developing countries adopted the WHO standard (Oumar & Tewari 2013). Cameroon like most developing countries, adopted the minimum standards for drinking water from the WHO which is being enforced together by the Ministry of Water and Energy and the Ministry of Public Health. These two ministries are responsible for certification of all community water supply plants and industries involved in commercial water supply throughout the territory (Takounjou et al. 2020). However, water purified at the level of individual household using sustainable technology made from local materials has very little literature on its efficiency in eliminating bacterial and other impurities in Nanga-Eboko community. There are many community water supply plants throughout the territory which are unable to meet-up the demand of the rapid growing population in the country. Example is the water purification plant located at Akomnyada which is made to supply Yaoundé city. The city is about thirty thousand inhabitants which require about 315,000 cubic meter of water a day. This plant has a capacity of 150000 cubic meters of water a day. The population projection of Cameroon by the UN may attain sixty million by the year 2050. The rapid growth of the population will require a larger and advanced water purification Plant to meet-up with demand in the whole cities.

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Figure 17. Water Treatment Plant at Akomnyada (source: Google image)

1.9.1. Stages involved in the treatment of a community water supply.

1.9.1.1. Screening

This process involved the removal of large suspended undissolved substances from water. It used a pumping engine that draws water from a permanent source like river, lake, or a borehole. The water passed through many grids with different diameters to trap various suspended substances of different sizes. The main objective of the process is to eliminate substances that may hinder the proper functioning of the system. Chlorination can be done depending on the source of water to prevent algae from growing in the treatment tank. This is usually referred to as Pre-treatment.

1.9.1.2. Coagulation

This is a process in which small dissolved charged molecules are activated to stick together and form large coagulants using chemicals like aluminium salts, iron salts etc.

1.9.1.3. Flocculation

At this stage, coagulants are forced to stick together to form a larger one called floc with the help of a rotor and more chemicals may be added to facilitate the process.

1.9.1.4. Sedimentation

This is the process of removing floc from the water. The floc is allowed to settle at the bottom of the tank and the supernatant flows into the filtration bed. The floc is removed from the sedimentation tanks, dried, and used in cropland as organic manure.

1.9.1.5. Filtration

This stage involved the removal of residual coagulant, micro-organisms and dissolved charged particles. The filter is made of sand, stones and activated charcoal. In some commercial industries, ultrafilters are used to obtain a better result.

1.9.1.6. Disinfection

Odour and pathogen are eliminated at this stage using various chemicals like chlorine or chloramine which can dissolve the cell wall and cell membranes of many micro-organisms. Ultraviolet radiation can be used to eliminate micro-organisms, but it is not capable of protecting the water alone the distribution pipe. Therefore, chemicals remain the best disinfectant for pipe borne water for its long-term protection (Ahmad & Azam 2019).

1.9.1.7. Fortification

This stage is not very common with most community water supply plants in developing countries. It is the addition of some components that will increase the quality of the water. The most common is calcium and magnesium ions which are needed for hardening of bones and teeth. Different companies have various ways of fortifying water to satisfy their customers (Kalidasan et al. 2021). Figure 18 below summaries all the stages involved in community water supply treatment.

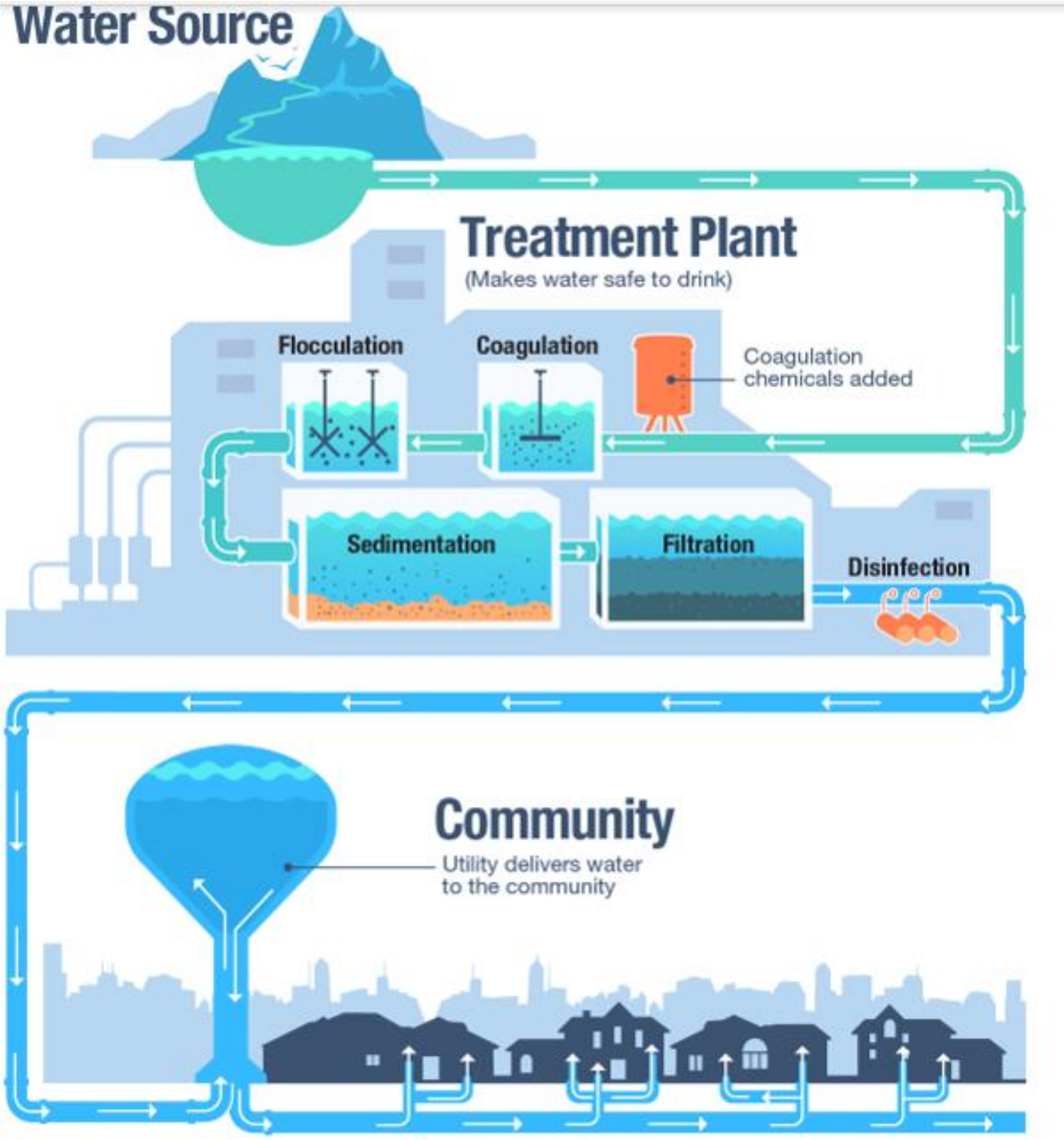

Figure 18. General Process of a Community Water Treatment Plant (Google Image)

1.9.2. Efficient Household Water Purification Technology.

1.9.2.1. Filtration

is a physical process in which suspended solid particles, dissolved organic substances or chemical ions and pathogens are removed from a fluid passing through any porous substance called filter. Water can be filtered using different types of filters depending on the purpose of the process. Electrically generated pressure or gravitational force can be used to force water molecules to move through a filter for purification.

A filter is any porous solid material which can allow fluid to pass through and can produce filtrate free or with limited number of impurities. They can be fabricated both locally and industrially using many types of materials including Clay, sand, Charcoal, Cotton Wool, Ceramic, Permeable Membrane fibres etc.

1.9.2.1.1 Characteristic of a Good Drinking Water Filter

- **Efficiency in Removing Impurities** A good filter should be a hundred percent efficient in eliminating what is considered as impurity from filtrate. Since different filters are adapted to be more effective in removing different impurities from water, one needs to understand the types of impurities in the water to use the correct type of filter (Mamchenko et al. 2009).
- **Rate of Filtration**. The amount of water filtrated in a day should be able to meet the demand required for a household or an individual.
- **Affordability**. A filter needs to be cost-effective and be affordable by low income earners which are the most vulnerable populaion.
- **Availability**. The presence of a filter in the local markets gives an individual the opportunity to acquire it at any time.
- **Maintenance**. A good water filter should be easy to repair and replace worn out parts.
- **Durability**. The filter should be able to last for long and still function efficiently.

- **Fabrication.** Filters that are manufactured by the local industries are always available and relatively cheaper than foreign ones.

1.9.2.1.2 Filters and Applications

1.9.2.1.2.1 Ceramic Filters

Household water ceramic filters depend on gravitational force. Water on the top reservoir is allowed to pass through a porous material made from clay, ceramic and carbon which is some time impregnated with silver nitrate. The material is capable of trapping micro-organism and impurities in the water that passes through and silver nitrate if present will kill the micro-organisms. The filtrated water which is stored at the bottom reservoir contain negligible number of impurities. Ceramic filters are cheap and can be found in many markets at affordable prices in various forms. Their efficiency in removing impurities was rated at 98 % and is recommended by UN for household (Lu 2001). On other hand the filters are not adopted to remove viral particles and chemical ions. Ceramic Filters are not manufactured in Cameroon which makes the prices more expensive for a lower income earner.

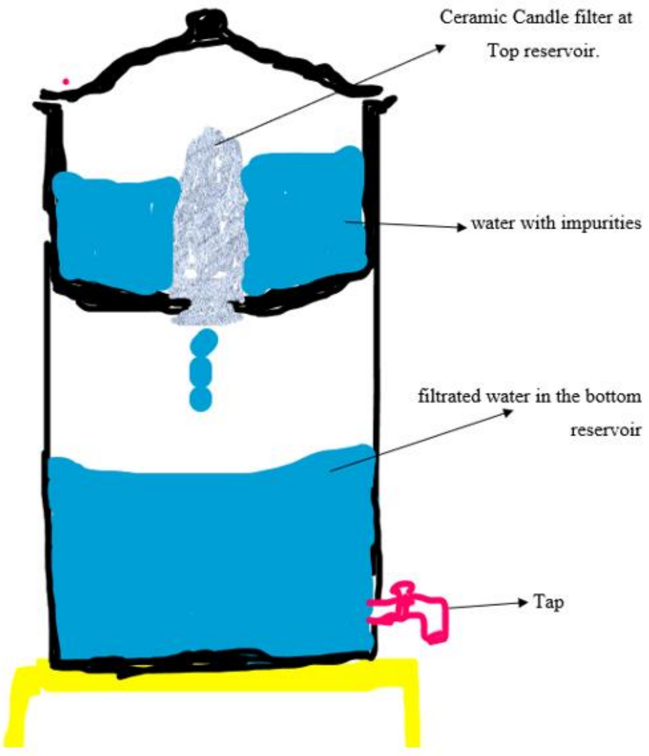

Figure 19. A Generalized Structure of a Ceramic Filter (Author)

1.9.2.1.2.2 Reverse Osmosis

is a process of water filtration in which water is forced to move through a semipermeable membrane from the side of high concentration to a side of low concentration. The system is usually made up of a minimum of three stages of filters. The first which is refer to as prefiltration or sediment filtration which remove suspended particles from the water, the second is the carbon filter which eliminates volatile organic compound, chlorine and odour from the water and the semipermeable membrane remove up to ninety eight percent of total dissolved solid (Ahmad & Azam 2019). However, the number of filters can be increased depending on the level of the contamination of the water to be filtered. This system of water treatment is very efficient and safe for drinking and the system is long lasting. On the other hand, it is very expensive to install. Even though the system is long lasting the filters needs to be replaced after every six months to one year.

Figure 20. An Installed Reverse Osmosis System at Home (Google Image)

1.9.2.1.2.3 Carbon Block and Activated Carbon

These are water filters made from charcoal block or granular charcoal be it activated or not. The charcoal filter water efficiently by its ability to easily form adhesive forces with some organoleptic compounds and metals ions removing it from water that passes through. Its porous nature makes suspended particles to be trapped absorbed into the charcoal. The activated carbon is made by subjecting charcoal under very high temperature which free the bonds making it more porous and susceptible to bind with other molecules. This property allows it to convert active contaminants like chlorine to chloride and efficiently remove pesticides and herbicides from drinking water (Gara et al. 2018). Despite the high efficiency of the filtration rate of carbon filters, dissolve salts cannot be removed by this method and the filters are also expensive for an average man in a developing country like Cameroon.

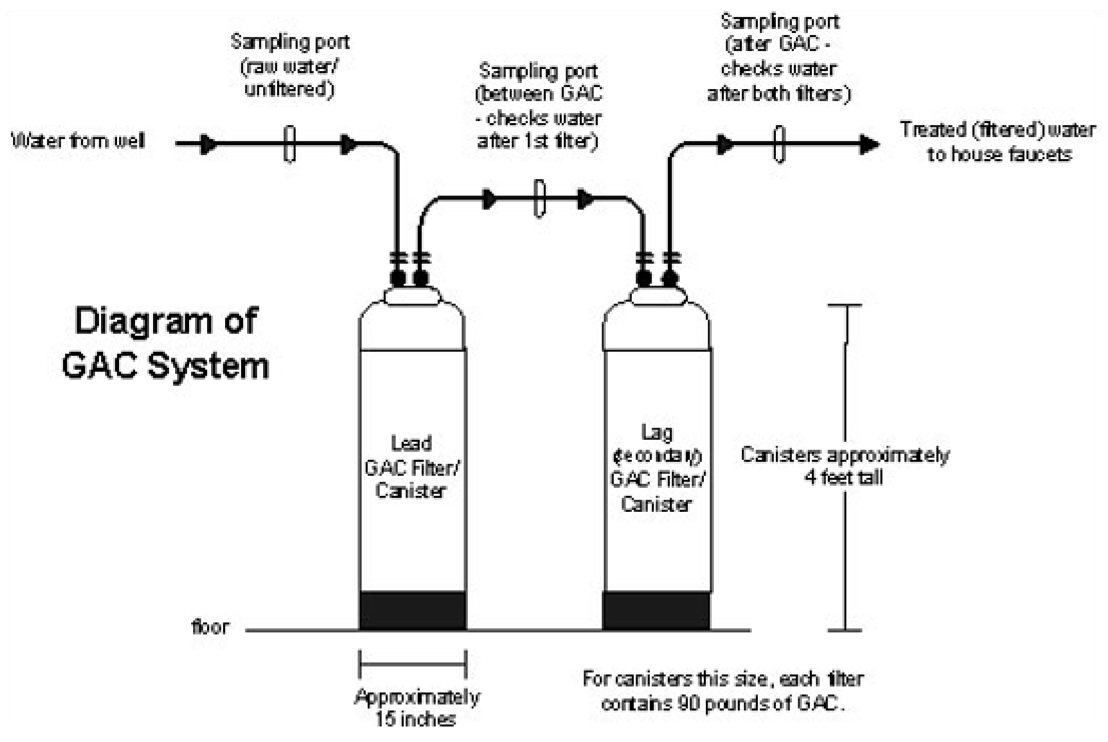

Figure 21. Flow Process of Granular Activated Carbon filter (Google Image)

1.9.2.1.2.4 Alkaline and Water Ionizer

It is a process in which Bio-ceramic and activated carbon filters are combined to filter water and the filtrated water is remineralizer with calcium and magnesium ions which raises the pH of the water more than seven. Alkaline water is usually oxygenated with antioxidant and free of contaminants. This provides a lot of health benefits. However, it is expensive and is mostly used in developed countries and high-income earners in the developing countries. The efficiency in purification is 100 % and the most highly recommended by WHO (Song et al. 2020).

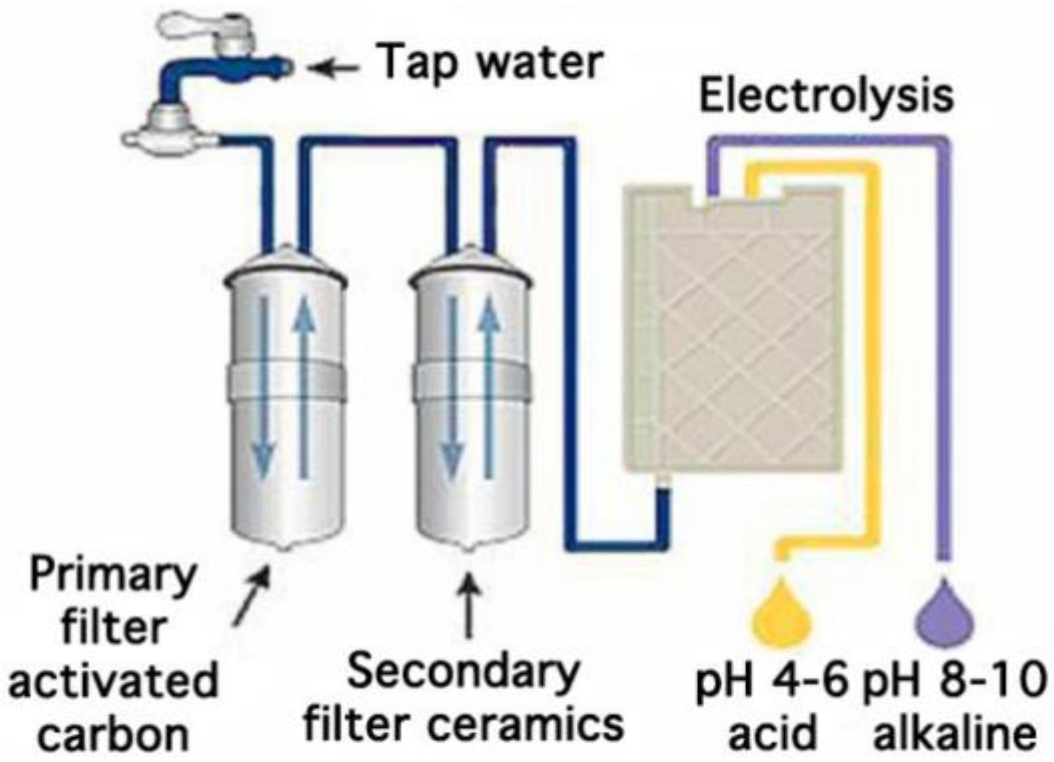

Figure 22. Functional System of a Household Alkaline and Ionizer Filter (Henry & Chambron 2013)

1.9.2.1.2.5 Activated Alumina (AL_2O_3)

Some countries are surrounded by oceans which flow during high tides into fresh inland water and increase their salt content. In this regard, it was necessary to adapt an efficient technique to desalinized marine water. It is also an efficient technology used for elimination of arsenic, and manganese from drinking water. An

Activated Alumina membrane can be incorporated in the Reverse Osmosis technology to extract salt from water. This will make the water soft and good for domestic activities. Although it is expensive, it is cost effective in countries with high scarcity of freshwater (Reshnyak et al. 2021)

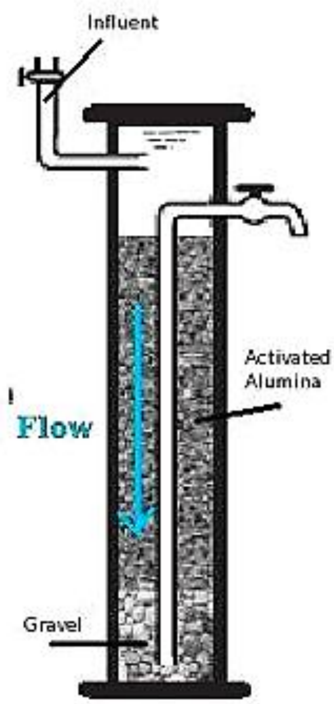

Figure 23. Alumina filtre (Swarnakar et al. 2016)

1.9.2.2. Distillation Method

It is a process in which impurities are separated from water by means of evaporation and condensation principles. The latent heat of vaporization is 2260 kj/kg the amount of energy required to evaporate one litre of water and this same energy will be required to condense the very amount of vapor back to liquid. Therefore 4520 kj/kg will be the amount of energy required to purified one litres of water (Ahmad & Azam 2019). Due to high consumption of energy this technology is best suited in countries where energy is cheaper and readily available example USA, China, Japan etc. The most sustainable distillation technology is adapted to use solar radiation as a source of energy, but the quantity purified per day is small. Since the technology depend on solar radiation, it will be unreliable due to inconsistency in weather conditions. This method is also recommended for desalination of sea Water. Water purified using distillation is 100 % pure but needs to be fortified with minerals ions (calcium and magnesium) before drinking (Speight 2020; Zewdie et al. 2021).

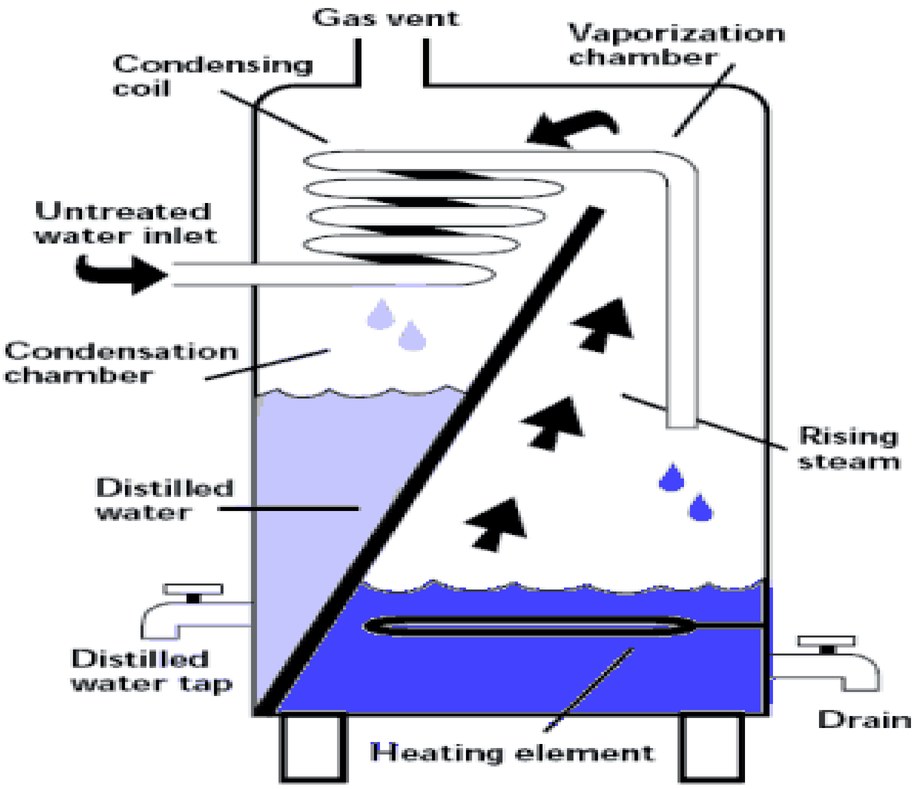

Figure 24. Electric Water Distillation System (Google Image)

1.9.2.3. Ultraviolet Light Water Purification Technology

It takes advantage of the germicidal properties of the UV wavelength at 253.7 nm. UV light at this wavelength, have the capacity to disrupt the DNA and RNA sequences of bacteria, viruses, protozoan and fungi in water rendering these organisms incapacitated. The higher the dose of the UV light the more effective the germicidal effect. The technology maybe conventional with the used of UV-Water Purifier Device that uses electricity and mercury to produce UV light for household or industrial water purification. UV-Water Purifiers are commonly used in the developed countries, and they are expensive and cannot protect the water against further contamination along a pipe.

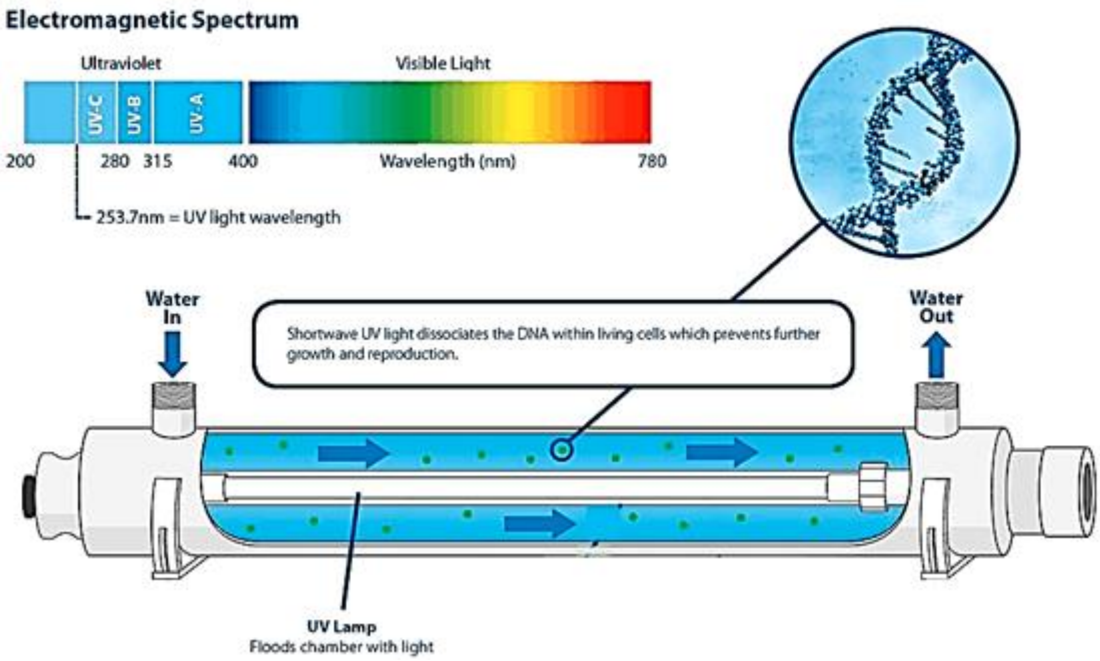

Figure 25. A UV Water Purifier Device (Google Image)

1.9.3. Local Technological Adaptation for Rural Household Water Purification in Cameroon

Before civilization, most African communities considered good quality water for drinking to be that which have no taste, no colour, and no smell. Water without any impurity that cannot be detected by human senses was considered healthy for drinking in most communities. This is because their knowledge of microbiology was limited and most biological diseases that affected humans were attributed to spiritual practices. The arrival of western civilization created awareness of the invisible impurities in water that cannot be detected by the human senses. After the independence of Cameroon, most rural communities were left without pipe borne water or modern water purification facilities. In this regard various traditional techniques are being used to increase the potability of water.

1.9.3.1. Sedimentation and Decantation

This method is being practice in rural areas where turbidity and TDS is a major issue for drinking water. water is kept in a clay container for the impurities to settle at the bottom and the supernatant is decanted for used. It incurred no cost, but it is not very efficient, and it has been abandoned by many communities affected by cholera epidemic (Ndam Ngoupayou et al. 2016).

1.9.3.2. Local Cotton Filters

It is a local technique which used cotton wool as a filter of water for drinking. The technique is mostly used by lower-income earners and those in the rural areas. It has high efficiency in reducing microbial load, turbidity and total dissolved solid from drinking water (SNV, 2017). But the scientific literature related to its efficiency in eliminating these impurities is unknown.

2. Aim

This thesis analyses the water quality from Sanaga River and the efficiency of a cotton filter and chlorine tablet to purify the water for drinking standard in a household to prevent cholera in the Nanga-Eboko community and low-income earners in Yaounde. Finally, to review the literature of other local sustainable water purification technologies and propose a better sustainable water purification techniques for the people in Nanga-Eboko.

2.1. Specific Objectives

- To align the performance of a locally made Cotton Filter with the general criteria laid down by WHO for filters to be used for household drinking water.
- To identify the major pollutants in the Sanaga river, correlate their possible sources.
- To propose a proper hygiene and sanitation scheme that will help to reduce the amount of pollutants released into Sanaga river.

3. Methodology

The procedure included comparative review of professional literature and scientific articles related to sustainable household water purification technology from the Ministry of Public Health in Cameroon, the National Archives Centre, recent Journals from WHO, FAO, Science Direct, etc. The next step was the collection of water samples from Sanaga River at Nanga-Eboko for experimental design in the laboratory. In the laboratory, the efficiency of a cotton filter in eliminating total coliform count, turbidity and TDS from the water was measured. The efficiency of chlorine tablet in eliminating coliform from filtrated and unfiltered water was also analyse. Lastly the result from both treatments were compared with the general guidelines for drinking water from WHO. Other local sustainable purification technologies used in other rural communities were reviewed and compared with cotton filter and the most sustainable and efficient technology was proposed for the population of Nanga-Eboko which will help to prevent cholera epidemic and other water borne diseases in the community.

3.1. Study Area

Nanga-Eboko is a small urban community which lies along River Sanaga about 131 km northeast from Yaoundé central city with geographical coordinates at latitude 4.674024 and longitude 12.375027. The total number of inhabitants is estimated to about thirty thousand on a total surface area of seven thousand kilometres squares. The city is bordered at the north by the Sanaga River which is a permanent source of water for the inhabitants of Nanga-Eboko and for Yaounde city. Nanga-Eboko is among the communities located less than one kilo meter to Sanaga River as shown on figure 26 and most of the inhabitants fetch water directly from the river for domestic activities especially during the dry season.

Figure 26. Communities in the Centre Region located nearest to Sanaga.

3.2. Justification

Nanga-Eboko is an urban periphery with a very fast-growing population. About 60 % of the inhabitants are less privileged farmer with limited knowledge of environmental Awareness. The inhabitants of this community are faced with enormous, improved drinking water supply crisis especially during the dry season. The scarcity of improved water supply had pushed the inhabitants of this community to used surface running water for drinking and other domestic activities. Among the various surface water, River Sanaga is a prominent source that do not dry during the dry season.

The prevalent of cholera in the community has been attributed to the source of water and household purification technology. According to Cameroon Ministry of Public health, “more than 90 % of the cholera cases in Nanga-Eboko comes from the group of people who are still using locally designed household water purification technology. Moreover, about 30 % of the population of this community used cotton filter and chlorine tablets to purify water fetch from Sanaga river for drinking”.

3.3. Data Collection

I personally collected the water samples from the common location where the inhabitants usually fetch water for their domestic activities as shown on figure 27 below. Two plastic containers measuring five litres each were washed with distilled water, dried, and sterilized with concentrated alcohol at ninety-five percent. The samples were collected on the 18th of January 2023 in the evening following WHO guidelines for drinking water. To avoid contamination of the samples during collection from the hand of the author. The container was strictly held from the handle lowered into the river and water flow into the container as shown on figure 27 below. The containers were corked labelled as raw river water (RRW I) and placed in an ice bath to maintain a temperature below four degrees Celsius and transported to a laboratory at the Department of Hydrobiology in the University of Yaounde I where the samples were immediately analysed.

Figure 27. Author Collecting Water from Sanaga River (source: Author)

3.4. Experimental Design in the Laboratory

I personally designed a cotton filter following the techniques used by the inhabitants using the available local material. A one litre plastic bottle, and a five-litre plastic bottle container was used for the design as shown in figure 28 below. All were properly washed and sterilized with alcohol to prevent contamination.

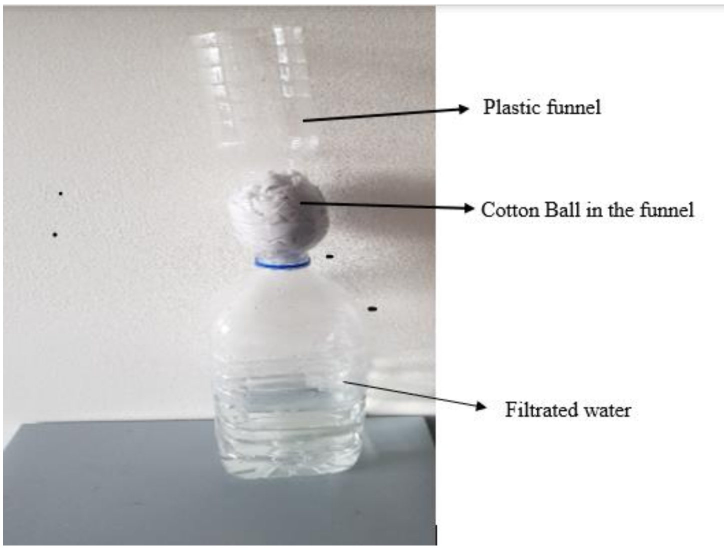

Figure 28. Cotton Filter Used to Filter Water Samples in the Laboratory by the Author (source: Author)

A ball of cotton was pressed tight fitted in the mouth of the one litter plastic bottle container that was cut from the bottom. The container was inverted into the mouth of a five-litter plastic container. One of the five litres of raw river water was filtrated by pouring through the funnel. The time taken for the water in the funnel to completely filtrate through the cotton down to the plastic reservoir at the bottom was recorded. The filtrated river water at the bottom of the container was divided into two portions labelled FRW and FRW1. The unfiltered part of the raw river water was also divided into two portion and labelled RRW and RRW1.The rate of filtration(r) was calculated by dividing the total volume(v) of water filtrated by the time taken(t) in hours.

$r = \frac{v}{t}$ ……………………………. Equation (1)

The samples FRW1 and RRW1 were treated with chlorine tablets locally known as 'aqua tablets.' The physios-chemical, and bacteriological content of the four (FRW, FRW1, RRW, and RRW1) samples were analysed at the same time using the WHO guidelines.

3.5. Physio-Chemical Analyses

A TDS-EZ-meter (figure 29a), turbidity meter (figure 29b) and a Paper Strip (figure 29c) were used to measure the following parameters TDS, pH, Lead, Iron, Nitrate, Nitrite, Hardness, Hydrogen Sulphide, Free chlorine, Cupper, Arsenic, Sulphate, and Manganese for all the four samples using the procedure outlined by the WHO (Dumitru et al. 2020). The efficiency(E) of performance of chlorine and cotton filter were obtained for each parameter using the formular.

$E = \left[\frac{a1-a2}{a1}\right] * 100$ ……………………. equation (2)

Where, E is efficiency in percentage,

a1 is measured quantity of a certain parameter in unfiltered river water,

a2 is measured quantity of the same parameter in the corresponding filtered river water.

All samples were at room temperature in the laboratory during the analytical process. Four glass bowl were washed with distilled water and a portion each of separate sample was place in a separate bowl. The TDS was obtained by recording the reading from a TDS-EZ meter that was place into each glass bowl of the respective water samples. The turbidity meter was used to measure the turbidity following the Hect’s 2100Q guideline (Kofa et al. 2017). This method measures the amount of light rays that pass through the water from a source of emission. The turbidimeter was set at a wavelength of 150 nm, and each water sample was place in the chamber for reading (figure 29b). A paper tissues was used to clean the side of the glass before insertion into the measuring chamber after each measurement. The turbidity was recorded from the electronic reading on the board for each sample. Paper Strips bought from a pharmacy was used to measure the rest of the parameter at the same time for each water sample. Each of the samples was placed in a separate test tube and a Paper Strip was deep inside for ten seconds and it was removed. The colour change at the different bands along the paper strip was used to compared with the colour on the reference Chart as shown on figure 29c. The corresponding value of each colour on the band from the chart was recorded against the respective parameter. The different colours for a particular parameter corresponding to a specific value on the reference chart was recorded.

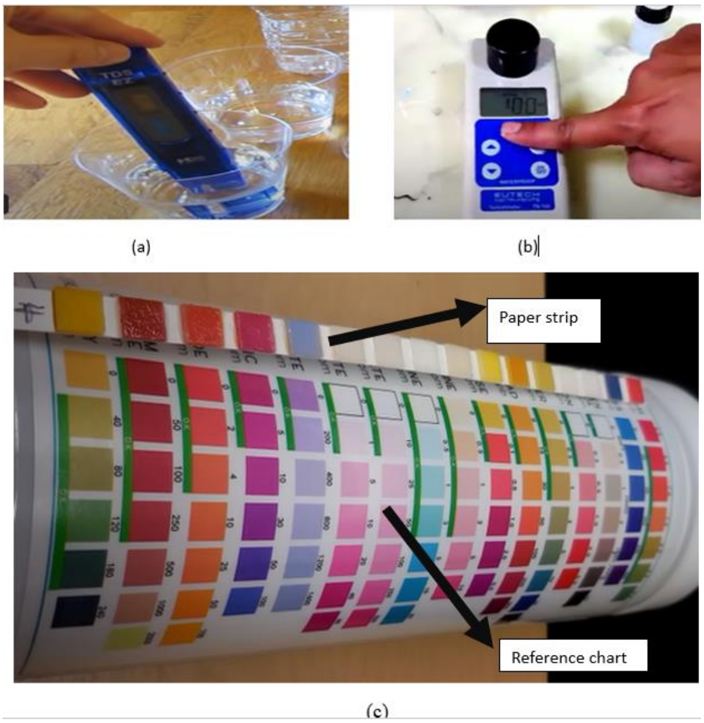

Figure 29. Measuring the TDS (a), Turbidity(b) and paper strip(c) (Author)

3.6. Bacteriological Analysis

A Multiple Tube Fermentation experiment was done using lactose broth as nutrient source. A lactose broth was prepared and place in fifteen test tube divided in three group A, B and C each containing five test tubes. In Each of the five-test tube in group (A, B and C) a water sample of 10ml, 1ml and 0.1m was put in it respectively using a twenty-mil dropper. The procedure was done for all the samples labelled with stickers. The test tubes were incubated at a temperature of thirty-five degrees Celsius for twenty-four hours. After the incubation period, the number of test tube with bubbles in each group were record in combination of A-B-C. The number combination was used to correlate the estimate total coliform count unit per 100mL from an MPN table reference in the laboratory. The experiment was repeated for all four water samples (RRW, RRW1, FRW, and FRW1). Figure 30 below shows the researcher incubating water samples in the laboratory of hydrobiology at the University of Yaunde I

Figure 30. Incubation of Samples in the Laboratory by the Author (source: Author)

4. Results

4.1. Laboratory Results

The results that were obtained by the researcher on physio-chemical and bacteriological analyses of the water samples from the laboratory are displayed on table 3 below. Column 1 shows the parameters or properties of the water samples that was investigated while column 2 shows the unit of measurements of the various parameters and column 3 to 6 shows the measured value of each parameter in the respective water samples that were prepared in chapter 3.4. Column 7 shows the WHO accepted limit values for each parameter for drinking water samples.

Table 3. Laboratory Result of Water Samples From Author

Parameters	**Units**	**RRW sample**	**FRW Sample**	**Chlorinated RRW1**	**Chlorinated FRW1**	**WHO Limit**
TDS	mg/L	800	80	800	80	500
Turbidity	NTU	6.1	2.2	6.1	2.2	5
pH		6.9	7.1	8.1	8.1	6.5 – 8.5
Temperature	ºC	30	25	25	25	
Lead	mg/L	0.03	0.01	0.03	0.01	0.01
Iron	Mg/L	0.6	0.01	0.6	0.01	0.2
Cupper	Mg/L	0.22	0.00	0.22	0.00	2
Fluoride	Mg/L		0		0	1.5
Nitrate	Mg/L	0.26	0.18	0.26	0.18	11.3
Nitrite	Mg/L	0.012	0	0.012	0	1
chlorine	Mg/L	0	0	12	19	0.0003
Sulfate	Mg/L					
Manganese	Mg/L	0.1	0.1	0.1	0.1	0.200
Hardness		84	35	84	35	
Ammonium	Mg/L	0.1	0	0.1	0	0
Aluminum	Mg/L	0.22	0.12	0.22	0.12	0
Total coliform	CFU/100mL	210	20	3	0	0
Arsenic	Mg/L	0.01	0	0.1	0	0.10

4.2. Data Analysis

Water purification using cotton filters is an old practice in Nanga-Eboko which aim has been to reduce the physio-chemical, Viral, and bacteriological load of water to eliminate the related health risk of consumers especially cholera. The TDS, nitrate, and nitrite content of the raw river water sample from Sanaga was lower compared to the WHO guideline limits. This is because the water sample was collected in the month of December which is the heart of dry season in Cameroon. These three parameters are usually higher in the rainy season because of runoff from nonpoint source pollution both from residential and farmlands (Wotany et al. 2019). The high turbulent nature of the river run across soluble rocks, stone and sand which is mostly oxides of silicon and other volcanic metals ions which dissolved into the water and render it slightly acidic but still within the recommended range of the WHO (Rakotondrabe et al. 2017). Although the raw water samples were collected during the dry season, the total coliform count load was very high (210/100ml. CFU) which is detrimental to human health. Even though there are many free-living Coliforms but their present in this river in a very high load during the dry season maybe an indication of a point source pollution in the city precisely human and animal faeces. These could be evidence of leaching from nearby Septic tank, latrines, Sanitary Landfills, sewages from range farm and slaughterhouses as well as direct defecation into the river. This can be correlated with data from WHO on figure 8 of chapter 1.4.3. which proved that the sanitary condition of rural areas in Cameroon is below 50 %. Moreover, temperature of thirty degrees Celsius of a water body provides a suitable growth medium for the Coliform colonies in the river. However, river duellers at the upper stream in most parts of the country usually have no concern about the detrimental effect of their activities to the people downstream (Sanou et al. 2015). The temperature of the water sample at the river side was higher because the water samples were collected in the evening after sun has heated the river while in the laboratory the temperature of the samples became in an equilibrium with the room temperature which is substantiated with the first law of thermodynamic. The TDS and total coliform count of the FRW samples was recorded as 80 and 20 respectively therefore, the efficiency of a cotton filter was rated at 90 % and 95 % respective using the equation (2) provided in the methodology above. This result aligned with that of SNV in 2017 in which Cholera incident in rural areas of the Littoral region was reduce by the used of cotton filter for household treatment of drinking water (SNV 2017). The efficiency of chlorine tablets in eliminating total coliform count from both RRW 1 and FRW 1 was recorded at 98.57 % and 100 % respectively. The lower performance of the chlorine in the RRW1 sample is due to the higher TDS and turbidity which was demonstrated by WHO in 2015. Lastly the pH values of both samples (RRW1 and FRW1) were raised to 8.1 in the application of chlorine tablets. This is because chlorine ionizes in water to form hypochlorite acid (OCL^-) the free anion in the water helps to raise the pH.

4.3. Proposed Technology

Comparing the laboratory result of this research and with those of Camwater, it is concluded that turbidity, TDS, and microbial load resulting from organic waste are the major threat to drinking water in Cameroon. This is because of poor sanitary situation of the country which resulted to high pollution of surface water. Therefore, purification needs to start from the river course to minimize the amount of pollutant that entered the river. This will help to enhance the performance of the local household purification technologies. Since Nanga-Eboko is a peasant community with majority of the population living below the poverty line of $ 1 per day, a sustainable technology for water purification is needed. Sustainable Technology is that which can be designed and managed using cheap and locally available materials and the functionality is well understood by the local population.

4.3.1. Mitigating Pollution Along the River Course

The used of aquatic plants and animals to eliminate pollutants along a water course has been proven cost effective by many researchers. Filter feeding and scavenging by crustacean and mollusc (oysters and Bivalves) were proven to be very efficient in reducing the amount of organic nutrient in water body. They also help to facilitate sedimentation of organic matter at the bottom of the river thereby reducing the turbidity and the total suspended solid (TSS) particle in the water (Sun et al. 2021). The introduction of these organisms into Sanaga river will be cost effective in the long term. The creation of a buffer zone along the river course will help to mitigate pollutant from both nonpoint and point source pollution. A buffer zone is a constructed trench near the river filled with sand and stones and algae, macrophytes (*Commelina benghalensis, Ipomoea aquatica* etc) together with bacteria are allowed to grow on it. Sewage from industries and runoff from farmlands are filtered through the sand in the buffer zone before joining the river course. The nitrate, phosphorus and organic matter trapped at the buffer zone are used by bacteria and plant as nutrient for growth. The distance between the buffer zone and the littoral zone of the river is occupied by shallow rooted plants (*Paspalum conjugatum, Cyperus distans etc*) that prevents erosion and keep the soil dry. Most of these plant contain symbiotic chemosynthetic bacteria which convert organic matter and other forms of nitrogen to nitrate needed by the plants. At the littoral zone of the river partially submerge and submerge plants like Elodea and Nymphaea are introduced to reduced nitrate and carbon dioxide while they produce oxygen in the process of photosynthesis. In any balance aquatic ecosystem, self-purification takes place in space and time if anthropogenic effects are best controlled (Dhote & Dixit 2009). The high turbulence nature of the pelagic zone of the river facilitates self-purification with time and space (Soda et al. 2013).

4.3.2. **Microbial Treatment of Household Drinking Water**

The high load of micro-organisms in the raw river water sample from Sanaga and the inefficiency of cotton filter to eliminate it from filtrate. This justifies the prevalent rate of cholera among low-income earners in Nanga-Eboko.

4.3.2.1. Boiling

This is the oldest method of purifying water, and it has been the most frequently used method for treating drinking water for new-born babies in most rural areas in Cameroon. It has been proven very effective in reducing the prevalent rate of polio and cholera among children below the age of five (World Bank 2021). Boiling is a physical technique in which water is boiled at a hundred degree Celsius for more than thirty minutes. At this temperature and duration no micro-organism can survive rendering the water sterile. During the boiling process some dissolved substances like calcium carbonate, magnesium is precipitated out of water. Despite its ability to makes water sterile, it requires filtration to remove suspended particles and reduces turbidity. The water is allowed to cool aerated before consumption.

4.3.2.2. Chlorination

It is common to find chlorine in the form of tablets with a commercial name ‘aqua tablets’ in most local markets in Cameroon. This chlorinated tablet sold at $ 0.82 can be dissolved in a gallon of water instantly eliminating about 99% of water borne pathogen (Nganje et al. 2020). This method has been effective to overcome Cholera Epidermic in most rural communities due to it bleaching ability which enable it to kill pathogen in water. However, ‘aqua tablets’ are always not available due to limited supply. Its efficiency is limited by the level of water turbidity (Mvongo & Defo 2021).

4.3.2.3. SODIS (Solar Water Disinfection)

The most sustainable application for UV-light purification technology which is adapted in rural areas of developing countries is called SODIS (solar water disinfection). The sun light is made of about 44 % visible light and 5 % UV-light Water in a transparent plastic bottle is kept under the sun for a period of at least six hours to eliminate pathogens. The germicidal properties of the sun rays come from its ability to disrupt protein sequences and nucleotide of DNA and RNA. This action will render a micro-organism inactive and unreproductive. The effectiveness of this technology depends on the turbidity of the water. The higher the turbidity the lower the ability to eliminate pathogen (Sakthivadivel et al. 2020). This method is not reliable due inefficiency and uncertainty in weather conditions. In recent years researchers have developed a photocatalytic water treatment container to combine with SODIS to obtain a better result. This container is made from special materials such as graphene and magnetic iron oxides that captured and amplifier the visible portion of light but the result of this research has not yet been proven successful out of the laboratory (Cowie et al. 2020).

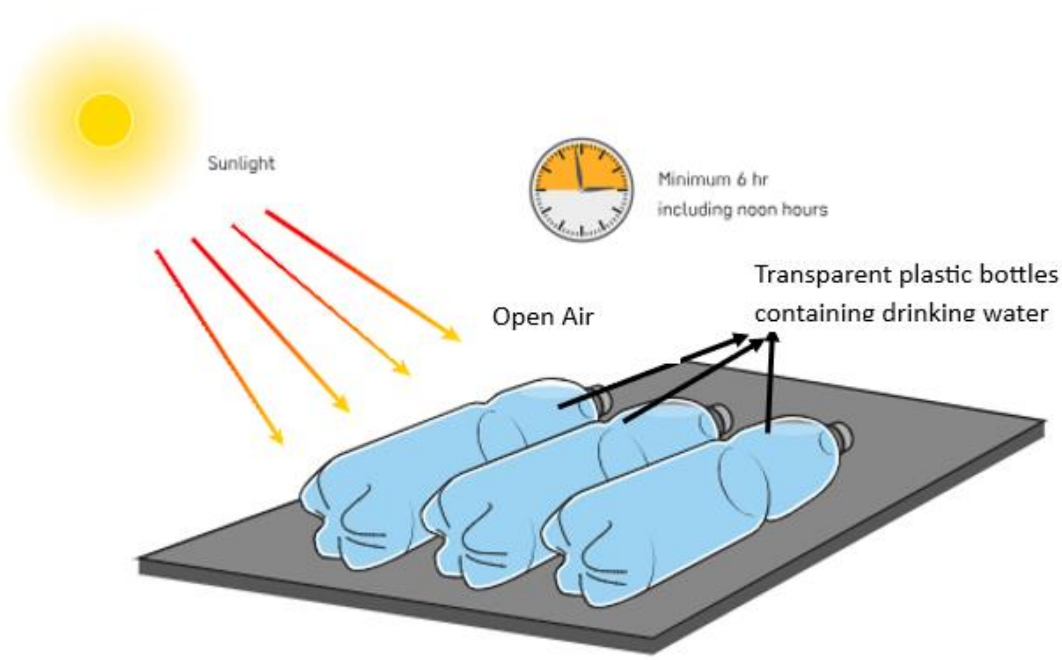

Figure 31. Solar disinfection of drinking water using transparent plastic bottles (source: Author)

4.3.3. Treatment of Turbidity and TDS

4.3.3.1. Solar Distillation

The most sustainable distillation technology is adapted to use solar radiation as a source of energy (passive). The total surface area required for these techniques is at least six-meter square for it to be effective. The used of solar still that captured solar energy to produce heat that raise the temperature of the polluted water. At 100 °C water evaporate leaving behind the pollutant that required higher temperature for evaporation. The rising vapour is then trapped by a glass at the top which force it to condense losing its energy and flow into a collector. Some of the limitation of these technology is that the quantity purified per day is small. Some pollutants with boiling points less or equal to 100 °C cannot be separated easily by this method. Since the technology depend on solar radiation, it is unreliable due to inconsistency in weather conditions. Solar still used for this technology are costly for a low-income earner in the rural areas. Water purified using distillation needs to be fortified with minerals ions (calcium and magnesium) before drinking (Speight 2020; Zewdie et al. 2021).

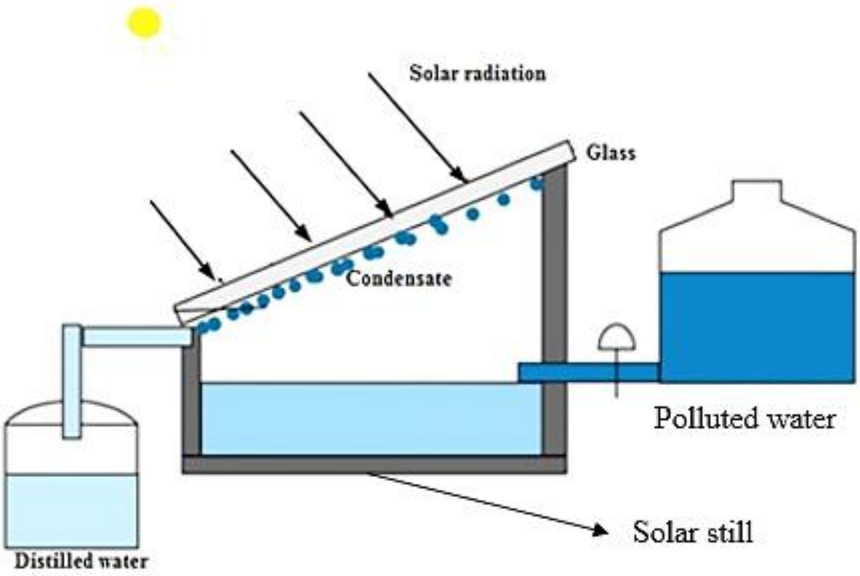

Figure 32. Solar Water Distillation Technology (Sakthivadivel et al. 2020)

4.3.3.2. Bio-sand Filter.

It is made up of three functional layers that help to remove suspended particles and micro-organisms from water. The first layer(biological) which is refer to as Diffused Layer is a thin membrane regularly perforated covering the sand layer. It helps to keep the sand layer steady and filter large particles that pass through. It also helps to keep water uniformly filtrated over the sand instead of creating a flow channel. The sand filter suspends particles and microbes from the infiltrated water before it reaches the gravel layer where it is collected in the drainage. The gravel layer only helps to support the sand and prevent it from entering the drainage. This method is extensively used for household and small community water supply in most developing countries because of its efficiency (up to 95% impurities is eliminated from filtrate). It is relatively cheap and can be used for a period up to ten years depending on the body frame material used (O'Connell et al. 2018). The filtrate will require chlorination to eliminate micro-organism to obtain the standard of WHO.

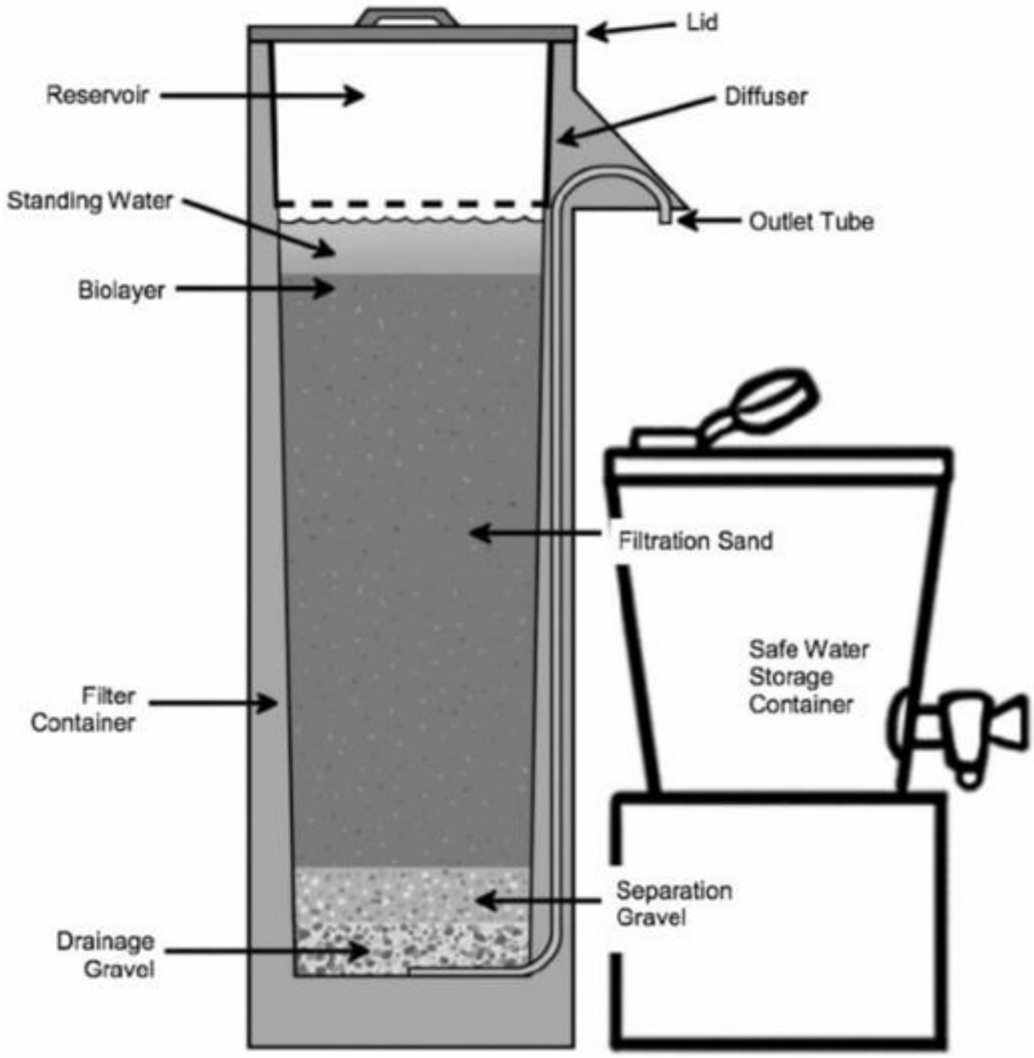

Figure 33. A Household Bio-sand Filter set-up (O’Connell et al. 2018)

4.4. SWOT Analysis

This technique was used to compare the different sustainable household water purification technologies and proposed the most effective one to be used by low-income earners in Nanga-Eboko and suggest the possible ways to improve the performance of the technology that can best be adopted by the low-income earners for household water purification against cholera.

Table 4. SWOT Analysis

Technology	**Strength**	**Weakness**	**Opportunity**	**Threats**
Boiling	Cheap. Water is sterile	Turbidity cannot be reduced	It can be replicated	Scales are produced
Chlorination (aqua tablets)	Cheap.	Not always available in the rural areas	It prevents further contamination	Chemical residue effect
SODIS	Cheap. Uses solar energy from the sun.	Weather conditions are unreliable	It can be investigated further	Some microbes are still present
Solar distillation	Cheap. Uses solar energy from the sun	Very limited amount of water is produced a day.	The technology can be enlarged	Organic volatile pollutants remain
Bio-sand filters	Cheap. Uses locally available material	Not very efficient	Easy to be managed and improved	Some microbes are present
Cotton filter	Cheap. Uses local available materials	It requires regular attention	Easy to be managed and improved	Some microbes are still present.

5. Discussion

5.1. Sustainable Household Water Purification Technology

Water purification technologies for drinking has been a major issue in most communities in Cameroon. This is due to financial constraints and technological underdevelopment of the country. To overcome household water supply crisis and prevent recurrent cholera epidemic in the country for the meantime, there is a need to improve a locally existing technology or proposed a technology that is affordable by low-income earners. An ideal household water purification technology according to WHO is that which can maintain good health of the consumer throughout his lifespan (WHO 2022). The cheapest and less efficient household water purification technology is SODIS, Bio-sand filter and cotton filter with less than 98 % efficiency rate of eliminating water borne pathogen. These methods are sustainable but do not meet the criteria for a household water purification technology prescribe by WHO (Denise et al. 2022). Solar distillation is very efficient in eliminating all pathogens, but it is unreliable since it depends on weather conditions. Moreover, solar panel are not designed in Cameroon this had made solar distillation dearth in Cameroon. Therefore, boiling and chlorination remain the best option to prevent water borne disease from Sanaga river since these two technologies can eliminate all pathogens from drinking water at a very low cost if it is properly used despite their inability to reduce turbidity and TDS (Clopeck et al. 2006). This is why chlorine tablet are often distributed for free in the rural communities in Yaounde by WFP which has help to reduce cholera incident in Cameroon.

5.2. Aligning the Performance of a Cotton Filter

According to the laboratory result of the research compared to that of CAMWATER, it was concluded that Sanaga river is faced with high microbial load, turbidity, and TDS (Denise et al. 2022). To overcome the cholera epidemic in Nanga-Eboko, the elimination of the total coliform count from filtrated water must be 100 %. To align the performance of a cotton filter to the standard of WHO for a household drinking water purification, all the physio-chemical and microbial property of the filtrate must be within the prescribe limits as shown on table 3 in chapter 4.1. (WHO 2022).

Since the cotton filter can reduce the turbidity and TDS of water below the accepted limit of WHO, any knowledge that can make it produce zero coliform filtrate can make it a standard filter for the people of Nanga-Eboko. The first method of improvement is to combine the used of chlorine tablet with cotton filter. According to experimental section of this thesis, chlorine tablets are 100 % efficient in eliminating total coliform from filtrated water. This suggestion aligned with the findings of SNV in 2017 for the fight against cholera epidemic in Cameroon. The second and most sustainable method is integrating the process with boiling. Water from Sanaga needs to be boiled first and allowed to cool before a cotton filter is used for filtration. This procedure will eliminate all coliforms and reduces TDS and turbidity below the threshold of WHO. During the filtration process oxygen is allowed to be dissolved into the water which help to improve the value of the filtrate for drinking (Chen et al. 2020).

5.3. Environmental Awareness and Source Pollution

High load of coliform present in the raw river water sample indicates contamination from animal faeces. This is because the sanitary conditions of the community are very poor and many individuals still practice open defecation. This is substantiated by finding of WHO on the Wash data on figure 9. which shows that 20 % of Cameroon practice open defecation and 30 % have unimproved sanitary facilities (washdata, 2022). The main reason for poor sanitary situation of the country is low environmental awareness and high level of illiteracy (Hou et al. 2019). Basic domestic hygiene and environmental awareness training programs involving women and children needs to be established in Yaounde and school establishments in the country.

5.4. Projection

Nanga-Eboko is fast growing in terms of population which means that waste generation will increase in the nearest future as projected by WHO in 2022. Urbanisation usually bring more water supply and purification challenges. The finding of SNV in 2017 shows the volume of the river is reducing as settlement increases around the river. These will increase the amount and type of pollutants present in the water in which local purification technologies like Bio-Sand filter, Cotton Filters and SODIS will not be able sustain (Hou et al. 2019). Therefore, a modern community water supply plant is needed in Nanga-Eboko to prevent future water supply crisis and it associated diseases in the community.

6. Conclusion

The major issue of purifying surface water for drinking in Yaounde is the presence of faecal coliform alongside turbidity and TDS arising from non-point source and point source domestic pollution which is the main cause of frequent cholera epidemic in the country. A Cotton filter with a filtration rate of 3 l/h, had an efficiency to eliminate total coliform, turbidity, and TDS from raw river water at 90 %, 97 % and 92 % respectively. While the used of chlorine tablet was investigated in both raw river water and cotton filtrated river water in total coliforms elimination and the result was 98.57 % and 100 % respectively. Following the WHO guideline, the total number of coliforms units accepted in drinking water is zero. Therefore, Cotton filters cannot be a reliable sustainable technology for purification of drinking water for a household to prevent cholera. Chlorine tablet or boiling should be integrated with either a bio-sand filter or a cotton filter to achieve a perfect result acknowledge by WHO for drinking water. To put the results of this thesis in practice, a water management committee should be trained on environmental management education and the proper used of cotton filter. This committee will be responsible for educating the population of Nanga-Eboko and managed the sanitation situation of the community drinking water source.

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