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Master's thesis

in specialty (specialization) 101 "Ecology", "Engineering ecology and resource conservation"

on the topic: "Information-analytical system and research on the impact of coastal pollution and degradation on West Africa"

Completed: student 2 course, groups ОЗ-91мп
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I certify that in this master's degree dissertation no borrowings from works other authors without relevant references.
Student ______________
(signature)

Kyiv – 2020.

The dissertation is a manuscript.

The work was performed at the Department of Engineering Ecology at the National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky" of the Ministry of Education and Science of Ukraine.

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Reviewer - Associate professor, PhD., Polukarov A. I., Department of Labor, Industrial and Civil Security, National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky.

The defense will take place on December 24, 2020 at 10am at the meeting of the examination commission №_237/20-ci_ at the National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky" at the address: 03056, Ukraine, Kyiv, st. Borshchahivska, 115, room 201.

1.1 General characteristics of the work

Relevance of the topic. Most of the countries in the West African sub-region are emergent nations which, for a long time, have been considered to be a part of the Less Developed Countries of the world. Due to their low level of development in these countries, they have generally considered economic growth, social and educational development and industrialization as a key development priority, while protection of the environment has not been given the same importance. Hence, the need for an information-analytical system on coastal ecosystem protection in West Africa. Also, the need for a better and stable economic value in West Africa with focus on the impact of coastal pollution and degradation. Another important issue is the availability of portable drinking water in coastal areas which have been threaten by several factors, making the water polluted and unsafe for consumption and domestic usage.

The purpose of research. Coastal pollution and degradation has got a major influence on the GDP of most West African countries, thus, the need to identify the driving coastal pollutants and find appropriate mitigation strategies and an information-analytical system. Particular attention should be given to the types of waste generated in these coastal areas and propose a way of minimizing its effects.

– **To fulfill the purpose of the research the following tasks were solved:**
– creation of an information-analytical system for the West African regions on coastal pollution and degradation;
– development of a purification system that will help reduce the risk of water pollution in coastal areas;
– determination of natural and anthropogenic factors of influence on the coastal ecosystem in West Africa;
– research on the impact of industrialization on West Africa’s coastal areas;
– determination of levels of anthropogenic burden on coastal ecosystems;
– search for effective methods of dealing with water pollution in the coastal areas of West Africa.

Object of study – coastal pollution and degradation in West African regions.

Subject of study – information-analytical system and research on the impact of coastal pollution and degradation.

Research methods. Analytical, theoretical methods of research and methods of mathematical processing of experimental data were used in the implementation of the work.

Scientific novelty of the obtained results. In the work was proposed an integrated approach to assess the state of water pollution on the coast of West Africa, conducted multifactorial analysis, which takes into account the sources of pollutant formation of aquatic ecosystems on the coastal water areas.

Practical significance of the obtained results: to inculcate the results of research findings on coastal pollutants that cause major pollution and degradation to environmental agencies to review and update management strategies in West African countries.

Publications. Four papers in the conference proceedings of the International Conference (<Problems of Energy Management System - PEMS)> in spring, 2020 http://pe$s.kpi.ual. Date: spring, 2020 and another one).

Two publications in the peer-reviewed scientific journals ("Energy: Economics, Technology, Ecology" and another one, Date: 2020.

1.2. The structure and scope of the dissertation.

This research work has been divided into five parts. The dissertation talks mainly about the information-analytical system of coastal pollution and degradation focusing on a development for promoting economic stability in West African countries. The dissertation also looks at finding mitigation processes with regards to the various sources of coastal waste materials that are generated in the West African regions.

1.3. The main content of the work

In the **introduction**, the relevance of the thesis theme is substantiated, the purpose of the work is laid out and scientific research tasks are formulated to achieve the goal, the scientific novelty and practical value of the work are presented.

In the first chapter climate influence and impact of pollution based on the information-analytical system is mentioned. The relevance of the research is emphasized. An information-analytical system is also developed focusing on the coastal pollutions. The coasts of West Africa are home to large marine ecosystems (the Canary Islands, Guinea and Benguela currents), mangroves, wetlands and several hundred species of fish. With more than a third of the region's population living along the coast, these natural assets allow several million people to live off the resources of fishing, aquaculture and tourism. However, the West African marine and coastal environment is under pressure from a multitude of threats that seriously affect its health and the populations that depend on it: coastal erosion, the impacts of climate change and ocean acidification, but also of the development of offshore activities, overfishing, land-based pollution [2]. West Africa’s coastal areas host an abundance of natural resources, on land and at sea, that provide an important ecosystem services and help serve as intermediate against severe weather events. These resources play a key role in the economic and physical resilience of coastal regions to existing and future challenges [3].

Again, the climatic conditions in the West African coastline is explained. West Africa, is defined to include the western portion of the Maghreb (Western Sahara, Morocco, Algeria, and Tunisia), which occupies an area in excess of 6,140,000 km2, or approximately one-fifth of Africa. The vast majority of this land is plains lying less than 300 meters above sea level, though there is isolated high points exist in numerous states along the southern shoreline of West Africa [5].

Rising sea levels will impact all West African countries (although to varying degrees relying on each country’s coastal environment), exacerbating coastal erosion rates. Over a period of time, this will result in a greater number of people beings being exposed to chronic and episodic disasters, such as loss of coastal homes and land, loss of wetland aquaculture areas, saltwater intrusion impacts to drinking water, and loss of inland homes that are within extended flood zones. While the data on actual impacts in West Africa are quite scanty, one study indicates sea-level rise impacts for West African coastal countries [1].

Quality of the coastline water is also detailed in this chapter. This project focuses more on the aspect of water pollution in the coastal areas of West Africa, with particular emphasis on the waste that is accumulated from various sources (ships, people, industries, etc).

Water pollution, amongst the other forms of pollution in West Africa plays a vital role in the economic status of the countries in these regions. Surface water pollution is very imperative, though on a quite local scale. However, the heavy runoff associated with perennial rainfall may make it less severe in terms of its impact. Lots of small and heavy industries involved in activities such as battery and paint manufacturing, petroleum refining, cement and ceramic production, steel production, are now being found haphazardly, mostly close to metropolitan centers. No existence of centralized sewage systems, and the industrial effluents from the factories are usually discharged untreated into streams, lagoons, open drains and other water bodies. This has resulted in high, although not alarming, levels of lead, cadmium and copper in some localized areas [9]. Some waste materials have been categorized (solid waste, liquid waste and gaseous waste) and the sources of these waste materials have also been outlined.

The quality and specialty of rainwater is discussed. This project focuses more on the aspect of water pollution in the coastal areas of West Africa, with particular emphasis on the waste that is accumulated from various sources (ships, people, industries, etc).

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Surface water pollution is very imperative, though on a quite local scale. However, the heavy runoff associated with perennial rainfall may make it less severe in terms of its impact. Lots of small and heavy industries involved in activities such as battery and paint manufacturing, petroleum refining, cement and ceramic production, steel production, are now being found haphazardly, mostly close to metropolitan centers. No existence of centralized sewage systems, and the industrial effluents from the factories are usually discharged untreated into streams, lagoons, open drains and other water bodies. This has resulted in high, although not alarming, levels of lead, cadmium and copper in some localized areas [9].

The ways of collecting and preparing the water for drinking from rain is discussed as well. The main components when it comes to water collecting or harvesting systems are [25]:

Catchment area: the part of land that contributes to some or the whole share of rainwater to the target area outside its boundary. Catchment surfaces can be either natural or treated (runoff inducement). It is a runoff producing area which may include agricultural, rocky or marginal land, rooftop, paved road, amongst others.

Silt trap/sediment pond: this refers to a small pit used to catch sediment carried by the water. It prevents also the tank from being clogged. The size of the trap depends on the amount of runoff (heavier runoff means a bigger trap) and the amount of sediment it carries. If there is a lot of sediment, it is preferred to make two-chamber trap- one chamber to catch sand and the second one to trap finer silt. Filter mesh to trap leaves and other debris can also be added. Mostly we dig the silt trap at least 3 meters away from the storage tank. This is to prevent water from overtopping during heavy rains and damaging the tank.

Diversion channels: this eventually leads water from the catchment area to the silt trap and then to the tank. It should be made of a compacted earth, or lined with cement. It should again have a very gentle gradient to prevent it from being damaged.

Storage facility: the place where runoff water is kept from the time that it is collected until it is used.

Target area: where the harvested or collected water is used. In agricultural production, the target is the plant or the animal, while in domestic use, it is human beings or the enterprise and its needs.

In the second chapter, there are discussions about the analysis of water cleaning systems for the developed resource saving ways to get drinking water for West African regions. A new development on a water supply plan was established in West Africa specifically Nigeria. Water supply plans should ensure the continued ability of community water systems to provide potable water to meet current and projected needs in the future [29].

The Lagos water supply plan is one-dimensional and lacks some important components that are necessary for the achievement of a sustainable water supply system in Lagos. As such, the intent to build upon the Lagos Water Supply Master Plan to create a more comprehensive and sustainable plan based on its gaps and the needs of the Lagos water sector. This new water supply plan will include additional initiatives, strategies and programs to ensure the protection of water resources and related natural systems and the sustainable provision of adequate water supply in Lagos through 2020 [30].

Also, this chapter talks about the justifications for choosing the source of water.

Water in Africa, as a limited resource, must be carefully managed for the benefit of all people and the environment to ensure food security today and in the future. With the global food crises and the growing population continent-wide, more food must be grown for the 212 million malnourished people across Africa and the one billion more people expected by 2050. Again, there are lots of financially unstable families living in these regions and as such, need access to a cheap and reliable source of water which should be of good quality for domestic use [32].

Again, the methods for cleaning the collected water is highlighted in this chapter.

Contaminants in water may include algae, bird excrement, and leaves, sand, and dust. Local wells have been used over decades to deal with these problems. Installation of filtration and purification equipment can remove these contaminants at home as well. First, foreign matter must be kept out of the incoming rainwater. And then flush devices, gutter screens and other screening mechanisms keep the rainwater as clean as possible before it enters the conveyance system. Using screens and filters will greatly reduce maintenance and lengthen the life of the pump and filtration or purification system [34].

The last part of this chapter talks about the justification system of cleaning water.

The commonly available purification technology is distillation. Distillation separates the water from the impurities through heating and then collecting the condensation. It is very energy intensive and loses about 5-10% of the water due to evaporation. Distillation removes almost all substances from the water with the exception of volatile organic chemicals (VOCs) that evaporate easily. To this end, some distillation systems are also equipped with carbon filters to remove the VOCs [34].

In the third chapter, parameters and elements utilized under information-analytical system for water cleaning systems is discussed.

Most of the water supply and sanitation systems in West African countries currently do not fully comply with modern technological, environmental and sanitary-hygienic requirements, which are set out in the relevant state standards, technological regulations and standards. The reason for this was the lingering nature of the transition of communal systems to market relations [37].

There are basic standards, norms, criterion and indicators for safe drinking water. There are also policies, strategy and program under safe drinking water [38]. Countries regulate drinking water differently depending on the quality of their water source. According to the WHO [39] and US Environmental Protection Agency [40], there are guidelines and principles that need to be followed for water to be considered fit for use.

Also, construction materials, size of elements of cleaning systems are justified in this chapter. A cleaning system is illustrated in the chapter which shows how it operates. A mixing tank is used to prepare and hold the cleaning solution. It should be large enough to hold a sufficient quantity of that solution. A good rule of thumb is that it have a 60-gallon capacity for each 8-in. vessel (holding six elements) being cleaned. The tank should be equipped with a mechanical mixer to ensure proper dilution of the cleaning chemical before use. In the absence of a mixer, the tank should be piped so that the cleaning solution can be re-circulated through the cleaning pump and back to the tank before being returned to the vessels being cleaned [45].

Lastly on this chapter, justification of temperature impact on West African region on system production is discussed.

Water vapor is one of the most important components of the atmosphere given that it is the means by which moisture and energy (as latent heat) are transported through the troposphere and lower stratosphere to influence weather. In addition to its role in balancing the atmospheric heat budget, water vapor plays an essential role in the global hydrological cycle and global climate system as the source of precipitation (rain, snow), clouds and fog [46].

In any vertical column of air, the amount of water vapor offers meteorologists a value of the maximum potential precipitation that could be retrieved from that air column under the right conditions. Although the air mass fraction of water vapor may approximately be around 1%, its effect on meteorology is very strong. It has the ability to cause small and large-scale temperature anomalies and influence atmospheric latent heat exchanges. Water vapor plays a major role in the climate system: recent studies have estimated that about 70% of the warming of the atmosphere is attributed to water vapor acting as a greenhouse gas. Despite its significance to atmospheric processes over a broad range of spatial and temporal scales, water vapor remains one of the least understood and inadequately described components of the Earth's atmosphere in current climate prediction models [46].

In the fourth chapter, a new development was made for purifying rainwater by a simple means of collection in a tank and sent to a reservoir storage which after, goes through a tube as steam and converted back to water with temperature change and this water goes through a series of different filters that serve different purposes and water comes out through a tap system, ready to be collected for use.

Water purification is of great relevance to all inhabitants on planet earth, there are many ways that water can be polluted based on the sheer number of bacteria and contaminants present in everyday interactions with pipe systems. As a matter of fact, there can be up to 2100 contaminants or toxins in your tap water. All of these contaminants can not only affect the taste of your water but also risk your health with the eventual development of cancers, gastrointestinal problems or other diseases. That's why it's important to understand how the water purification works and what can be done to improve upon it [47].

1.4. Conclusion

Based on the research, these were the following conclusions;

Climate change has a significant effect on the coast. This includes water pollution, erosion and flooding as lasting effects on the West African regions. Various types of waste materials are deposited on the coastal areas through several means including anthropogenic, artificial or mechanical sources amongst few. Rainwater in West African regions is very important for people living in these areas just as water in general is important universally. Due to the high rate of water pollution and considering its relevance to human life, water cleaning systems are implemented to purify rainwater specifically. The implementation of this proposed purification system will benefit people living in these regions since it is a cheaper system to use, and in a broader view, it will help improve upon the GDP of the economy.

1.5. List of Scientific Work

- The impact of urban development on aquifers in large coastal cities of West Africa.

A. Abstract

Master's work on obtaining an educational qualification level "Master" by specialty 101 Ecology National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky", Kyiv, 2020.

The thesis is devoted to the Information-analytical system and research on the impact of coastal pollution and degradation on West Africa.

Forty percent of the West African population lives in coastal cities, and it proposed that by 2020, more than 500 kilometers of coastline between Accra and the Niger delta will be developed into a continuous urban megalopolis of more than 50 million inhabitants in these areas.

Water purification is of great relevance to all inhabitants on planet earth, there are many ways that water can be polluted based on the sheer number of bacteria and contaminants present in everyday interactions with pipe systems. As a matter of fact, there can be up to 2100 contaminants or toxins in your tap water. All of these contaminants can not only affect the taste of your water but also risk your health with the eventual development of cancers, gastrointestinal problems or other diseases. That's why it's important to understand how the water purification works and what can be done to improve upon it.

It is recommended that a water purification system be developed mainly to trap or collect rainwater in a tank which will then go through some process of steaming taking into consideration temperature of the water. This steam will then flow through a chamber of various filtrations points before the steam is converted back to water which will be ready for use (either domestic or commercially).

KEYWORDS: INFORMATION-ANALYTICAL SYSTEM, POLLUTION, DEGRADATION, RAINFALL, PURIFICATION SYSTEM, WASTE, COASTAL POLLUTION

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1. CLIMATE INFLUENCE AND IMPACT OF POLLUTION BASED ON INFORMATION-ANALYTICAL SYSTEM

1.1 Relevance of Research

Forty percent of the West African population lives in coastal cities, and it proposed that by 2020, more than 500 kilometers of coastline between Accra and the Niger delta will be developed into a continuous urban megalopolis of more than 50 million inhabitants in these areas. In Nigeria, about 20 million people (22.6 percent of the national population) already live along the coast; in Senegal, approximately 4.5 million people (66.6 percent of the national population) live in the Dakar coastal areas, along with 90 percent of the industries; and in Ghana, Benin, Togo, Sierra Leone, and Nigeria, most of the economic activities can be found within the coastal zone. For this report, the coastal zone is broadly defined as dry land and adjacent ocean space (water and submerged land) in which terrestrial processes and land uses directly affect oceanic processes and uses, and vice versa. Coastal areas in West Africa also form the food basket of the region. Fisheries in the West African Marine Eco-Region generate $400 million annually, making them the single most important source of foreign exchange in the region and a key source of revenue for economic and social development [1].

The coasts of West Africa are home to large marine ecosystems (the Canary Islands, Guinea and Benguela currents), mangroves, wetlands and several hundred species of fish. With more than a third of the region's population living along the coast, these natural assets allow several million people to live off the resources of fishing, aquaculture and tourism. However, the West African marine and coastal environment is under pressure from a multitude of threats that seriously affect its health and the populations that depend on it: coastal erosion, the impacts of climate change and ocean acidification, but also of the development of offshore activities, overfishing, land-based pollution [2]. West Africa's coastal areas host an abundance of natural resources, on land and at sea, that provide an important ecosystem services and help serve as intermediate against severe weather events. These resources play a key role in the economic and physical resilience of coastal regions to existing and future challenges [3].

The continent of Africa sits on the equator and extends to approximately 35° latitude both north and south. It is dominated by warm water regions and its coastline includes environments such as coral reefs and mangroves, except at the northwest and southwestern ends, where temperate environments are evident. The African coastline, excluding Madagascar (4,000 km), totals 35,000 km. A review of the literature dealing with sandy beaches in Africa found the earliest paper to have been published in the 1880s and, of more than 1,000 papers published over 100 years, 19% concerned north Africa, 16% west Africa, 15% east Africa and Madagascar, and 55% southern Africa, particularly South Africa. Early papers were primarily taxonomic but later publications were mainly ecological. English was the language of 59% of the papers, followed by French (29%), German (7%), and Italian (3%). This sketch for literature on sandy beaches is probably a representative of all papers dealing with coastal ecology in Africa. If so, it can be concluded that coverage of coastal ecology in Africa is patchy, whereas the coastal ecology of South Africa has been extensively well researched, most of the other regions are less well known [4]. Figure 1.1 below shows the map of West Africa and its coastal zone.

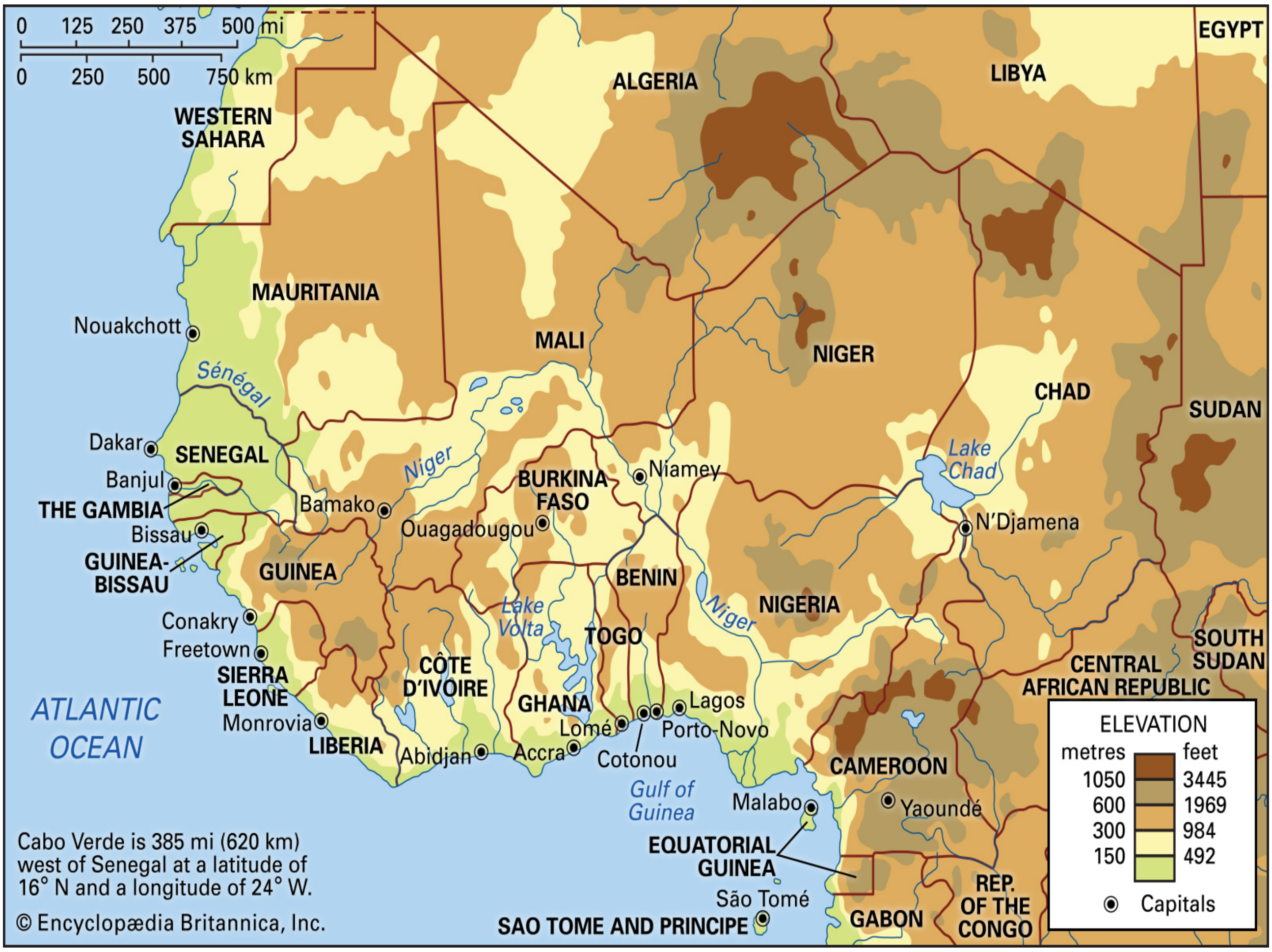


Figure-1.1 West African Geographical Map

1.2 Climate features of West African Coastline.

West Africa, is defined to include the western portion of the Maghreb (Western Sahara, Morocco, Algeria, and Tunisia), which occupies an area in excess of 6,140,000 km2, or approximately one-fifth of Africa. The vast majority of this land is plains lying less than 300 meters above sea level, though there is isolated high points exist in numerous states along the southern shoreline of West Africa [5]. Figure 1.2 shows the West African tropical eco zone.

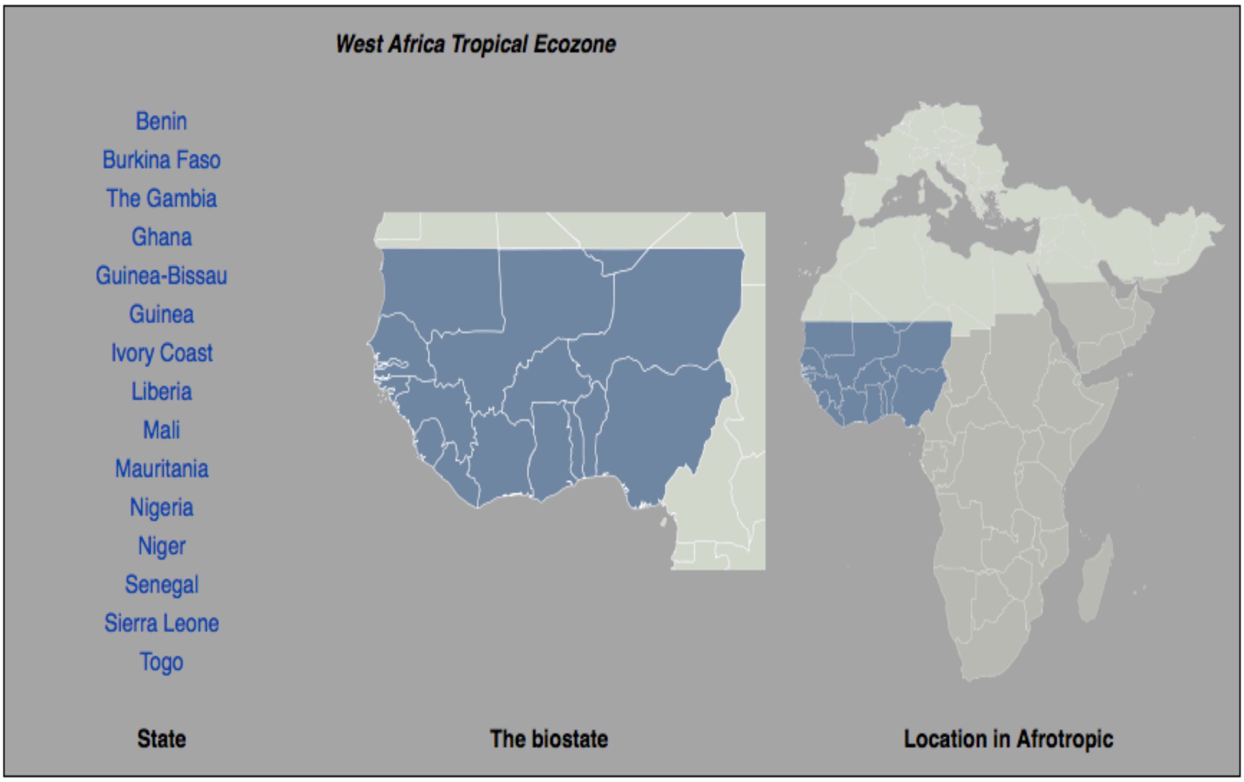


Figure-1.2 West Africa Tropical Eco Zone.

The northern section of West Africa (narrowly defined to exclude the western Maghreb) is made up of semi-arid terrain which is called Sahel, a transitional zone between the Sahara and the savannahs of the western Sudan. Forests form a belt between the savannas and the southern coast, ranging from 160 km to 240 km in width [5].

The northwest African region of Mauritania periodically suffer a country-wide plagues of some locusts which consumes water, salt and crops on which the human populations depends on for survival [6].

1.2.1 Climate change drivers in coastal systems.

The Intergovernmental Panel on Climate Change (IPCC, 2007) has made available six major climate drivers for the coastal systems. These driving forces have interactions in complex ways with coastal systems, affecting landforms and infrastructure (physical effects), as well as the ecosystems [1]. Figure 1.3 below shows the coastal climate drivers and their impacts on the coastal system.

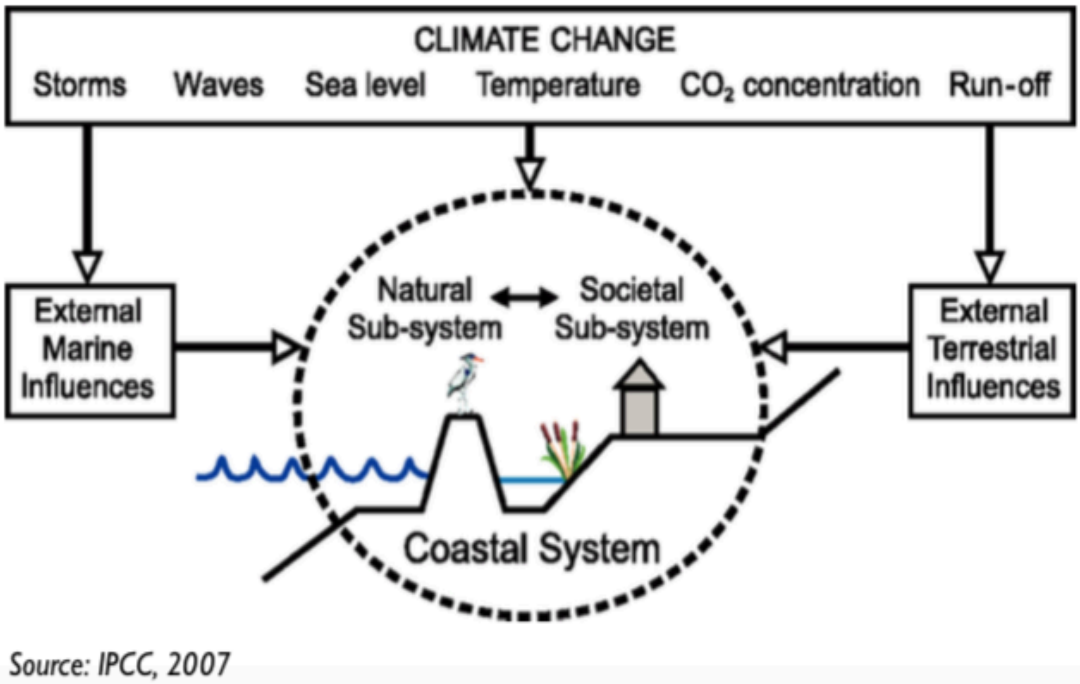


Figure-1.3 Coastal climate drivers.

Table 1.1 provides a qualitative assessment of the level of knowledge and research of the impacts of selected climate drivers on West Africa coastal systems.

Table-1.1 level of knowledge or research regarding the impacts of selected climate drivers on West Africa coastal systems [1]

Main Climate Drivers in Coastal Systems	Potential Main Physical and Ecosystem Effects of Changes in Drivers on Coastal Systems (based on IPCC 2007)	Level of Knowledge/Research in West Africa Based on Rapid Assessment of Literature	Timeframe/ Certainty & Impact Direction	Source(s)
Ocean Acidification	Absorption of anthropogenic CO_2 and atmospheric deposition of acidity can both contribute to the acidification of the global ocean. Decreased seawater pH can negatively impact pH sensitive organisms. Coral reefs are the most widely recognized ecosystem threatened, as well as commercial fisheries of calcifying organisms (e.g., shellfish).	**Low:** Coral reefs and commercial fisheries of calcifying organisms are not of major commercial importance in the West Africa region; as a result, literature on the topic is limited. However, shellfish fisheries are important for local livelihoods (especially women), and non-calcifying organisms, mainly fish, may also be affected by ocean acidification but this is *new and emerging research.*	Long-term, threshold-based impact, with potentially devastating negative impacts	Bodin et al., 2011, Gosling, 2013
Sea Surface Temperature (SST)	Increased stratification/changed circulation; poleward species migration and changes in species composition; coral bleaching (if any corals are present) increased algal blooms	**Low/Medium:** Some research on historical climate changes (e.g., over 10,000 to 100,000 years) and climate variability exists, including on El Niño/upwelling phenomena and links with rainfall patterns and fish distribution, informing knowledge about future climate change. But understanding of localized impacts of future SST changes is still limited.	Short- to medium-term, differential impacts on species uncertain	Janicot & Fontaine, 1997; Binet et al., 2001; Giresse, 2008; Zeeberg et al., 2008
Sea-Level Rise (SLR)	Inundation, flood, and storm damage; erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change)	**Medium:** Historic data (50 years) of continuous sea-level rise in West Africa are fairly limited compared with other global regions; deficiency of data has been addressed by the implementation of new tide gauges in recent decades. Studies using sediment core provide information on past climate changes and ecosystems (e.g., over 10,000 to 100,000 years). Future impacts of SLR on coastal zones have been more studied in countries such as Senegal, Ghana, and Nigeria, compared to the rest of the region.	Long-term, and/but contributes to a variety of other impacts	Kim et al., 2010; Niang et al., 2010; Addo et al., 2011; Fashae & Onafeso, 2011; Hinkel et al. 2012
Storm Intensity/ Storm Frequency	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, risk of flooding, and defense failure	**Low:** As for SLR, limited ocean observation network inhibits a better understanding of *future* ocean dynamics. Ocean storm surge events normally occur in the Gulf of Guinea in summer months of April to October with significant impact on infrastructure. Research on the impact of storms, on the impact of storms on shoreline ecosystems, and the compounded effects of SLR and storms on coastal systems is limited, compared to other regions.	Short-/medium-term, predicted increases will be a negative impact	Dasgupta et al. 2009
Wave Action	Altered wave conditions, including swell; altered patterns of erosion and accretion; reorientation of beach form	**Low:** Limited or no information on predicted impacts related to climate change was found, though action is related to wind speed and storm intensity.	Unclear relationship. Increased wave action will have negative impacts.	N/A
Runoff/Changes in Precipitation	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply	**Low/Medium:** Some studies on the impact of changes in runoff on ecosystems have been identified	Short-term with varying, though generally negative, impacts	Niang et al., 2010

Rising sea levels will impact all West African countries (although to varying degrees relying on each country's coastal environment), exacerbating coastal erosion rates. Over a period of time, this will result in a greater number of people beings being exposed to chronic and episodic disasters, such as loss of coastal homes and land, loss of wetland aquaculture areas, saltwater intrusion impacts to drinking water, and loss of inland homes that are within extended flood zones. While the data on actual impacts in West Africa are quite scanty, one study indicates sea-level rise impacts for West

African coastal countries [1]. Table 1.2 below shows the impact of climate change on the coastal zones of Africa.

Table-1.2 Impact of climate change on the coastal zones of Africa [1]

Country	Area at Risk (square kilometer)	People Affected	Economic Value at Risk ($M)
Cape Verde	NA	100	33.7
Senegal	6,042–6,073	109,000–78,000	499–707
Gambia	92	42,000	217
Guinea-Bissau	NA	1,600	34.7
Guinea	289–468	500,000	NA
Sierra Leone	NA	26,000–1,220,000	5,860
Liberia	NA	NA	NA
Cote d'Ivoire	NA	NA	NA
Ghana	NA	NA	NA
Togo	NA	NA	NA
Benin	230	1,350,000	118
Nigeria	250	3,200,000	18,000
Cameroon	NA	2,300	619.7

Note: NA reflects information Not Available. Source: Niang-Diop, 2005

1.3 Influence of Climate on Quality and Quantity of Water.

The West African coastline is very dynamic, with rocky parts of coasts that represents 3 percent of the coast. The remaining part of the coastline is predominantly composed of mangroves and sandy formations with little resistance to the action of the coastal currents. Changes in climate drivers have the potential to result in significant physical impacts on these unstable and very dynamic coastlines [1]. Figure 1.4 shows the West Africa coastal shoreline composition.

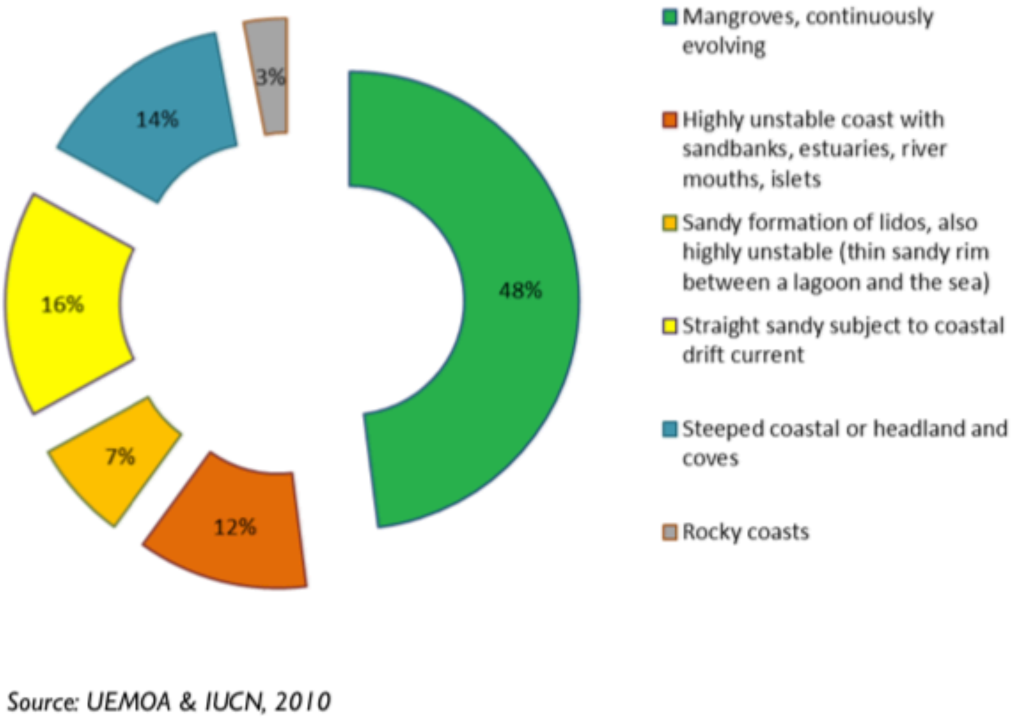


Figure-1.4 West Africa coastal zone shoreline composition.

Water pollution, erosion and flooding are the latest lasting effects from natural disaster on the West African coast. Costs of the damages are some of the biggest concern [7].

A study estimates in monetary terms the main Cost of Environmental Degradation (COED) in the coastal zones of Benin, Côte d'Ivoire, Senegal, and Togo. Specifically, it takes into account the impacts of degradation that occur during one year, as a result of three major factors: flooding, erosion, and pollution (from water, air and waste). The final results are expressed in 2017 prices. They are presented in absolute (US$) and in relative terms, as percentage of the countries' GDP. Overall, the COED of the four countries is estimated at about US$3.8 billion, or 5.3 percent of the countries' GDP in 2017. Flooding and erosion are mentioned as the main forms of degradation, accounting for more than 60 percent of the total cost (Figure 1.5). Moreover, coastal degradation causes more than 13,000 deaths a year, primarily because of air and water pollution, and to floods [8].

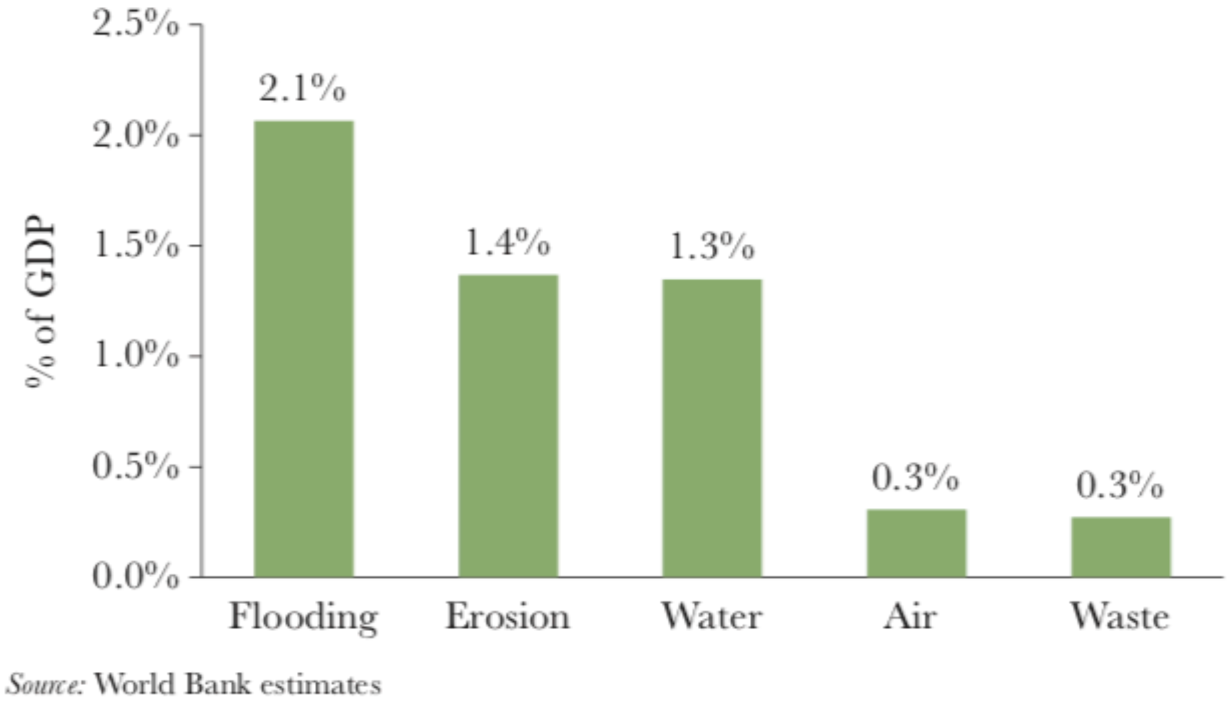


Figure-1.5 Estimated COED by category, 2017

At country level, coastal degradation causes costs varying between 2.5 percent of GDP in Benin to 7.6 percent of GDP in Senegal in 2017 [8].

These estimates are the result of three major factors that influence the coastal area [8]:

- **Flooding** due to high rainfalls (pluvial floods) and overflowing rivers (fluvial floods) causes deaths that also leads to major damage to houses, infrastructure and critical ecosystems, such as beaches and mangroves. Floods are highly damaging in Côte d'Ivoire, costing the society US$1.2 billion per year, which is mainly due to large areas affected by pluvial floods (Table 1.3). In the other countries, flooded areas and the its connected water depths are smaller, and is leading to comparatively lower flooding costs.
- **Erosion** is a result of both natural and anthropogenic factors. Some areas have no erosion at all, others have got land losses (erosion), and others also have land gains (accretion). About 56 percent of the coastline in Benin, Côte d'Ivoire, Senegal and Togo is subject to an average erosion of 1.8 meters per year. Erosion

is the most disturbing factor in Benin, Senegal, and Togo, primarily due to losses of high value urban land. The highest cost, estimated at US$0.5 billion per year, occurs in Senegal. In all countries, the cost of erosion is expected to increase substantially in the future, as the phenomenon is likely to affect larger urban areas.

- **Pollution** from air, water and waste mismanagement imposes an important influence on human health and the quality of life. It can reach as high as US$0.7 billion, in Côte d'Ivoire. In all countries, unsafe water, sanitation, and hygiene are particularly very harmful, causing more than 10,000 deaths per year; they affect basically Côte d'Ivoire and Senegal, with more than 4,000 deaths with each country. Air pollution and waste mismanagement are also significant forms of degradation, but are considerably under-estimated: the cost of air pollution (2,500 deaths) refers only to the impacts of fine particulate matter in the countries' capitals, while the cost of waste covers only the effects of inadequate collection and inappropriate disposal of municipal waste.

Table 1.3 below Estimated COED (US$ million, current prices, 2017).

Table-1.3 Estimated COED (US$ million, current prices, 2017) [8]

	Benin	**Côte d'Ivoire**	**Senegal**	**Togo**
Flooding	29	1,183	230	10
Erosion	117	97	537	213
Water	53	485	375	36
Air	10	166	17	23
Waste	20	53	90	28
Total	**229**	**1,985**	**1,250**	**310**

Source: World Bank estimates

1.4 Quality and Pollution on the Coastline Water.

This project focuses more on the aspect of water pollution in the coastal areas of West Africa, with particular emphasis on the waste that is accumulated from various sources (ships, people, industries, etc).

Water pollution, amongst the other forms of pollution in West Africa plays a vital role in the economic status of the countries in these regions.

Surface water pollution is very imperative, though on a quite local scale. However, the heavy runoff associated with perennial rainfall may make it less severe in terms of its impact. Lots of small and heavy industries involved in activities such as battery and paint manufacturing, petroleum refining, cement and ceramic production, steel production, are now being found haphazardly, mostly close to metropolitan centers. No existence of centralized sewage systems, and the industrial effluents from the factories are usually discharged untreated into streams, lagoons, open drains and other water bodies. This has resulted in high, although not alarming, levels of lead, cadmium and copper in some localized areas [9].

Coastal waters basically are one of the nation's biggest assets, yet they are being bombarded with pollution from all sorts of directions. The heavy concentration of activities in coastal areas, accompanied with pollutants flowing from streams far inland and others carried through the air great distances from their source, are the primary causes of nutrient enrichment, hypoxia, harmful algal blooms, toxic contamination, sedimentation, and other problems that plague coastal waters. Not only do degraded waters cause significant ecological damage, they also lead to economic impacts due to beach closures, curtailed recreational activities, and additional health care costs. Reducing water pollution will significantly result in cleaner coastal waters, healthy habitats that support aquatic life, and also a suite of economic benefits [10].

Sometimes it is not only the type of materials, but its concentration levels that determines whether a substance is a pollutant or not. For example, the nutrients nitrogen and phosphorus are important elements for plant growth. However, if they are too much in a body of water, they can stimulate an overgrowth of algae, triggering an event called an algal bloom. Harmful algal blooms (HABs), which is also known as the "red tides," grow very fast and produce toxic effects that can affect marine life and sometimes even humans. Excess nutrients entering a body of water, either through natural or human activities, can also result in hypoxia or dead zones. When large amounts of algae sink and decompose in water bodies, the decomposition process consumes oxygen and depletes the supply available to healthy marine life. Many of the marine species that live in these areas either die or, if they are mobile species (such as fish), leave the area [11].

The majority of these pollutants that get access into the ocean come from human activities (anthropogenic pollution) along the coastlines and far inland. One of the biggest sources of pollution is nonpoint source pollution, which occurs as a result of runoffs. Nonpoint source pollution can come from many sources, like septic tanks, vehicles, ships, farms, livestock ranches, and timber harvest areas. Pollution that comes from a single source, like an oil or chemical spill, is known as point source pollution. Point source pollution more usually have large impacts, but fortunately, they occur less often. Discharge from faulty or damaged factories or water treatment systems or plants, is also considered point source pollution [11].

Marine debris is a continually persistent pollution problem that gets throughout the entire ocean. Anything that is man-made, including litter and fishing gears, can become marine debris once they are lost or thrown into the environment (marine). The commonest materials that mostly make up marine debris are plastics, glass, metal, paper, cloth, rubber, and wood. Glass, metal, and rubber are similar to plastics in that they can be used for a wide range of products. While they can be worn away-broken down into smaller and smaller fragments, and they generally do not biodegrade completely. As these materials are used commonly in most societies, their occurrence as marine debris is overwhelming [12].

Marine litter can be seen in all oceans around the world, not only in densely populated regions, but also in remote areas far from obvious sources and human contact. Every year marine litter takes a huge social and economic toll on people and communities all over the world. The persistence of marine litter is the result of a lack of coordinated global and regional strategies and of deficiencies in the implementation and enforcement of existing programs, regulations and standards at international, regional and national levels [13].

1.4.1 Coastal Waste Material Sources

The coastal areas have a very wide range of sources of these waste materials that adversely have impact on the coastal ecosystem entirely. These sources could either be from natural or human based (anthropogenic activities).

1.4.2 Solid Waste

Solid wastes are generally referred to as any discarded or abandoned materials. [14].

Solid waste can be classified into different types depending on their source [15]:

a) Household waste is classified as municipal waste,

b) Industrial waste as hazardous wastes, and

c) Biomedical wastes or hospital waste which is infectious waste.

Solid waste materials could be municipal wastes which consists of household wastes, construction and demolition debris, sanitation residue, and waste from streets. This garbage is generated mainly from residential and commercial complexes. With the rise of urbanization and change in lifestyle and food habits, the amount of municipal solid waste has been increasing rapidly and its composition is also changing [15].

There are also different categories of wastes which is generated, each take their own time to degenerate (this is illustrated in the table below) [15].

Table-1.4 The type of litter generated and the approximate time it takes to degenerate [15]

Type of litter	Approximate time it takes to degenerate the litter
Organic waste such as vegetable and fruit peels, leftover foodstuff, etc.	a week or two.
Paper	10–30 days
Cotton cloth	2–5 months
Wood	10–15 years
Woolen items	1 year
Tin, aluminium, and other metal items such as cans	100–500 years
Plastic bags	one million years?
Glass bottles	undetermined

Hospital waste could be contaminated by some chemicals that is considered hazardous. These chemicals may include formaldehyde and phenols, which are used as disinfectants, and mercury, and is used in thermometers or equipment that measure blood pressure [15].

In the industries, the main generators of hazardous waste are metals, chemicals, papers, pesticides, dyes, refining, and rubber goods industries. Direct exposure to these chemicals in hazardous waste such as mercury and cyanide can be deadly [15].

Solid wastes that are not contaminated from the construction, remodeling, repair and demolition of utilities, structures and roads; and uncontaminated solid waste from land clearing. Such as bricks, concrete and other masonry materials, soil, rock, wood (including painted, treated and coated wood and wood products), land clearing debris, wall coverings, plaster, drywall, plumbing fixtures, non-asbestos insulation, roofing shingles and other roof coverings, asphaltic pavement, glass, plastics that are not sealed in a manner that conceals other wastes, empty buckets ten gallons or less in size and having no more than one inch of residue remaining on the bottom, electrical wiring and components containing no hazardous liquids, and pipe and metals that are incidental to any of the waste items mentioned above [14].

Marine waste materials and the associated garbage have been researched as being majorly responsible in polluting the world's oceans. Shipping industries, which is entirely responsible for marine and cargo transportation, is one of the ,main sources for pollution at sea. With over 70% water covering our planet, marine industry is booming each passing day. With such rapid industrial growth the marine ecological system is bound to get perturbed by unwanted issues such as those of the marine wastes and effects of marine pollution. Due to this, there are high concerns about the impact of waste from ships [16].

Cruise ships carry a lot of passengers and crew have been compared to "floating cities," and the amount or volume of wastes that they produce is comparably large, consisting of sewage; wastewater from sinks, showers, and galleys (graywater); hazardous wastes; solid waste; oily bilge water; ballast water; and air pollution [17].

Solid waste generated from ships may include glass, paper, cardboard, aluminum and steel cans, and plastics. Solid waste that enters the ocean may become marine debris, and it can then pose a threat to marine organisms, humans, coastal communities, and industries that utilize marine waters. These solid wastes can be either non-hazardous or hazardous in nature. Cruise ships typically manage solid waste by a combination of source reduction, waste minimization, and recycling. However, as much as 75% of solid waste is incinerated on board, and the ash typically is released at sea, although some is left ashore for disposal or recycling. Marine mammals like fish, sea turtles, and birds can be injured or killed from entanglement with plastics and other solid waste that may be released or disposed off of cruise ships. On the average, each cruise ship passenger generates at least two pounds of non-hazardous solid waste per day and disposes of two bottles and two cans [18].

A report on the research on waste discharge in Nigeria, which is one of the focal points on West Africa's coast focuses on ship generated wastewater including ballast wastewater and wastewater from domestic activities of the crew living onboard. Figure

1.6 below shows the classification of ship and cargo generated waste discharge in and out of the port environment [19].

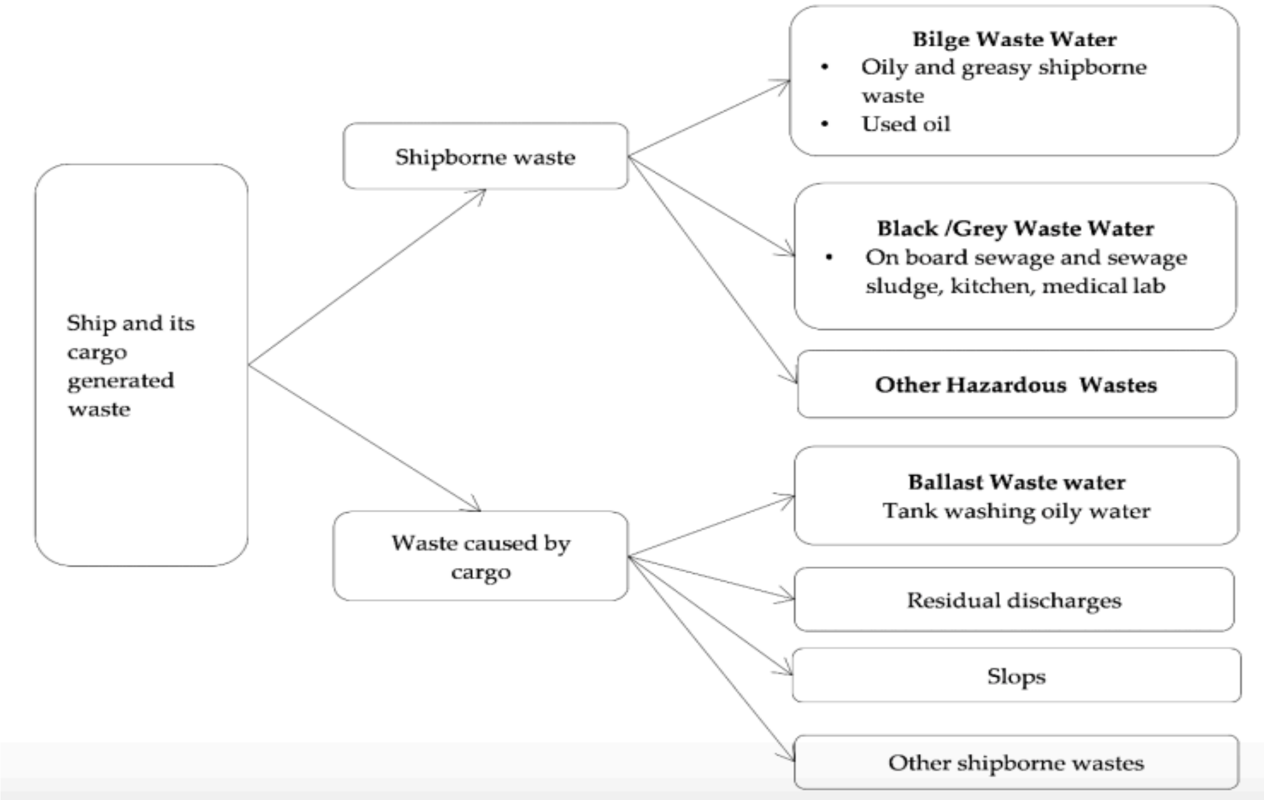


Figure-1.6 Classification of ship and cargo generated waste discharged in and out of the port environment.

1.4.3 Liquid Waste.

The main means of transportation of pollutants from the land to the sea evidently occurs through rivers. Rivers carry different forms of waste materials from the land, which ends up in the sea. The load of pollutants most directly comes from the urban and industrial sewage systems that are dumped in the rivers, often preceded by a sanitation step in a water sanitation installation (and even more often not). This urban and industrial runoff, together with agricultural run-off, contains high levels of nitrogen and phosphorus. These two elements are necessary for plants life (and as a matter of fact, for the establishment of any food chain in any ecosystem on the planet), but are often only present in the ocean in a limiting concentration to allow for abundant organismal growth. A constant influx of nutrient-rich water from the land can therefore upset any balance in the aquatic ecosystems in coastal areas. As the levels of nitrogen and phosphorus rise, the microalgae populations find themselves less and less restrained in their growth. This often results in algal blooms: massive growth of the unicellular algae in the sea. When they die, the remaining biomass is mineralize by bacteria, which thereby consume so much oxygen that the water beneath these blooms becomes anaerobic. Any fish or invertebrate life there is bound to die. Hence, the eutrophication due to the influx of nutrients is bound to cause severe distortion to the balance of the marine ecosystems. A third source is the runoff from dust particles coming from metal ore and metal mines, washing away in the rivers. These metals can then wreak havoc with the normal metabolism of plant and animal life [20].

The figure below shows the inputs of pollution into the marine environment [20].

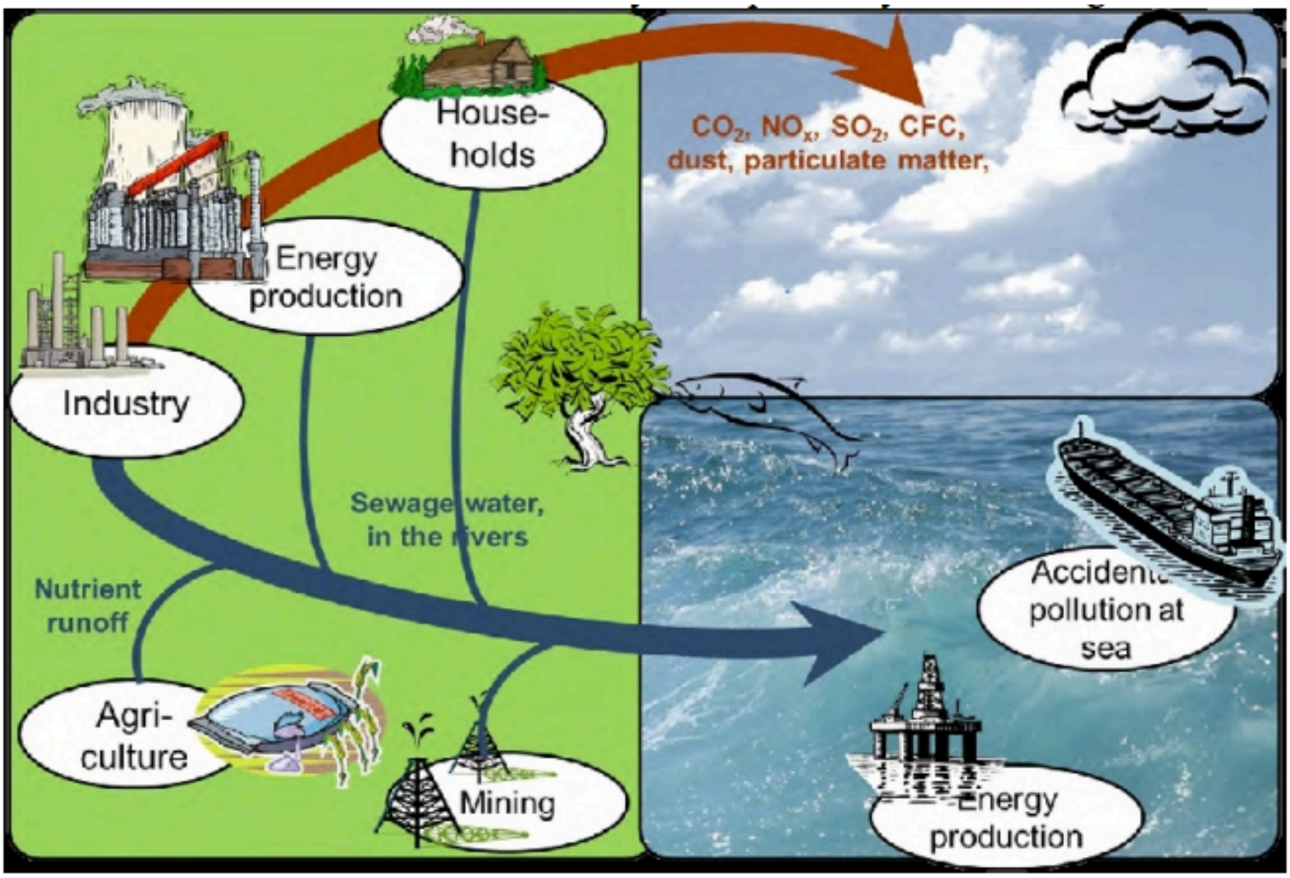
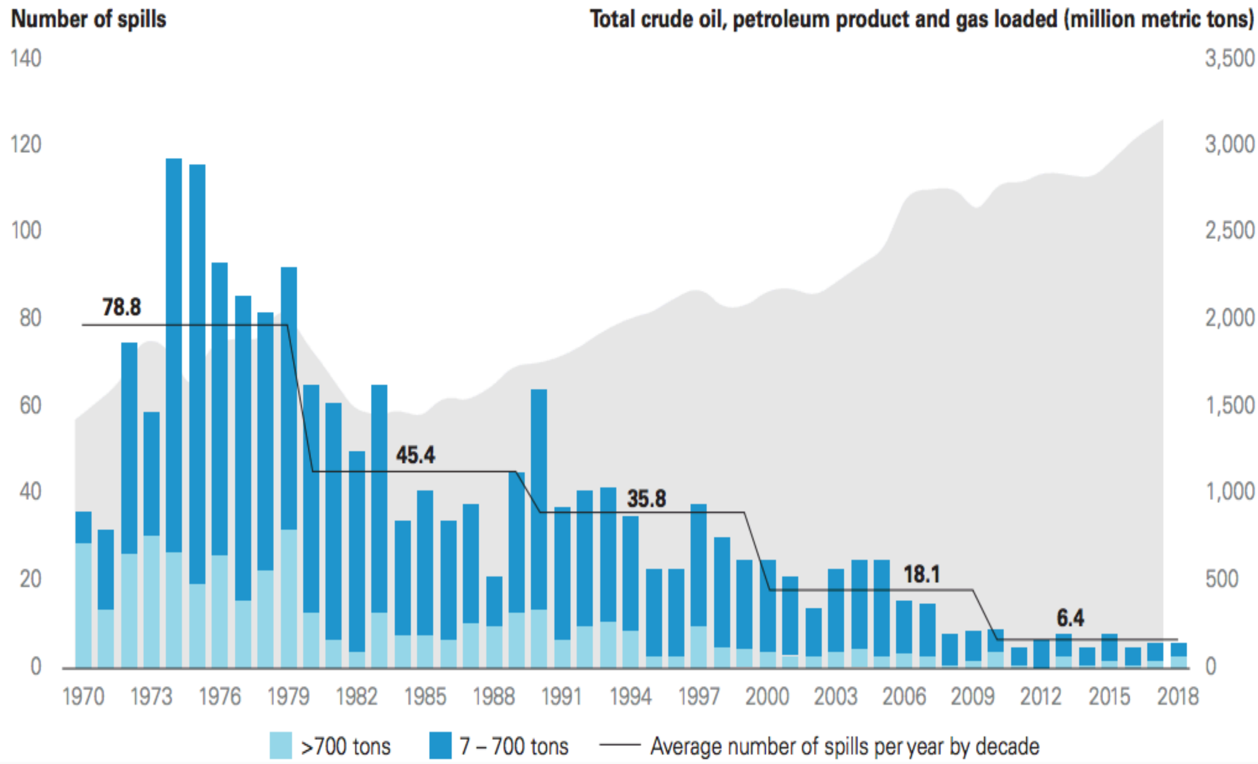


Figure-1.7 Inputs of pollution into the marine environment.

Oil spillages are very common with harbors and ports in Africa as a whole. This results in the discharge of harmful chemicals which may be hazardous to the ecosystem.

The figure below shows how oil spill frequency declines despite increases in volume [21].



Source: UNCTADStat, quoted by ITOPF

Figure-1.8 Tanker oil spill frequency in decline despite increases in volume.

Quantitatively, the largest aquatic form of accidental pollution caused as a result of the maritime sector is also the one that has been highlighted the most (oil spills). Other forms of pollution sources include sewage, garbage, exhaust from engines, incineration of garbage, heavy metals from anodes, discharge from cargo residues, etc. The figure below shows how pollution finds its way from ships [20].

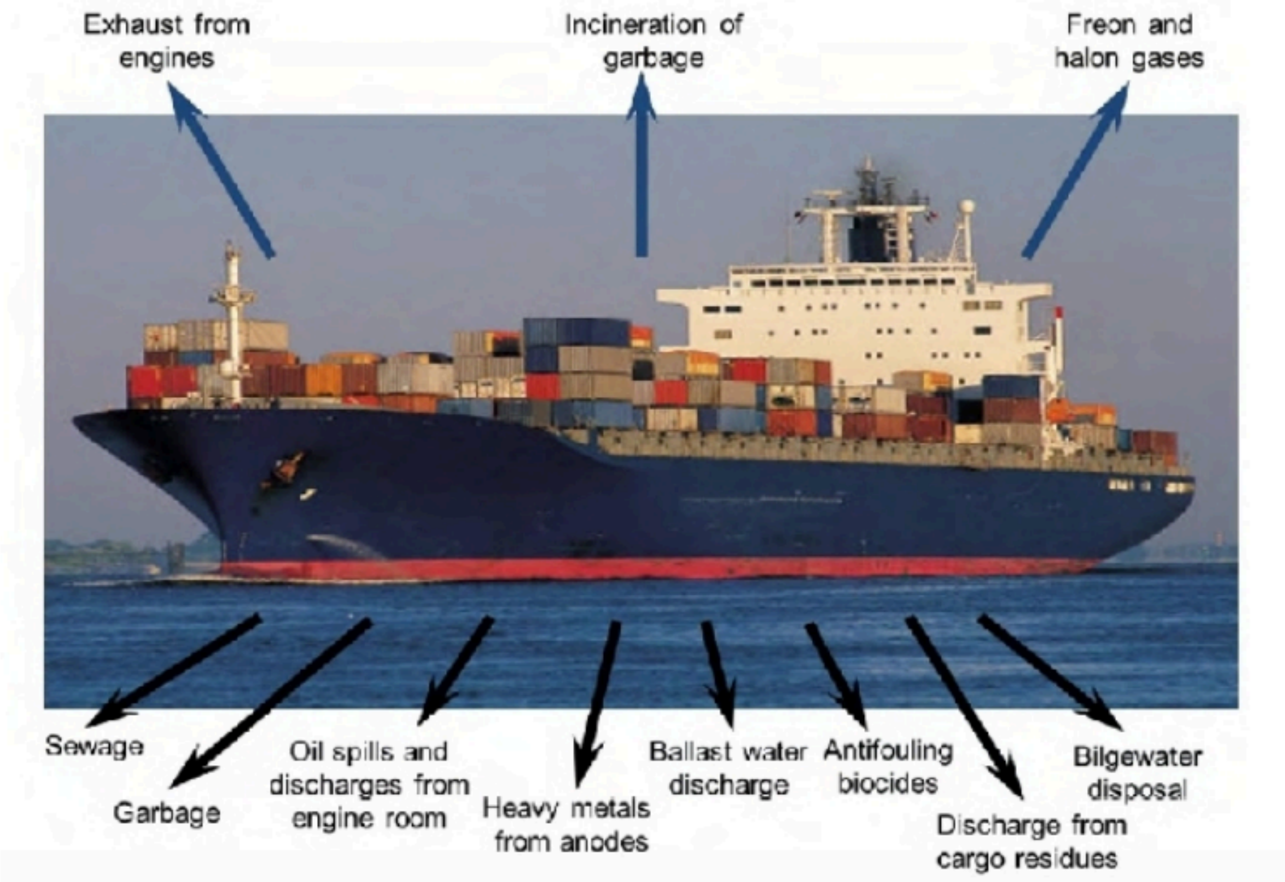


Figure-1.9. Pollution finds its way off the ship

Another factor or agent of liquid pollution is rain and run off water. This could be from various parts of the coastal region and ending up in water bodies in the area. Talking about run off water, it can be generally connected to industries or industrial processes in the coastal sectors. As mentioned in earlier discussions, these run offs carry lots of litter items including harmful and hazardous chemicals that is very unsafe when they are discharged into water bodies, hence, causing fatality to living organism in these water bodies, most especially the ecosystem as a whole.

Since 2002, the chemicals that were used in gold mining activities (including cyanide) in Mali, have been found in the water in neighboring Senegal. The rainy season promotes the transport of toxic waste in the groundwater and the surrounding creeks. The only sources of water are now polluted. The treatment of polluted water from the mining process is supposed to follow strict international, recognized standards but chemical levels have, at times, been double of the acceptable levels. This shows how detrimental such mining processes can be dangerous to the ecosystem especially when the legal standards and requirements for their activities with toxic substances are not followed appropriately [22].

The water degradation resources on the West African coastal zones is often due to human activities like poor water and sanitation service provision, mining, tourism, agriculture and natural factors such as sea level rise leading to salt water intrusion in groundwater. This degradation affects the water quality and also quantity, with impacts on the health of people and services provided by ecosystems. As a result, there are several water-borne diseases that humans are exposed to. The table 1.5 below shows coastal population and water-borne disease risk factors in Benin, Côte d'Ivoire, Senegal and Togo. This analysis completely relies on the 2017 Global Burden of Disease (GBD) data, which was to calculate the number of deaths and disability adjusted life years (DALYs) associated with unsafe WASH (water, sanitation and hygiene) at the country level [8].

Table-1.5 Coastal Population And Water-Borne Disease Risk Factors [8]

Category	Unit	Benin	Côte d'Ivoire	Senegal	Togo
Coastal Population	# million	1.88	8.17	7.84	1.97
Coastal urban population	# million	1.79	4.57	4.89	1.71
Coastal rural population	# million	0.09	3.60	2.95	0.26
WASH risk factors					
Mortality lower bound (urban)	#/100,000	45.7	38.7	39.5	34.2
Mortality higher bound (rural)	#/100,000	86.0	71.3	74.5	67.9
Morbidity lower bound (urban)	DALY/100,000	95	106.2	106.7	105.8
Morbidity higher bound (rural)	DALY/100,000	139.9	156.1	159.4	155.8
Physical valuation					
Mortality in coastal area	#	899	4,338	4,127	762
Morbidity in coastal area	DALY lost	1,833	10,476	9,915	2,216
Economic valuation					
Estimated VSL	US$	46,100	97,300	78,100	31,500
Annual income, 2017	US$	1,600	2,700	1,200	1,200
Estimated mortality cost	US$ million	41	422	322	24
Estimated morbidity cost	US$ million	3	28	12	3
Total	**US$ million**	**44**	**450**	**334**	**27**

Sources: CIESIN Gridded Population of the World (GPWv4) (2015) and ESA Global Land Cover (2015) for the coastal population; https://vizhub.healthdata.org/gbd-compare/ for WASH risk factors.

Considering the known sources of pollution in the coastal regions of West Africa, the need to develop an analytical-information system is of high relevance in order to clearly outline the steps that needs to be taken in relation to coastal pollution, whether from sea, soil or underground pollution. The figure 1.10 below clearly shows the analytical-information system.

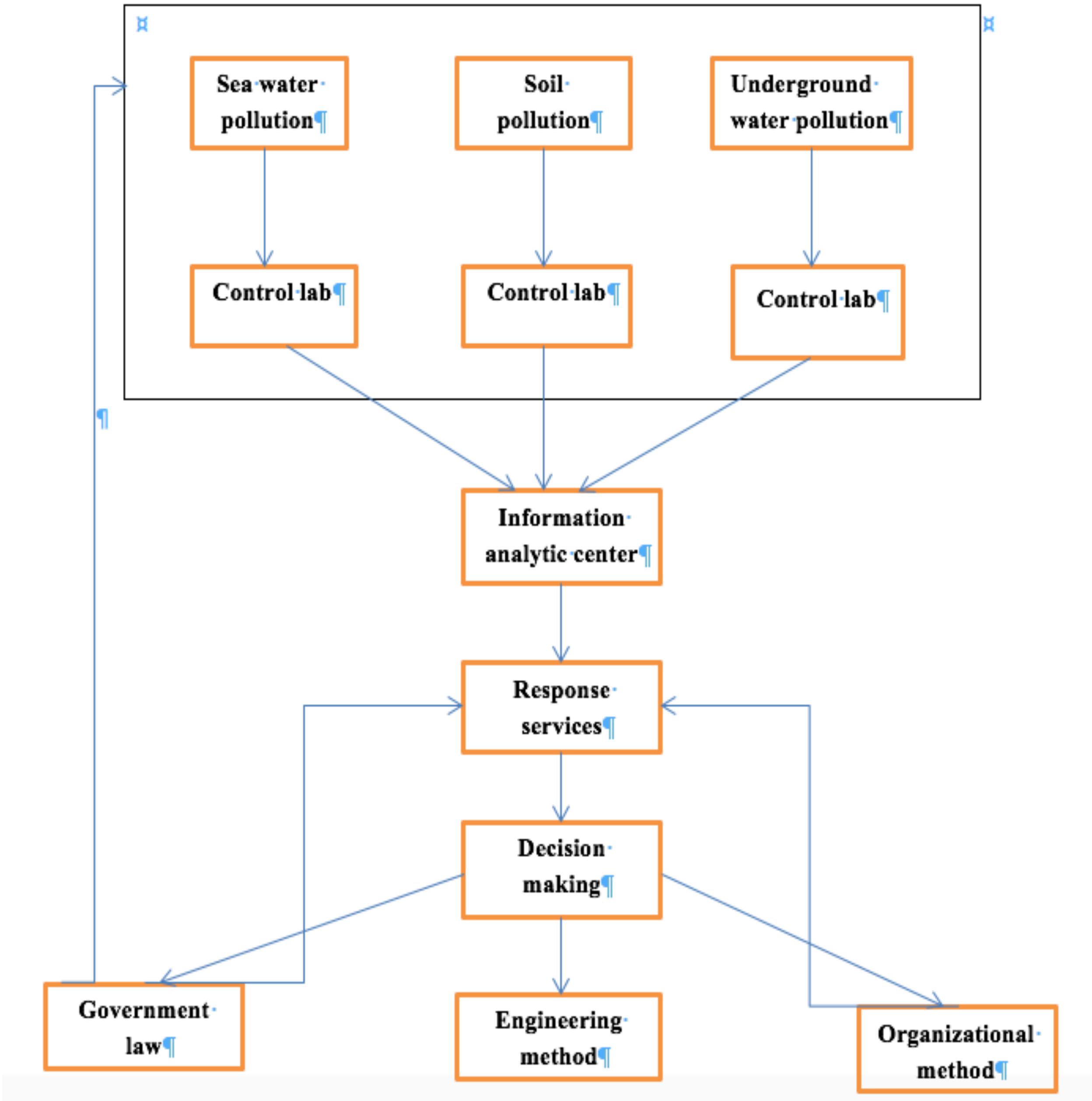


Figure-1.10 Analytical-information system

A further explanation to this analytical-information system can be discussed with all types of pollution, and here basically is the problem formulation after which the sources of pollution will be characterized then will be followed by an exposure assessment of the pollutants. With the exposure assessments and ecological characterization done, there should also be the risk characterization and risk management of the pollution materials. With all these processes, a more significant assessment can be made on the uncertainties regarding all risks.

1.5 Quantity and Specialty of Rainwater.

There is an increasing demand on water resources for development whilst maintaining a healthy ecosystems, which puts water resources under pressure. Rainfall and soil water are fundamental parts of all the terrestrial and aquatic ecosystems which supplies goods and services for human well-being. Availability and quality of water determines ecosystem productivity, both for agricultural and natural systems. Ecosystem services suffer when both rain and soil water becomes scarce due to changes from wet to dry seasons, or during within-seasonal droughts. Climate change, demand for development and already deteriorating state of ecosystems add to these pressures so that future challenges to sustain our ecosystems are escalating [23].

Farms are undisputedly the most imperative ecosystems for the human welfare. Rain fed agriculture as a matter of fact provides nearly 60% of global food value on 72% of harvested land. Rainfall variability is an essential challenge for farming in tropical and sub-tropical agricultural systems. These areas also coincide with many rural smallholder subsistence farming systems, with high incidence of poverty and limited opportunities to cope with ecosystem changes. Water for domestic supply and livestock is irregular through temporal water flows and lowering ground water in the landscape. The variable rainfall also results in poor crop water availability, which reduces rain fed yields to 25- 50% of potential yields, often less than 1 tone cereal per hectare in South Asia and sub-Sahara Africa. The low agricultural productivity often offsets a negative spiral in landscape productivity, with the certain degradation of ecosystem services through soil erosion, reduced vegetation cover, and species decline [23].

Although forest and trees 'consumes' rainfall, they also safe-guard and generate many ecosystem services for livelihoods and economic good. All vegetation use rainwater, whether they are managed such as crops or tree plantations, or if they are natural forests, grasslands and shrubs. Often the ecosystems services from natural vegetation are not fully appreciated for its livelihood support until it is severely degraded, or disappeared, through for example, deforestation. Natural and permanent crop cover has the same effect as many rainwater harvesting interventions. By landscape water flows retention, increased rainfall infiltration increase growth of vegetation, and decrease soil erosion, surface runoff and incidence flooding [23].

A much critical analysis shows that rainwater harvesting has much more impacts, both positive and negative on ecosystem services, and extending to regulating, cultural and supporting services [23] (Table 1.6).

Table-1.6 Ecosystems functions and the effect of rainwater harvesting [23]

Ecosystem services	Effect of rainwater harvesting intervention…
Provisioning	can increase crop productivity, food supply and income can increase water and fodder for livestock and poultry can increase rainfall infiltration, thus recharging shallow groundwater sources and base flow in rivers can regenerate landscapes increasing biomass, food, fodder, fibre and wood for human consumption improves productive habitats, and increases species diversity in flora and fauna
Regulating	can affect the temporal distribution of water in landscape reduces fast flows and reduces incidences of flooding reduces soil erosion can provide habitat for harmful vector diseases bridges water supply in droughts and dry spells
Cultural	rain water harvesting and storage of water can support spiritual, religious and aesthetic values creates green oasis/mosaic landscape which has aesthetic value
Supporting	can enhance the primary productivity in landscape can help support nutrient flows in landscape, including water purification

Rainwater harvesting has in many cases not just only increased human welfare and ecosystem services, but also acted as a way of having improvement in equity, gender balance and strengthen social capital in a community. It also improves household sanitation and health. The value of community organization enabled through implementation of rainwater harvesting in the watershed has strengthen communities to address other issues relation to development, health and knowledge in their livelihoods and environment. To improve domestic water supply with rainwater harvesting interventions, save women and children from the tedious work of fetching water. These are essential benefits which can further help individuals and communities to improve both ecosystems management as well as human well-being. The table below explains some of the roles that rainwater plays in a community [23].

Table-1.7 The Millennium Development Goals (UN MDG, 2009) and the role of rainwater harvesting [23]

Millennium Development Goal	Role of rainwater harvesting	Relevance
1. End poverty and hunger	can act as an entry point to improve agricultural production, regenerate degraded landscapes and supply water for small horticulture and livestock can improve incomes and food security	Primary
2. Universal education	can reduce time devoted to tedious water fetching activities, enabling more time for schooling	Secondary
3. Gender equality	interventions have been shown to improve gender equality and income group equity by reducing the time spent by women gathering water for domestic purposes provides water so that girls can attend school even during theirr menstrual cycles, thus increasing school attendance	Primary
4. Child health	contributes to better domestic water supply and improves sanitation reducing the incidence of water borne diseases which are the major cause of deaths among the under fives	Primary
5. Maternal health	can supply better quality domestic water, which helps suppress diarrhoea etc. can release time from tedious water fetching activities	Secondary
6. Combat HIV/AIDS	no direct linkages	Secondary
7. Environmental sustainability	interventions provide fresh water for humans and livestock can regenerate ecosystem productivity and suppress degradation of services by soil erosion and flooding rainwater harvesting can improve environmental flows by increasing base flow where groundwater is recharged	Primary
8. Global partnership	rainwater management is part of IWRM which is transnational issue	Secondary

These technologies can be divided mainly into two areas depending solely on the source of water collected; namely, the in situ and the ex situ types of rainwater harvesting, respectively. In essence, in situ rainwater harvesting technologies are soil management strategies that enhance rainfall infiltration and minimize surface runoff.

The in situ systems have a relatively minimal rainwater harvesting catchment typically not greater than 5-10 m from point of water infiltration into the soil. The rainwater catchment area is within the field where crops are grown (or point of water infiltration). In situ systems are also characterized by the soil being the storage medium for water. This has two significant effects. First, it is difficult to control outtake of the water over a period of time. Normally, soil moisture storage for crop uptake is 5-60 days, depending on vegetation type, root depth and temperatures in soil and overlying atmosphere. Secondly, the outtake in space is also determined by the soil medium characteristics, including slope. Due to gradients and sub-surface conditions, the harvested water can act as recharge for more distant water sources in the landscape, including groundwater, natural water ways and wetlands, and shallow wells. Harvesting rainwater by increasing soil infiltration using in situ technologies also counteracts soil loss from the farmed fields or forested areas. The in situ rainwater harvesting systems are often identical to a range of soil conservation measures, such as terracing, pitting, conservation tillage practices, commonly implemented to counter soil erosion. In situ rainwater harvesting often serves primarily to recharge soil water for crop and other vegetation growth in the landscape. The water can also be used for other purposes, including livestock and domestic supplies if it serves to recharge shallow groundwater aquifers and/or supply other water flows in the landscape. The ex situ systems are defined as systems which have rainwater harvesting capture areas external to the point of water storage. The rainwater capture area differs from being a natural soil surface with a limited infiltration capacity, to an artificial surface with low or no infiltration capacity. Commonly used impermeable surfaces are rooftops, roads and pavements, which can generate substantial amounts of water and which can be fairly easily collected and stored for different uses [23].

Water shortage or inferior quality of water is still a major problem for millions of people in Africa (as well as elsewhere) and a hindrance for economic development. It is estimated that about 200-500 million m^3 of rainfall is lost in the form of runoffs in the Sub-Saharan Africa region every year, which could potentially irrigate quite a substantial areas [24].

Rain forms the most essential source of natural water in a lot of regions in West Africa, and the world in general. Rain that falls on the surface of the earth can do one of the three things:

I. It may evaporate quickly

II. It may seep into the soil, or

III. It may run, as surface runoff

If the water evaporates, it is lost into the atmosphere (though it may fall somewhere else as rain). If the water penetrates, it may stay in the soil where plant roots can reach it. Or it may filter further down in to the ground to recharge ground water. This water may be reached by deep-rooted plants, or it may reappear at a lower surface down as a spring or people can tap it by digging wells. Rainwater harvesting is a concept of make use of this runoff water for any productive uses. Rainwater harvesting technique, therefore, serves the dual purpose of preserving the environment and providing water, the most needed input. Too much rainfall can result in excessive runoff or flooding. Water that runs off the surface may remove small soil particles and carry them away, which could result in erosion [25].

1.6 Analysis of Ways of Collection and Classification of Rainwater.

The main components when it comes to water collecting or harvesting systems are [25]:

Catchment area: the part of land that contributes to some or the whole share of rainwater to the target area outside its boundary. Catchment surfaces can be either natural or treated (runoff inducement). It is a runoff producing area which may include agricultural, rocky or marginal land, rooftop, paved road, amongst others.

Silt trap/sediment pond: this refers to a small pit used to catch sediment carried by the water. It prevents also the tank from being clogged. The size of the trap depends on the amount of runoff (heavier runoff means a bigger trap) and the amount of sediment it carries. If there is a lot of sediment, it is preferred to make two-chamber trap- one chamber to catch sand and the second one to trap finer silt. Filter mesh to trap leaves and other debris can also be added. Mostly we dig the silt trap at least 3 meters away from the storage tank. This is to prevent water from overtopping during heavy rains and damaging the tank.

Diversion channels: this eventually leads water from the catchment area to the silt trap and then to the tank. It should be made of a compacted earth, or lined with cement. It should again have a very gentle gradient to prevent it from being damaged.

Storage facility: the place where runoff water is kept from the time that it is collected until it is used.

Target area: where the harvested or collected water is used. In agricultural production, the target is the plant or the animal, while in domestic use, it is human beings or the enterprise and its needs.

There are some rainwater harvesting technologies which exist, and the figure below (figure 1.11) shows some of the classifications of rainwater harvesting technologies and systems.

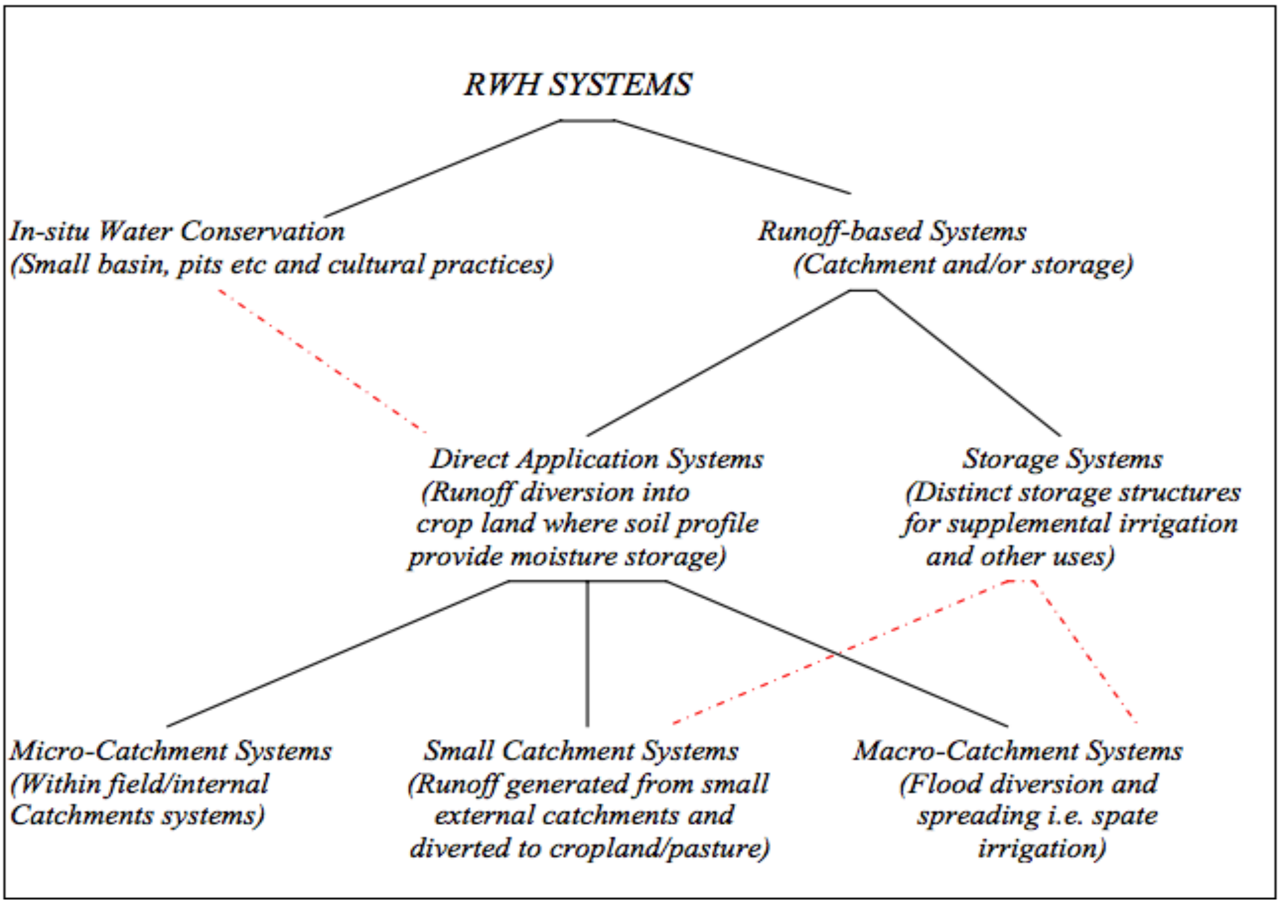


Figure-1.11 Classification of RWH technologies and systems.

As it has been shown in the figure above the classification is based on runoff generation process, type of storage, use and size of catchments is adopted. Each will be discussed in detail.

I. Runoff generation criteria:

These criteria of classifying RWH system yield two categories- runoff based systems and in-situ water conservation. In situ rainwater harvesting differs from runoff farming in that they do not include a runoff generation area, but instead aims at conserving the rainfall where it falls in the cropped area or pasture. Runoff-based systems entail runoff generation .It has further division based on type of storage and size of catchment adopted.

II. Runoff storage criteria:

The runoff based system yields two types of storage categories- direct runoff application (where the soil profile acts as the moisture storage reservoir within cropland) and the storage system (which has distinct storage structures like ponds, tanks etc. to store water to be used for different productive uses). As shown in figure 1.8, it must be noted that in-site water conservation could also be considered under soil profile storage systems, except that direct rainfall is stored, but not surface runoff.

III. Size of catchment criteria

Within the runoff based system the direct runoff application yields three categories based on the size of catchment system that is –micro catchments (Within field or internal or on farms), macro catchments and small external catchments (sometimes it is put as non-land micro catchment). Note that in the case of storage system we have two categories -the small external catchments (the dominant one especially for small scale land users) and macro catchments with large storage structures (which may be used for large scales or community based projects).

A. Micro-catchment (land based water harvesting)

In this system there is a distinct division of catchment area and cropped basin (storage area) but the areas are adjacent to each other. It is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin. This system is mainly used for growing medium water demanding crops like maize, sorghum, groundnuts and millet [26].

According to a research, some of the most important land-based micro catchment or on farm water-harvesting systems known over the world may include zay pits, runoff strips, contour bunds, semi-circular bunds, meskats, contour ridges and negarims [27].

Pitting: These are small semi-circular pits dug to breakdown the thick soil surface. In West Africa, they are called 'Zay', the pits are about 30 cm . in diameter and 20 cm deep [26].

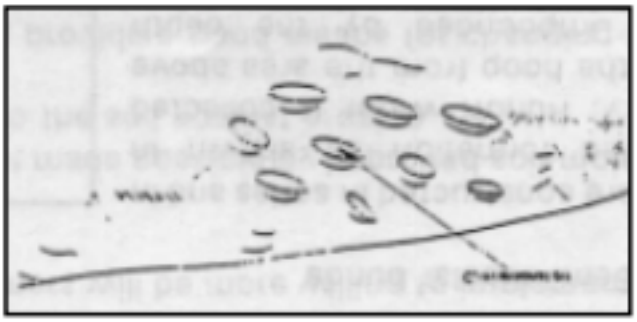


Figure-1.12 Layout of pitting

Strip catchment tillage: It involves tilling strips of land along crop rows and leaving appropriate sections of the inter-row space uncultivated so as to allow runoff access. It is normally used where slopes are gentle and the runoffs from uncultivated parts add water to the cropped strips [26].

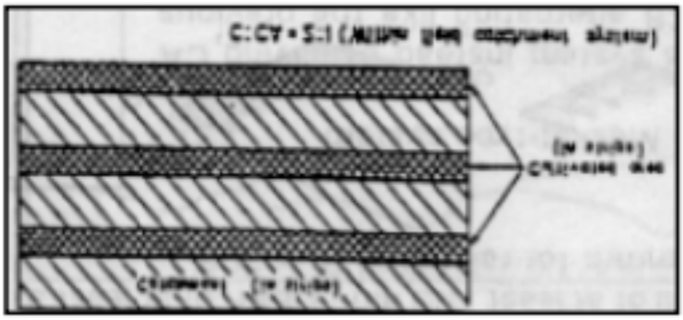


Figure-1.13 Strip catchment layout

Contour bunds: This system particularly consists of small trash, earth or stone embankments, constructed along the contour lines. The embankments strap the water flow behind the bunds allowing for a much deeper infiltration into the soil. The height of the bund basically determines the net storage of the structure. This is a versatile system for crop production in a variety of situations. The water is stored in the soil profile and above ground to the elevation of the bund or overflow structure. They can be easily constructed but they are limited to availability of power (for earthmoving), stones and trash [26].

Figure-1.14 Contour bunds

Semi-circular bunds: These are constructed in a series of staggered formation as shown in Figure 1.12. Excess water is released around the tips and is intercepted by the second row. Runoff water is collected within the hoop from the area above it and impounded by the depth decided by the height of the bund and the position of the tips. [26].

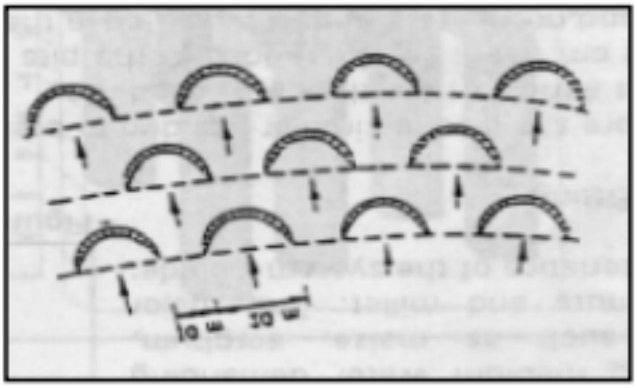


Figure-1.15 Semi-circular bunds

Meskat-type system: This system instead of having CA and CB alternating like the previous methods, the field is divided into two distinct parts, the CA and CB, whereby CB is below the CA. In this system, the CA is treated by the removal of vegetation's in order to allow increase in generation of runoff. The cropped basin (CB) is enclosed by a U-shaped bund to pond the harvested water. It can be used for almost all cereal crops such as maize, sorghum and millet [26].

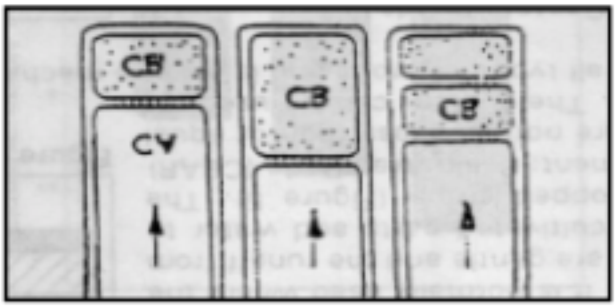


Figure-1.16 Meskat layout

Contour farming and Ridging: This is important on areas where cultivation is done on slopes, ranging from 3% and above. All farm husbandry practices like tilling and weeding are done along the contours so that it can form cross-slope barrier to the flow of water. In cases where this is not enough, it is complemented with ridges, which are sometimes tied to create a high degree of surface roughness to enhance the infiltration of water into the soil [26].

Negarims: They are regular squares made of soil bunds that is turned by 45^0 from the contour to concentrate runoff water at the lowest corner of the square. At this corner, an infiltration basin is made. At the basins center, the a planting pit is made. The whole square consists of a catchment area and a cropped area. Runoffs collected from the catchment area and flows into the cropped area [28].

B. Macro-catchments and flood water systems.

Macro catchment and floodwater harvesting systems are categorized by having a runoff water collected from a relatively large catchment area, which is at an appreciable distance from where it is being used. The macro catchment system consists of upland runoff harvesting and farming before water reaches natural drainage channels. This is also called harvesting from external catchments, and in this case runoff from hill-slope catchments is conveyed to the cropping area located at hill foot on flat terrain [27].

Generally, runoff capture is much lower than in the case of micro catchments, ranging from a low percentage to 50% of annual rainfall. Water is often stored in soil profile for direct use by crops, but this may also be stored in surface or subsurface reservoirs, for a more later use. The cropping area is either terraced on gentle slopes or located on flat terrain. Sometimes water is stored as ground water recharge system [25].

The table 1.8 below outlines the differences between micro and macro catchment systems [27].

Table-1.8 Differences between micro and macro catchment systems [27]

No	Microcatchment systems	Macro catchment systems
1	Rain locally	Rainfall can be out of the locality
2	Runoff source local	Runoff source primarily channel
3	Short slope length	Long slope length
4	High runoff coefficient, frequent runoff	Low runoff coefficient, runoff less frequent
5	Spillway/control requirement for overflow may not be required	Spillway/control structure required for overflow
6	Steady flow(stable or orderly)	Turbulent flow(unstable or disorderly)
7	Designer controlled	Not designer controlled – amount of runoff
8	Predetermined area ratio (small area) i.e. catchement to cultivated area C:CA - 1:1 to 10:1	Difficult to fix area ratio (could be very large) C:CA - 10:1 to 100:1, 100:1 to 10,000:1 in the case of floodwater harvesting
9	Primarily only for soil storage	Structural storage possible (supplementary irrigation – earth dam, pond, cistern)
10	Saturation is up to field capacity	Saturation is up to inundation(flood)
11	Less crop choice	High crop choice
12	Favors perennial/forage/tree crops	Favors annual and perennial crops
13	Individual ownership	Primarily communal ownership – flood irrigation
14	No upstream/downstream issue	There could be upstream/downstream issue
15	Individual involvement	Organization group/community involvement
16	Only local rainfall water balance study	Basin wide water balance study required
17	Require less effort	Require more effort
18	Macro can not be part of micro	Micro can be part and parcel of macro (IWM)

Source: Differences between micro and macro catchment systems (Desta, 2004)

1.7 Conclusion

The coastline of West Africa is home to millions of people, who are exposed to several coastal pollution and degradation problems, most especially water pollution amongst others. There are some factors such as climatic changes which in one way or the other affect coastal waters and as such, contributes to pollution. There are also the presence of waste materials from various sources and these waste materials may be solid, liquid or gaseous wastes.

Water in these regions is very important for people living in the coastal zones just as in any other region. Due to this, the existence of an analytical-information system and a rainwater harvesting systems are very essential in order to help for domestic and also increase economic productivity.

2. ANALYSIS OF WATER CLEANING SYSTEMS

2.1 Developed Resource Saving Ways To Get Drinking Water For West African Regions.

A new development on a water supply plan was established in West Africa specifically Nigeria. Water supply plans should ensure the continued ability of community water systems to provide potable water to meet current and projected needs in the future [29].

The Lagos water supply plan is one-dimensional and lacks some important components that are necessary for the achievement of a sustainable water supply system in Lagos. As such, the intent to build upon the Lagos Water Supply Master Plan to create a more comprehensive and sustainable plan based on its gaps and the needs of the Lagos water sector. This new water supply plan will include additional initiatives, strategies and programs to ensure the protection of water resources and related natural systems and the sustainable provision of adequate water supply in Lagos through 2020 [30].

Inventory and Analysis:

Because of the limitations of this study to obtain significant data and perform the needed analysis, and for the purpose of this study, there will be the utilization of inventory data and subsequent analysis performed by the Lago State Water Corporation (LWC) to formulate strategies and programs to create a more comprehensive and sustainable plan, which facilitates a more pragmatic realization of sustainable water supply in Lagos. However, it is necessary to state that the Lagos State Water Corporation and other relevant water agencies, lack substantial data as they have limited capacities due to limited funding, manpower, and required technical skills to gather data and perform analyses [30].

Goals:

To formulate an environmentally holistic, community-based, and economically viable and reasonable water supply plan that will:

1. Governance: Reform current water governance structure to improve the efficiency and facilitate a more successful enforcement and implementation;

2. Infrastructure and Planning: Improve the Lagos water infrastructure to ensure reliability, efficiency, and high quality of the Lagos water supply system;

3. Quality: Ensure the proper quality of Lagos drinking water;

4. Management: Achieve profitability and realize higher efficiency through improved operations and management;

5. Sustainability:

- Achieve 100 percent coverage and eliminate the water demand gap in Lagos by 2020; and
- Provide sustainable groundwater and surface water use, development, and protection to serve the present and future citizens of Lagos [30].

Objectives

Governance:

- Restructure the current governance structure through consolidation of water agencies to eliminate redundancy and improve efficiency;
- Improve communication and cooperation among Lagos water agencies to facilitate effective and sustainable water management;
- Facilitating public participation by educating and engaging users and general public in matters related to water management;
- Establish the necessary structures for a successful implementation of the Plan and;
- Establish processes to promote water justice.

Infrastructure & Planning

- Defining priorities for investments in infrastructure; - Improving the efficiency of water supply infrastructure;
- Identify ways to reduce 60% unaccounted-for-water losses;
- Integrate planning to ensure sustainable water development and
- Identify mechanisms and help ensure that the water systems have the long-term capacity to meet standards and requirements.

Quality

- Define and include measures for water source protection including a source protection plan for improving and protecting the quality of the water bodies used in Lagos;
- Define measures to reduce the risk of groundwater pollution including saltwater intrusion; and
- Establish measures to eliminate sources of diffuse pollution and illegal dumping.

Management

- Institute effective and responsible management;
- Ensure successful adoption of privatization of water operations and management in Lagos; and
- Enhance the cost recovery associated with the use made by each consumer.

Sustainability

- Recommend ways to deliver water from existing and future water systems to Lagos residents in the most reliable, cost-effective, and environmentally responsible means;
- Define, encourage and implement water conservation measures, including wastewater recycling;
- Regulate and control excessive groundwater abstraction;
- Define measures for the adaptation or the control of damage caused by climate change; and
- Adopt appropriate measures to reduce flood risk by heavy floods.

Strategies

Governance

Goal: Reform current water governance structure to improve efficiency and facilitate successful enforcement and implementation.

1. Water Governance Restructuring

The current structure of the water system in Lagos state is fragmented, no collaborative and restrictive. Many policies and plans have been developed but the state still faces significant challenges in implementing them. Lagos lacks adequate and appropriate political, social, economic and administrative systems required to develop and manage resources and ensure delivery of water services at all levels of the society. This is very significant as the presence of water governance determines who gets water, when and how, and who has the right to water [31]. A successful governance structure must be able to deliver: clear vision and goals; secure resources; define clear roles and responsibilities; establish benchmarks for performance and monitoring; accountability to key stakeholders; transparency and access to information; and integrated management of surface and groundwater quality and quantity [30].

Action 1: Water Governance Assessment: A water governance assessment must be performed on stakeholders and institutions; on Lagos' governance principles such as transparency, accountability, collaboration, and participation; and on the performance and organization of water management functions of the Lagos water governance structure, to identify gaps and needs and help improve the Lagos water sector performance. The sustainable use of water, efficient use of water, equitable use and access to water, and equal democratic opportunities should be reviewed to assist the water governance assessment [30].

The eight steps for conducting a water governance assessment includes [30]:

- Clarify the objective;
- Conduct a stakeholder analysis;
- Decide on a stakeholder engagement strategy;
- Decide on assessment framework and scope;
- Select indicators;
- Collect data;
- Analyze results; and
- Communicate results

The developed water governance assessment framework should combine different approaches to better understand current water governance realities and measure the performance of current governance systems in relation to the desired future. There should also be extensive assessment of the roles of the various water agencies, as well as the mode of operation of the private service providers to ensure relevance, clarity of rules & functions, participation & mutual support within the provisions of regulations [30].

Action 2: Water Governance Scorecard: Developed by the Overseas Development Institute (ODI), the water governance scorecard provides insight into where gaps and challenges in a water governance system can occur and can be used to assess effective water management. The scorecard stipulates that the following legislative and regulatory instruments, and institutions, service providers, and coordination mechanisms must be in place and function effectively [30].

Categories of the Water Governance Scorecard (Adapted)

Appropriate legislative frameworks, including [30]:

1. Legislation for water allocation
2. Legislation for water quality
3. Existence of conflict-resolution mechanisms
4. Legislation for privatization

Appropriate regulatory instruments, including

5. Groundwater regulation
6. Land-use planning control
7. Water body protection

Functioning institutions, including:

8. Apex bodies
9. Basin organizations
10. Community resource management organizations
11. Regulatory bodies
12. Enforcement agencies

Functioning water service providers that secure:

13. Awareness campaigns

14.Urban water supply

15.Water treatment

16. Irrigation, drainage and flood control

Functioning coordination mechanisms with:

17.Sectors: Hospitality, agricultural, marine, and energy

18.Local governments

It is necessary that the Lagos government utilize this scorecard to identify legal and regulatory structures and mechanisms that it lacks and requires. This will help eliminate redundant procedures and agencies and set up mechanisms and structures that will help ensure effective water management. This process will also help facilitate the consolidation of the numerous water agencies that bear similar functions into one, thus removing inefficiencies and opportunities for bottlenecks. This will enable a more uniformed process of water governance in Lagos [30].

Action 3: Mandated Monthly Meetings: Cooperation between state water agencies and local water systems should be encouraged to facilitate effective water supply planning. Greater collaboration may mitigate any conflicts of functions or operations between the various water agencies in the exercise of their respective regulatory and policy development functions. To foster sustainable planning, regular monthly reviews and meetings among agencies should be mandated and would be a proactive and effective mechanism for promoting expeditious procurement activities, cost savings and resolving problems. By working together, water agencies, specifically LWC, LASEPA, LWRC and LSWMO, would be more able to plan more efficiently for interrelated water issues such as wastewater management, water pollution, and water supply, thus eliminating the self-sabotaging processes that exist in the Lagos water sector. Furthermore, by ensuring coordination amongst water sector agencies, institutional capacity building can be encouraged [30].

<u>Examples of Functions From Proposed Water Governance Structure</u>

Sovereign Water Agency

Policy-making, their implementation and enforcement

- Developing a long-term framework for water resources and service;

- Setting strategies and priorities;
- Ensuring human resources management, including training;
- Budgeting and fiscal transfer; and
- Governing all Lagos water agencies.

Water Regulatory Agency

Regulating water resource and services

- Monitoring water agencies and private water service providers;
- Economic regulation by setting water tariffs;
- Monitoring and enforcing water regulations, permits and standards, ensuring compliance and implementation;
- Applying incentives and sanctions;
- Implementing water rights systems; and
- Settling disputes

Water Planning Committee

Planning and organizing and building capacity in water

- Facilitating coordinated decision-making within and among different water agencies and sectors;
- Developing planning and management tools to support decision making;
- Designing strategies for long-term planning of water resources and service development, including infrastructure investments;
- Collecting, managing, storing, sharing, and utilizing water-relevant data; and
- Facilitating stakeholder participation.

Water Quality Agency

Ensuring Water Quality & Protection

- Protecting ecosystems and water bodies;
- Ensuring cleanup of polluted water bodies; and
- Prevention of pollution through permits, standards, and sanctions.

Wastewater Agency

Managing & Treating Wastewater

- Treating wastewater for recycling;

- Ensuring coordinated and uniformed wastewater system; and
- Building a centralized wastewater system.

Water Supply Agency

Developing & Managing Water Resources

- Construction of public water infrastructure and authorizing private sector infrastructure for other sectors;
- Monitoring and evaluation of private water suppliers; and
- Tendering and procurement.

Private Water Operators

Water Supply Service Delivery

- Operating and maintaining infrastructure;
- Organizing water services delivery, such as water supply and irrigation;
- Forecasting and managing the effects of floods and droughts; and
- Organizing stakeholder participation [30].

Basically, the main concept or idea behind the Lagos project is to enhance the quality of water and also have a more economically viable supply of water.

2.2 Justification For Choosing Source of Water.

Water in Africa, as a limited resource, must be carefully managed for the benefit of all people and the environment to ensure food security today and in the future. With the global food crises and the growing population continent-wide, more food must be grown for the 212 million malnourished people across Africa and the one billion more people expected by 2050. Again, there are lots of financially unstable families living in these regions and as such, need access to a cheap and reliable source of water which should be of good quality for domestic use [32].

Rainwater happens to be one of the most important source of water for both domestic and commercial use in most African regions. Much of Africa has a tropical or desert climate, while it may be warm or hot in other areas; humidity and rainfall vary dramatically from one place to another. The map in Figure 2.1 shows Africa’s climate patterns. The map indicates the average January and July temperatures and the average yearly precipitation (rain, melted snow and other forms of moisture). The variations between summer and winter temperatures are slight. In fact, the difference between daytime and night-time temperatures in most parts of the continent is greater than the difference in the average temperatures between the coldest and warmest months. Africa has the largest tropical area of any continent. The equator runs through the middle of Africa, and about 90 percent of the continent lies within the tropics. In countries south of the equator, the seasons are opposite to those of countries that lie to north. However, temperatures are high around the year almost everywhere in Africa [32].

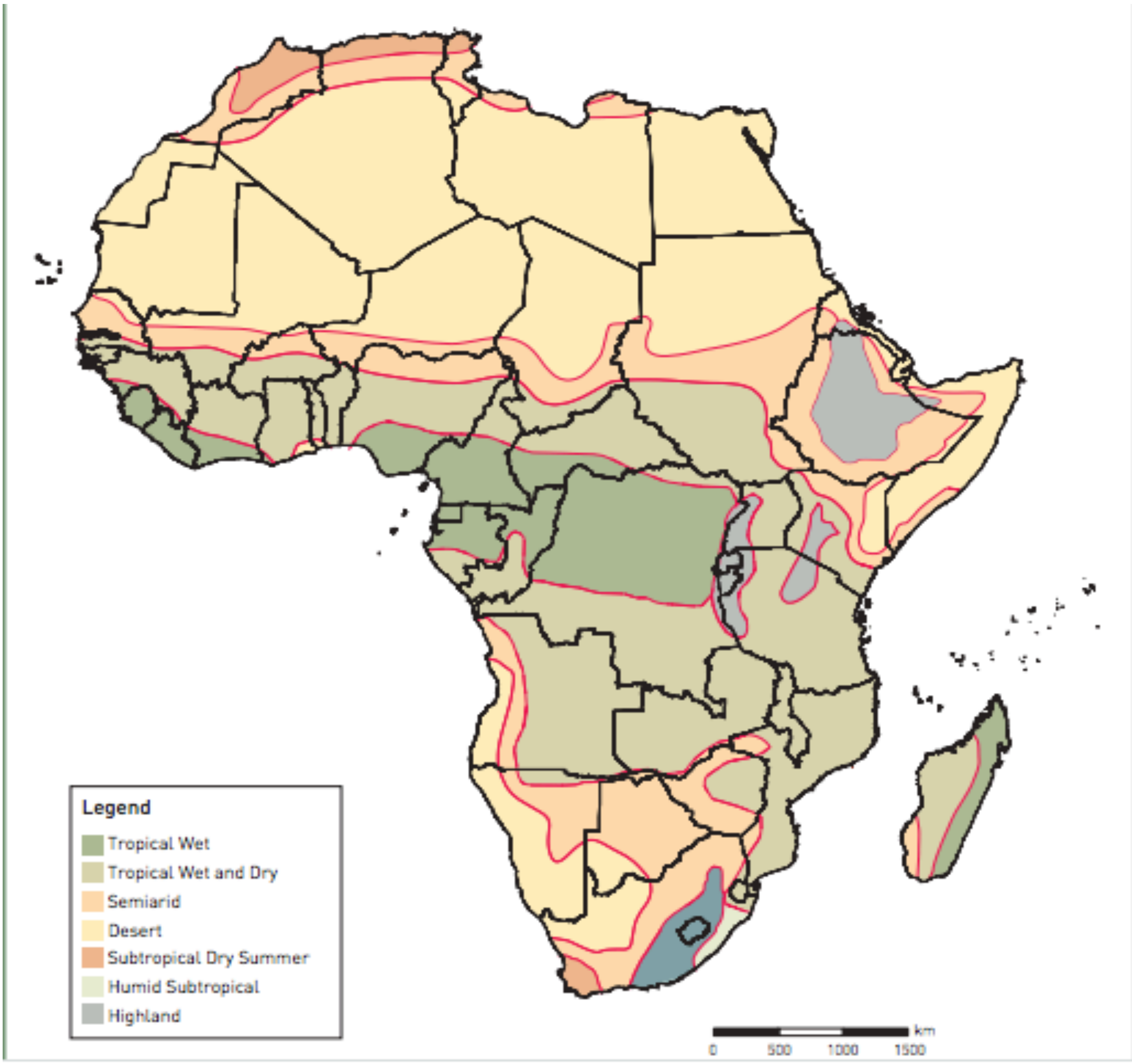


Figure-2.1 Africa’s climate pattern

Africa's highest temperatures occur in the Sahara and in parts of Somalia. The highest temperature ever recorded was 58˚C in the shade at Al Aziziyah, Libya, on 13 September 1922. At Ibn-Salah, Algeria, and along the north coast of Somalia, July temperatures soar to 46˚C or higher almost every day. Night-time temperatures, however, may drop sharply. Winter temperatures in the Sahara average from 10 to 16˚C. Near the equator, temperatures may average 24˚C or more around the year. However, temperatures of more than 38˚C are rare. The Sahara also has the greatest seasonal range of temperatures in Africa. The coolest regions in Africa are the northwest, the highland areas of the east, and parts of the south. In Johannesburg, South Africa, for example, the average temperature in January, the warmest month, is 20˚C. Frost and snowfall are common in the mountains of Africa [32].

Africa's share of global freshwater resources, at 10 percent, closely matches its share of world population at 12 percent. The problem stems from the uneven distribution of rainfall (this is shown in figure 2.2), and from the fact that, for the African continent as a whole, 86 percent of water withdrawals are directed towards agriculture, and this percentage is even higher in the arid and semi-arid part of Africa [33]. In those areas the water withdrawn for agriculture from the hydrologic system may represent a significant part of the water resources [32].

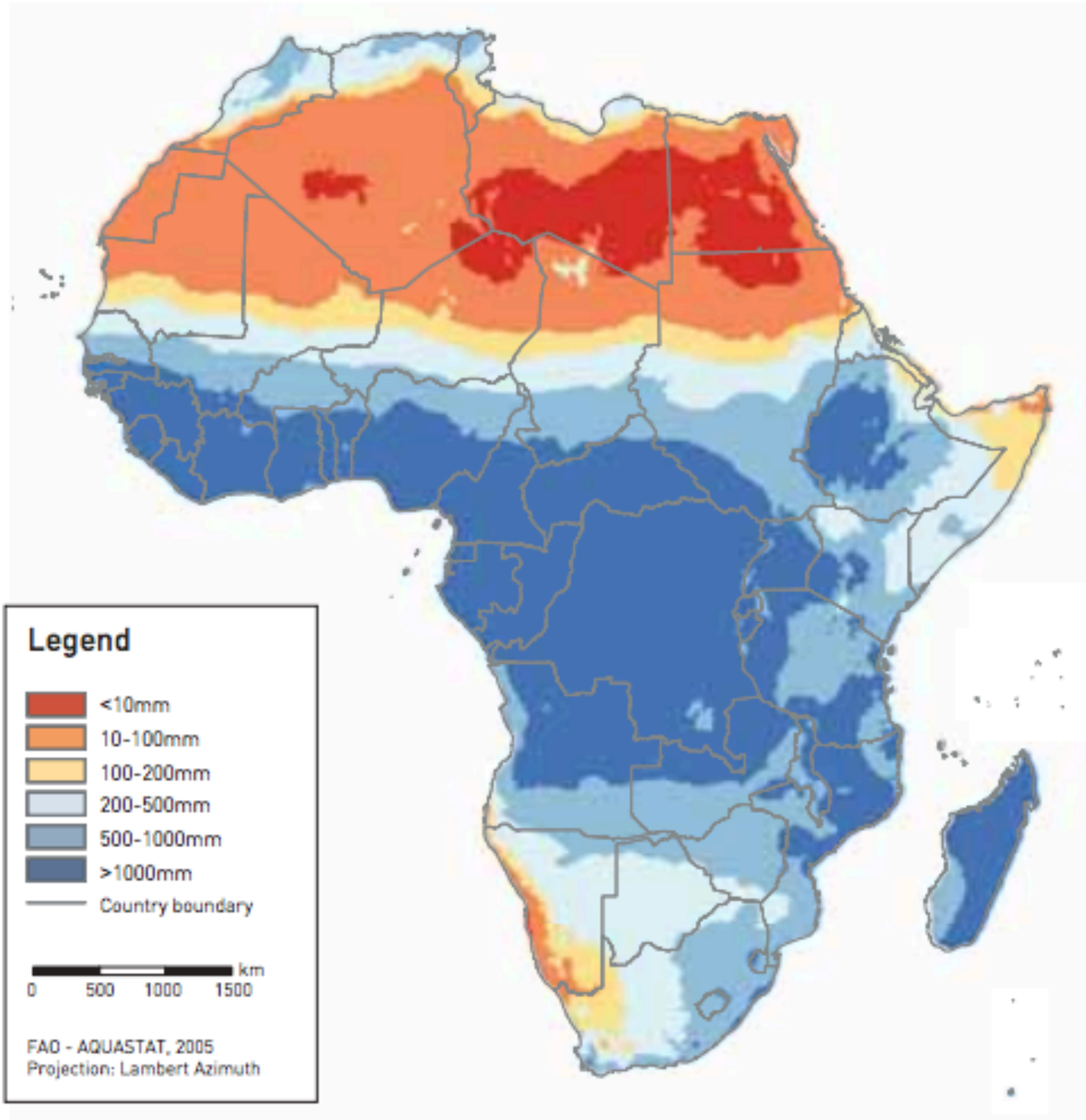


Figure-2.2 Average annual precipitation

As can be seen in Table 2.1, most areas receive either too much rain or too little. In parts of the west coast, for example, annual rainfall averages more than 250 cm. In Monrovia, Liberia, an average of more than 100 cm of rainfalls during the month of June alone. In contrast, more than half of Africa receives less than 50 cm of rainfall yearly. The Sahara and the Namibia deserts receive an average of less than 25 centimeters a year. In parts of the deserts, rain may not fall for six or seven years in a row. Both droughts and floods have increased in frequency and severity over the past 40 years. Over the past fifteen years, Africa has experienced nearly one-third of all water related disaster events that have occurred worldwide, with nearly 135 million people affected, 80 percent by droughts. Since the late 1960 s, droughts have caused much suffering in Africa. Millions of Africans have died of starvation and related causes. Rain falls throughout the year in the forests of the Congo Basin and the coastal regions of western Africa. However, almost all the rest of Africa has one or two seasons of heavy rainfall separated by dry periods. In some regions of Africa, the amount of rainfall varies sharply from year to year rather than from season-to-season. The hardest-hit areas include Ethiopia and the Sahel region on the southern edge of the Sahara [32].

Table-2.1 Regional rainfall distribution in Africa [32]

Sub-region	Area	Annual precipitation		Annual internal renewable resources (IRR)			Annual withdrawals for agriculture, community water supply and industry			
	1 000 km²	mm	million m³	million m³	In % of Africa	Per inhabitant (2004)	million m³	% of Africa	m³ per inhabitant (2004)	% of IRR
North	5 753	96	549 959	49 495	1	325	93 889	43.7	616	189
Sudano-Sahelian	8 587	311	2 671 364	260 200	4	1 418	54 948	25.7	486	35
Gulf of Guinea	2 119	1,356	2 873 971	951 940	24	4 853	12 395	5.8	63	1.3
Central	5 329	1,425	7 592 517	1 876 180	48	19 845	1 993	0.9	21	0.1
Eastern	2 925	920	2 665 720	280 960	7	1 521	14 215	6.6	77	5
Southern	4 736	659	3 110 159	270 130	7	2 518	21 657	10.0	202	8
Indian Ocean Isl.	592	1,510	895 250	340 951	9	17 042	15 717	7.3	786	4.6
Total	30 041	678	20 358 940	3 929 856	100	4 527	214 814	100	247	5.5

Source: *FAO-AQUASTAT, 2005*
Northern: *Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia;*
Sudano-Sahelian: *Burkina Faso, Cape Verde, Chad, Djibouti, Eritrea, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, Sudan;*
Gulf of Guinea: *Benin, C te d Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo;*
Central: *Angola, Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe;*
Eastern: *Burundi, Ethiopia, Kenya, Rwanda, Uganda, United Republic of Tanzania;*
Southern: *Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe;*
Indian Ocean Islands: *Comoros, Madagascar, Mauritius, Seychelles.*

Because of the lack of rainfall in some countries, large numbers of people are dependent on groundwater as their primary source of freshwater, as shown in Table 2.2 [32].

Table-2.2 African countries highly dependent on groundwater resources [32]

Country	Groundwater use (%)
Algeria	60
Libya	95

Source: Table based on UNEP, 2002. Africa Environment Outlook.

With only 64 percent of the population having access to improved water supply, Africa records the lowest proportional coverage of any region in the world. The situation is worse in rural areas, where coverage is only 50 percent compared with 86 percent in urban areas. Yet more than half of the urban dwellers have inadequate provision if the definition is a house connection or yard tap. The continent is home to 27 percent of the world's population that is without access to improved water supply. Table 2.3 shows the percentage of African population having access to improved water supply facilities and also to household connections [32].

Table-2.3 Percentage of access to sanitation services in Africa [32]

Year	Access to improved water supply facilities (%)	Access through household connections (%)	Not served (%)
1990	59	17	41
2000	64	24	36

Source: ONU/WWAP, 2003, UN World Water Development Report.

2.3 Method For Cleaning Collected Water in West African Regions.

Rainwater harvesting is viewed by a lot of people, including the EPA, as a partial solution to the problems posed by water scarcity: droughts and desertification, erosion from runoff, over-reliance on depleted aquifers, and the costs of new irrigation, diversion, and water treatment facilities [34].

Contaminants in water may include algae, bird excrement, and leaves, sand, and dust. Local wells have been used over decades to deal with these problems. Installation of filtration and purification equipment can remove these contaminants at home as well. First, foreign matter must be kept out of the incoming rainwater. And then flush devices, gutter screens and other screening mechanisms keep the rainwater as clean as possible before it enters the conveyance system. Using screens and filters will greatly reduce maintenance and lengthen the life of the pump and filtration or purification system [34].

Even the best screening systems will allow unwanted particulates into the cistern (an artificial tank or reservoir). To keep sediment where it belongs, at the bottom of your tank, screen incoming rainwater, give the remaining sediment time to settle, avoid disturbing it, and don't pull water from the bottom of the tank. Use of a floating filter, extracts water from the middle of the tank, leaving sediment undisturbed. Next is filtration, which removes debris from the water. Disinfection or purification follows, which kills contaminants and removes harmful substances that may be present [34].

To determine the type of system needed, the rainwater must be tested at a reliable laboratory. Without testing, a lot of money could be spent on equipment that will not give safe water. Filtration is included in every system, even simple irrigation systems. Examples of filtration systems include: screen filters, paper filters, and carbon or charcoal filters [34].

Almost all systems use multiple filters. For example, after gutter screens and/or a first flush device, a system often includes two in-line filters of increasing fineness, a carbon filter and a UV light. Each of these are described below to assist you in evaluating what might be the right alternative for your planned water use and required water quality [34].

Filters and Disinfection

Filters are measured in microns. One micron is about $1/25{,}000_{th}$ of an inch. For comparison, sand is about 100 – 1,000 microns, a human hair is about 100 microns, a particle of dust is about 1 micron and a virus can be smaller than .01 micron [34]

The first filters in a system are cartridge filters. They range widely in what they are capable of removing and are used in a series (e.g., a 20 micron followed immediately by a 5 micron filter) [34].

Filters are rated by the smallest size of particle they are capable of filtering. The smaller the micron size the better the filter. However, the finer the filter, the higher its cost and the slower its process. Filters have to be changed regularly, as an old, used filter is an excellent environment for microorganisms and potentially harmful pathogens [34].

For wells and rainwater systems a larger (e.g., a 50 micron) filter or equivalent screen (e.g., 300 mesh) should be used first to eliminate sand and large particles. This screen should be easily accessible and cleaned quarterly. Next is a 20 or 10 micron filter, followed immediately by a 10 or 5 micron filter. These are cleaned less frequently, but at least annually [34].

Filters will not eliminate all substances in the water. To create drinking quality water, filtration is always followed by disinfection. The EPA requires surface and ground water to be disinfected before it is consumed. Consequently, public water systems add disinfectants to destroy microorganisms that can cause disease in people and animals [34].

This is also necessary for rainwater, as the natural environment contains many microorganisms. Most are not harmful to us. Some, however, such as Giardia lamblia, can be deadly. These need to be eliminated from water before it is consumed [34].

Kinds of disinfection include chlorination, ultraviolet (UV) light, and membrane filtration. In evaluating disinfection methods, be aware that some actually create unhealthy byproducts that need to be treated [34].

The effectiveness of disinfection is judged by looking for an indicator organism that, if present, indicates other more harmful pathogens may be present. In getting a water test, this indicator organism is Total Coliform Bacteria that, if present, indicates other pathogens may be present as well [34].

Chlorine has been used as a disinfectant in public water systems for most of the past century. The introduction of chlorine to disinfect water has virtually eliminated waterborne diseases such as cholera, typhoid, dysentery and hepatitis, saving thousands of lives. However, it is often maligned due to suspected side effects [34].

For disinfection purposes, 2.3 fluid ounces of household bleach must be added per 1,000 gallons of water. Chlorine dosage rate will vary depending on quantity of water to be treated, pH and temperature [34].

A major downside of chlorine is that it is very reactive and easily combines with naturally occurring organic material to create harmful trihalomethanes (THMs) like chloroform. Chloroform is formed when chlorine reacts with either humic and/or fulvic acids, which are commonly found in water [34].

Because chlorine is reactive, it quickly dissipates. Keeping the dosage rate correct is critical when using this method of disinfection. THMs should be tested for in the water source if you are going to use Chlorine [34].

To reduce the possibility of harmful byproducts with the use of Chlorine, do the following [34]:

- Remove the byproducts after they have been created. This is costly, typically meaning other purification systems must be employed (e.g., Reverse Osmosis or other purification systems) or
- The concentration of particulates/organics in the water before it is treated. This is accomplished by using filters to remove these substances from the water prior to chlorine treatment.

The Chlorine smell and taste can be removed with an activated carbon filter, often referred to as a charcoal filter. Granulated activated carbon filters may be made from coconut shells and can be considered a “green” solution. Carbon block filters are compressed activated carbon, fused with a binding substance into a solid block [34].

2.4 Justification System of Cleaning Water.

Distillation

The commonly available purification technology is distillation. Distillation separates the water from the impurities through heating and then collecting the condensation. It is very energy intensive and loses about 5-10% of the water due to evaporation. Distillation removes almost all substances from the water with the exception of volatile organic chemicals (VOCs) that evaporate easily. To this end, some distillation systems are also equipped with carbon filters to remove the VOCs [34].

Distillation works slowly to reduce energy requirements and, like RO systems, will store the purified water in a tank for later use. In addition to using a lot of electricity to operate, distillation systems generate heat [34].

Distillation units producing 5 -12 gallons of water a day will typically cost about $1,500 - $2,000. Cost will increase as capacity increases and as options are added. High-end automatic home units with larger storage capacity may cost upwards of $4,000. New solar distillers give the option of reducing the electrical requirements [34].

Standard Practice for Household Use

A common practice in off the grid homes is to filter all the incoming rainwater and then store it in a small pressure tank. From the pressure tank the outgoing water is split into two separate paths - one path for potable and the other for non-potable water. A purification process is added to produce potable water. The major advantage of this approach is that it requires a much smaller unit and costs less, since it treats less water than a whole-house unit. But the disadvantage is that it requires a dual plumbing system – one to supply filtered but non-potable water to the toilets, clothes washer, irrigation faucets, etc., and one to supply potable water to the faucets [34].

An apparently low-cost, entry-level system is a countertop or pitcher type unit for potable water. However, when measured on gallons of water processed between changing filters, these units tend to be much more expensive in the long run. For example, a typical faucet unit available at most large hardware stores needs its filter changed every 100 gallons. For a family, this would be more than once a month and each filter costs about $30 [34].

Before investing in filtration or purification equipment, invest in removing particulates before they enter into the system by installing gutter screens, leaf screens and roof washers. Removing materials before they enter the system is far easier and less expensive than dealing with them afterwards. There is no perfect solution for disinfecting water, as all solutions have some environmental cost. Some require substantial energy, some create harmful by-products and some waste water. Generally, the smaller the capacity the less expensive the unit will be overall [34].

2.5 Conclusion

Notably, freshwater resources are continually decreasing in quality and quantity. The review aimed at assessing the water resources with focus on freshwater, the quality of our freshwater resources in terms of physical, chemical and biological variables, the main mechanisms of management, and the challenges associated with these mechanisms as well blending integrated water management with the indigenous or traditional management of water resources for sustainable development and peaceful co-existence [35].

Rainwater purification is very vital for human consumption and also commercial or industrial purposes. There are several methods that can be used for these purification processes but rainwater testing must be carried out in the laboratory to be able to identify the most effect and less expensive methods to adapt to. This way, there will be a direct connection to the developed analytical-information system.

3. PARAMETERS AND ELEMENTS UTILIZED UNDER INFORMATION-ANALYTICAL SYSTEM FOR WATER CLEANING SYSTEMS

3.1 Justification Parameters and Properties of System Elements For Cleaning Water.

Analysis of methods of water purification from heavy metals has shown that practically all methods used in water body protection against pollution are quite effective. At the same time, the problem of received waste recovery, as a rule, is not rectified. In the meantime, metals that can be found in extremely polluted wastewater are of market interest [36].

Most of the water supply and sanitation systems in West African countries currently do not fully comply with modern technological, environmental and sanitary-hygienic requirements, which are set out in the relevant state standards, technological regulations and standards. The reason for this was the lingering nature of the transition of communal systems to market relations [37].

There are basic standards, norms, criterion and indicators for safe drinking water. There are also policies, strategy and program under safe drinking water [38]. Countries regulate drinking water differently depending on the quality of their water source. According to the WHO [39] and US Environmental Protection Agency [40], there are guidelines and principles that need to be followed for water to be considered fit for use.

3.1.1 Description of Water Quality Parameters

Physical parameters:

Physical quality parameters are related to total solids content, which is composed of floating matter, matter that has ability to settle, colloidal matter and matter in solution. The following physical parameters are determined in water [41]:

- **Color**: caused by dissolved organic materials from decaying vegetation or landfill leachate.

- **Taste and odor**: can be caused by foreign compounds such as organic compounds, inorganic salts or dissolved gases.
- **Temperatures**: the most desirable drinking water is consistently cool and does not have temperature fluctuation of more than a few degrees. Groundwater generally meets these criteria.
- **Turbidity**: refers to the presence of suspended solid materials in water such as clay, silt, organic material, plankton, and others.

Chemical parameters:

The chemical constituents have more health concerns for drinking water than for the physical constituents. The objection ability of most of the physical parameters are based on esthetic value than health effects. But the main objection ability of some of the chemical constituents is based on esthetic as well as concerns for adverse health effects. Some of the chemical constituents have an ability to cause health problems after prolonged period of time [42]. That means the chemical constituents have a cumulative effect on humans. The chemical quality parameters of water include alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved gases, nitrogen compounds, pH, phosphorus and solids (organic). Sometimes, chemical characteristics are evidenced by their observed reactions such as in laundering, redox reactions, and so on [41].

Below is a list of some of the chemical compounds and elements found in water [43]:

- **Arsenic**: occurs naturally in some geologic formation. In drinking water, it has been linked to lung and urinary bladder cancer.
- **Chloride**: most waters contain some chloride. The amount found can be caused by the leaching of industrial or domestic waters. Chloride should not exceed 100 mg/L in domestic water to be palatable.
- **Fluoride**: is a natural contaminant of water. It is one of those chemicals given high priority by WHO [44] for their health effects on humans. High F in drinking water usually causes dental and skeletal fluorosis. Excessive F (>2 mg/L) causes a dental disease known as fluorosis (mottling of teeth), while regular

consumption in excess may give rise to bone and skeletal fluorosis [41]. On the other hand, F < 2 mg/L causes dental cavities in children.

- **Zinc**: is found in some natural waters, particularly in areas where zinc ore deposit have been mined. Though it is not considered detrimental to health, but it will impart a bad taste to drinking water.
- **Iron**: small amounts of iron frequently are present in water because of the large amount of iron in the geologic materials. This will cause reddish color to water.
- **Manganese**: naturally occurring manganese is often present in significant amounts in groundwater. Anthropogenic sources include discarded batteries, steel alloy production and agricultural products.
- **Toxic substances**: generally classified as inorganic substances, organic substances and heavy metals. The toxic inorganic substances include nitrates (NO_3), cyanides (CN) and heavy metals. These substances are of major health concern in drinking water. High NO_3 content can cause *Methemoglobinemia* in infants ("infant cyanosis" or "blue baby syndrome"); while CN can cause oxygen deprivation [41]. There are more than 120 toxic organic substances [40], generally exist in the form of pesticides, insecticides and solvents. These compounds produce health effects (acute or chronic). The toxic heavy metals are arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se) and silver (Ag) [41]. Like the organic substances, some of these substances are acute poisons (As and Cr) and others produce chronic diseases (Pb, Cd and Hg).

Biological parameters:

Biological parameters are the basic quality parameters for the control of diseases caused by pathogenic organisms, which have human origin. Pathogenic organisms found in surface water include bacteria, fungi, algae, protozoa, plants and animals and viruses. Some of these disease-causing organisms (bacteria, fungi, algae, protozoa and viruses) are not identifiable and can only be observed microscopically. Microbiological agents are very important in their relation to public health and may also be significant in the modification of physical and chemical characteristics of water [41]. Water for drinking and cooking purposes must be free from pathogens. The greatest microbial risks are associated with consumption of water that is contaminated with human or animal feces. Feces can carry pathogenic bacteria, protozoa, helminthes and virus. Pathogens originating from feces are the principle concerns in setting health-based targets for microbial safety. Water-borne diseases are particularly to be avoided because of the capacity of result in the simultaneous infection of large number of people. While water can be a very significant source of infectious organisms, many of the diseases that may be waterborne may also be transmitted by other routes, including person-to-person contact, droplets and aerosols and food intake [42].

The techniques for comprehensive bacteriological test are complex and time consuming. Different tests have been developed to detect the relative degree of bacterial contaminations in terms of an easily defined quantity. There are two mostly used test methods widely used to estimate the number of microorganism of coliform groups (*Escherichia coli and Aerobacter aerogenes*). These include: total coliforms or *E. coli*, but the second one is found to be a better indicator of biological contamination compared to the first one [41].

3.1.2 Choosing and Justifying Construction Materials, Size of Elements of Cleaning Systems.

A well-equipped membrane cleaning system is illustrated in figure 3.1 below. As is evident, the system's components are commonly found pieces of equipment [45].

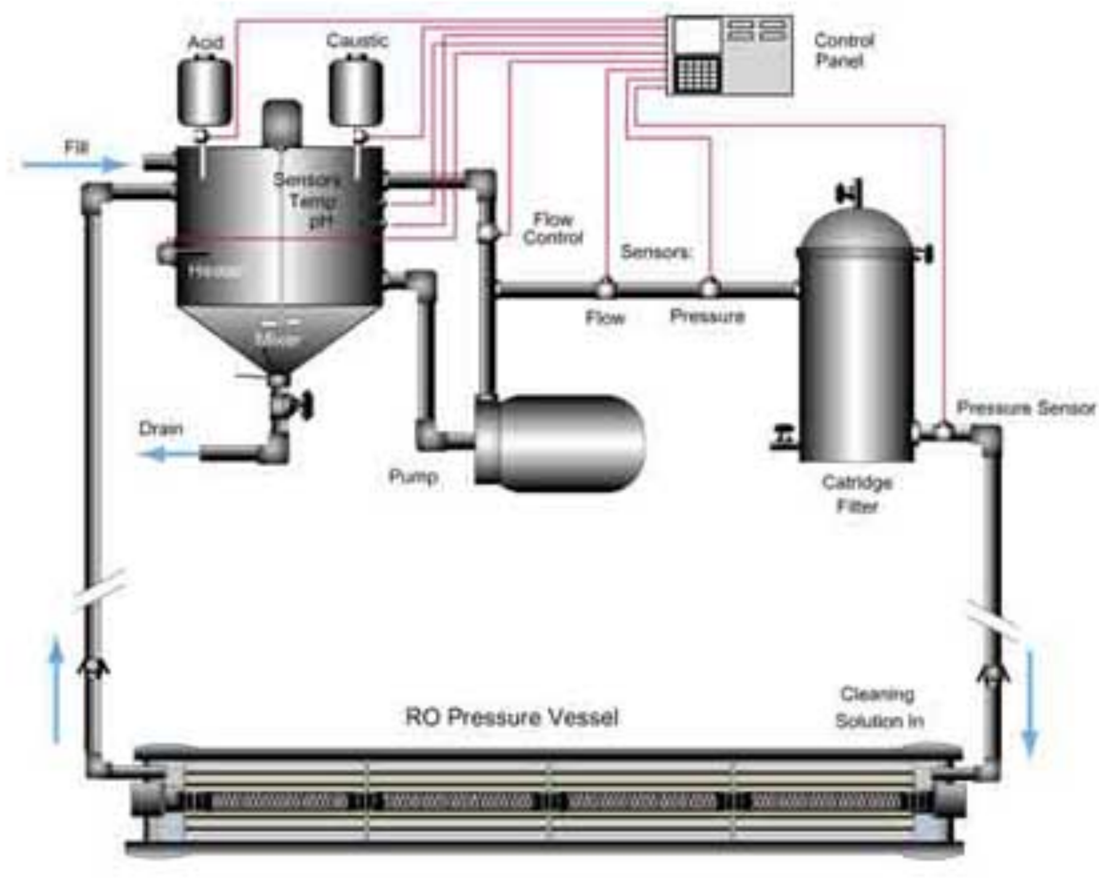


Figure-3.1 Membrane cleaning system

A mixing tank is used to prepare and hold the cleaning solution. It should be large enough to hold a sufficient quantity of that solution. A good rule of thumb is that it have a 60-gallon capacity for each 8-in. vessel (holding six elements) being cleaned. The tank should be equipped with a mechanical mixer to ensure proper dilution of the cleaning chemical before use. In the absence of a mixer, the tank should be piped so that the cleaning solution can be re-circulated through the cleaning pump and back to the tank before being returned to the vessels being cleaned [45].

The tank should be equipped with a means to heat the cleaning solution. In smaller systems, this can be accomplished with an electric submersible heater. In larger systems, it may require a steam coil. The temperature should be thermostatically controlled to prevent overheating the solution. A thermometer and pH sensor should be installed to monitor the temperature and pH of the solution during cleaning. The tank should be equipped with a cover to prevent splashing outside its walls and to keep foreign material from falling into it. Ideally, it should have a cone-shaped bottom or some other configuration to allow it to be drained completely. This eases considerably the cleaning of the tank before the next use [45].

The pump incorporated in the system has to be large enough to provide sufficient cleaning velocity (flow). It should be able to produce at least 40 gpm for each 8-in. vessel being cleaned at the same time. For instance, if the first stage of an RO system contains nine vessels and the entire stage is cleaned at once, the pump should be able to produce 360 gpm. The pressure output of the pump should be such that 50 psi of pressure drop is available across the vessel(s) being cleaned. The system should be designed to permit control of the output from the pump. A flow sensor is required to monitor the flow from the cleaning system to the vessels [45].

A cartridge filter is necessary to prevent large particles from entering the membrane treatment system during cleaning. This filter usually is located between the pump and the pressure vessels (in the supply line) rather than between the pressure vessels and the mixing tank (the return line). In this way, any foreign material such as trash in the mixing tank or inert components in the cleaning chemical will not find their way into the membrane elements being cleaned. Because the filter is used to prevent relatively large particles from plugging the feed spacers in the elements being cleaned, cartridge hole sizes in the 10-20 micron range are generally sufficient. The pressure drop across the filter should be monitored during the cleaning process. Cartridges should be changed when the pressure drop reaches 10-15 psi.

While the size of the cleaning system will vary with the size of the membrane treatment system being cleaned, the basic components of the cleaning system will be the same regardless of system size. Materials of construction should be compatible with the cleaning solutions being used. This usually means compatibility with high or low pH. Aluminum especially should be avoided since it is soluble at high and low pH, but less so at a neutral pH. Aluminum can cause problems, even in small quantities such as the amount that might be contained in hose connectors [45].

Connections between cleaning system and membranes are important. It is important that the cleaning system is connected correctly to the membrane system being cleaned. Never should more than one stage of vessels be cleaned at once (Figure

3.2). During cleaning it is important to achieve as much flow as possible. Because little water permeates through the membrane during cleaning, the majority of the flow remains in the feed spacer area of the elements, where it should accomplish more effective cleaning. If multiple stages in series are cleaned at the same time, the flow will be either low in the first stage or excessive in the second stage. Cleaning one stage at a time allows the maximum flow to be attained in each vessel. Permeate produced during the operation should be returned to the mixing tank to prevent loss of the cleaning solution [45].

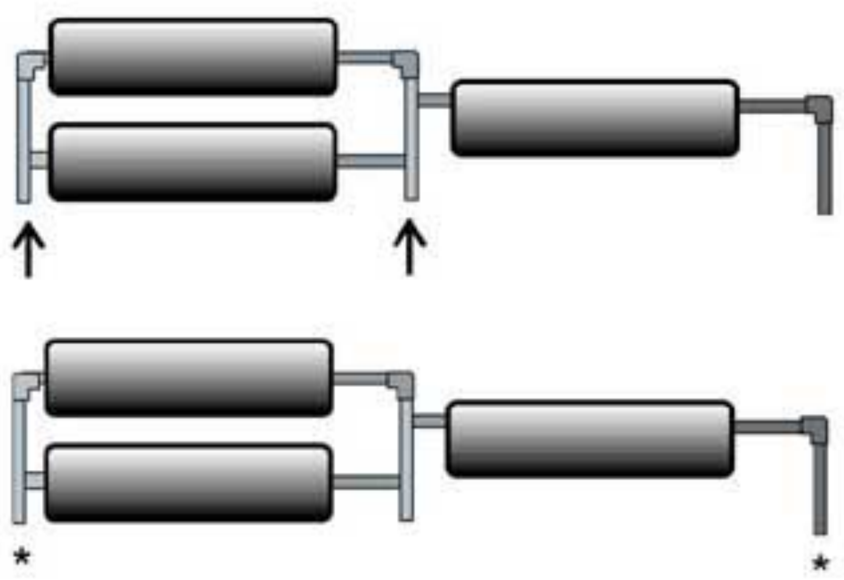


Figure-3.2 Proper cleaning connections

In some cases, such as in ultrafiltration systems, vessels can be cleaned individually. In instances of extreme fouling it may be necessary to clean elements individually. This is accomplished by using a stand-alone cleaning system that incorporates a single-element vessel to hold the element being cleaned [45].

While vessels holding multiple elements are being cleaned, it is necessary to move the cleaning solution in the same direction as the feed water when the system is being used in the normal operating mode. The cleaning flow may be reversed only if the thrust collar is moved from the discharge end of the vessel to the feed end. If the flow is reversed without moving the thrust collar, the high differential pressure on the element stack inside the vessel can cause element telescoping since the last element in the vessel is supported only by its permeate connection (the end cap adapter). At all times, follow the membrane element manufacturer's recommendation for pressure drop across the vessel (typically 50-psi for a vessel holding six elements) [45].

Small-to-medium sized cleaning systems usually are connected to the membrane elements by a flexible hose. Such hoses are to be in place only when cleaning is taking place. Large cleaning systems may be hard piped to the membrane system, with appropriate valves or short sections of flexible hose used to direct the cleaning solution through various stages in the system being cleaned. Regardless of the method of connection, one must be able to monitor the pressure across the vessel or stage of vessels being cleaned. The pressure drop across the vessel(s) is the primary indicator of progress during the cleaning process. It also is necessary to monitor this pressure drop to ensure that the elements are not damaged (telescoped) during the process[45].

A variety of factors basically decides the cleaning procedure, actual cleaning procedures will vary depending on membrane type, cleaning system, cleaning chemical (especially if commercial formulations are used), and cleaning experience. The following procedure is a good starting point if an effective method is not already in use [45]:

Step 1: Make sure the mixing tank is clean and that fresh cartridges have been installed in the filter. Also, make sure that the hoses or piping used to connect the cleaning equipment to the membrane system is clean.

Step 2: Thoroughly mix the cleaning solution and adjust for proper pH and temperature. Allow enough time for the pH and temperature to stabilize before starting the cleaning process. If you are using a commercial cleaning formulation, make sure to follow the manufacturer's instructions.

Step 3: Begin to transfer the cleaning solution to the vessels slowly (3 gpm for 4-in. vessels and 12 gpm for 8-in. vessels). Allow the flow to remain at this rate for approximately 15 minutes. This prevents loose particles from being dislodged suddenly and becoming caught in the feed spacers of the elements downstream.

Step 4: Increase the flow to an intermediate flow rate (6 gpm for 4-in. vessels and 24 gpm for 8-in. vessels). Allow the flow to remain at this rate for an additional 15 minutes.

Step 5: Gradually increase the flow rate until the maximum pressure drop across the vessel has been reached. As the elements in the vessel(s) become cleaner, the pressure drop will decrease. Adjust the flow frequently to keep the pressure drop at its maximum, making sure that it does not exceed the maximum allowed value. Continue to monitor the flow rate. At some point, the flow will no longer increase. This indicates that the maximum amount of cleaning has been attained. If the flow and pressure drop do not correspond to desired levels (usually those attained after a previous cleaning), it may be necessary to use a different cleaning solution.

Also, it may be advantageous to allow the cleaning solution to soak in the vessels in one stage while cleaning is started in another stage. If so, when returning to the original stage, start with the low flow step before going to the higher flow rates. Soaking loosens material that may suddenly break free and plug the feed spacer if high flows are started initially [45].

It is important always to flush the membrane elements thoroughly with clean water (preferably deionized water or RO permeate) before switching to a different cleaning solution. If possible, adjust the pH and temperature of the rinse water to match that of the previous cleaning solution. Mixing various types of cleaning solutions within the elements in the vessel can have disastrous results because of precipitate formation [45].

Due to the variability in typical feed water sources, fouling materials and equipment characteristics, finding the most effective cleaning procedure is almost always a matter of trial and error. For this reason it is important to keep a log of cleaning activities. The log should include information such as time, date, operator ID, cleaning solution formulation, solution mixing procedures, and frequent temperature, pH, pressure and flow readings. By referring to the information gained from previous cleaning operations, the procedure will become more effective and thus more cost effective [45].

3.2 Justification of Temperature Impact on West Africa Region on System Production.

Water vapor is one of the most important components of the atmosphere given that it is the means by which moisture and energy (as latent heat) are transported through the troposphere and lower stratosphere to influence weather. In addition to its role in balancing the atmospheric heat budget, water vapor plays an essential role in the global hydrological cycle and global climate system as the source of precipitation (rain, snow), clouds and fog [46].

In any vertical column of air, the amount of water vapor offers meteorologists a value of the maximum potential precipitation that could be retrieved from that air column under the right conditions. Although the air mass fraction of water vapor may approximately be around 1%, its effect on meteorology is very strong. It has the ability to cause small and large-scale temperature anomalies and influence atmospheric latent heat exchanges. Water vapor plays a major role in the climate system: recent studies have estimated that about 70% of the warming of the atmosphere is attributed to water vapor acting as a greenhouse gas. Despite its significance to atmospheric processes over a broad range of spatial and temporal scales, water vapor remains one of the least understood and inadequately described components of the Earth's atmosphere in current climate prediction models [46].

Traditionally, atmospheric water vapor observations may be measured directly by *in situ* instruments, such as radiosondes or humidity sensors onboard aircraft (downward looking radiometry), or indirectly based on remote sensing estimates from instruments such as microwave radiometers (upward looking radiometry). Because measurement techniques differ, so do measurement accuracies of the observed water vapor. A better understanding of climate and weather patterns thus requires data sets that are more comprehensive. Conventional techniques of measuring atmospheric water vapor do not offer the spatial and temporal resolution required for comprehensive investigation of the weather and climate systems [46].

The Global Navigation Satellite System (GNSS), through a concept referred to as ‘GNSS meteorology’, provides water vapor knowledge to atmospheric scientists. A network of ground based GNSS stations is used primarily for surveying, geodesy and navigational purposes. Due to the robustness that the ground based GNSS technique has shown in studying the distribution of water vapor, many networks of Continuously Operating Reference Stations (CORS) are being constructed around the world for multidisciplinary applications including meteorology [46].

The global number of CORS is much larger than the number of radiosonde stations. For instance, in Nigeria about 30 ground-based GNSS CORS are owned and managed by different institutions and organizations under various initiatives, whereas only three radiosonde stations in the same area are on the list of upper stations published by the World Meteorological Organization (WMO). The large number of ground-based CORS enables scientists to study water vapor distribution at a large geographical scale with a dense horizontal resolution. Compared with other observational techniques, the GNSS water vapor monitoring method yields better results in terms of spatial coverage and has higher temporal resolution. Additionally, as a continuous monitoring system, it is capable of measuring multiple lines between the station and the GNSS satellites under all weather conditions [46].

This study in essence addressed a fundamental issue in Global Navigation Satellite System (GNSS) meteorology in the West African region, where little or no work has been previously carried out in modelling weighted mean temperature [46].

3.3 Conclusion

As water is a basic need for human life, access to clean, safe drinking water is a basic human right. As a criterion, an adequate, reliable, clean, acceptable and safe drinking water supply has to be available for various users. From the developed information-analytical system, water pollution is seen to be a formulated problem that needs to be checked through a control lab for a better source characterization. Everyone needs access to safe water in adequate quantities for drinking, cooking, sanitation facilities, personal hygiene, which do not compromise health or dignity [43].

A set of models and methods have been proposed for assessing the health, optimization and reconstruction of developing water supply and sanitation systems which is to help improve the quality of water [37].

4. MATHEMATICAL MODEL OF A WATER PURIFICATION SYSTEM.

Water purification is of great relevance to all inhabitants on planet earth, there are many ways that water can be polluted based on the sheer number of bacteria and contaminants present in everyday interactions with pipe systems. As a matter of fact, there can be up to 2100 contaminants or toxins in your tap water. All of these contaminants can not only affect the taste of your water but also risk your health with the eventual development of cancers, gastrointestinal problems or other diseases. That's why it's important to understand how the water purification works and what can be done to improve upon it [47].

A water purification system has been developed mainly to trap or collect rainwater in a tank which will then go through some process of steaming taking into consideration temperature of the water. This steam will then flow through a chamber of various filtrations points before the steam is converted back to water which will be ready for use (either domestic or commercially). The figure 4.1 below illustrates the rainwater purification system.

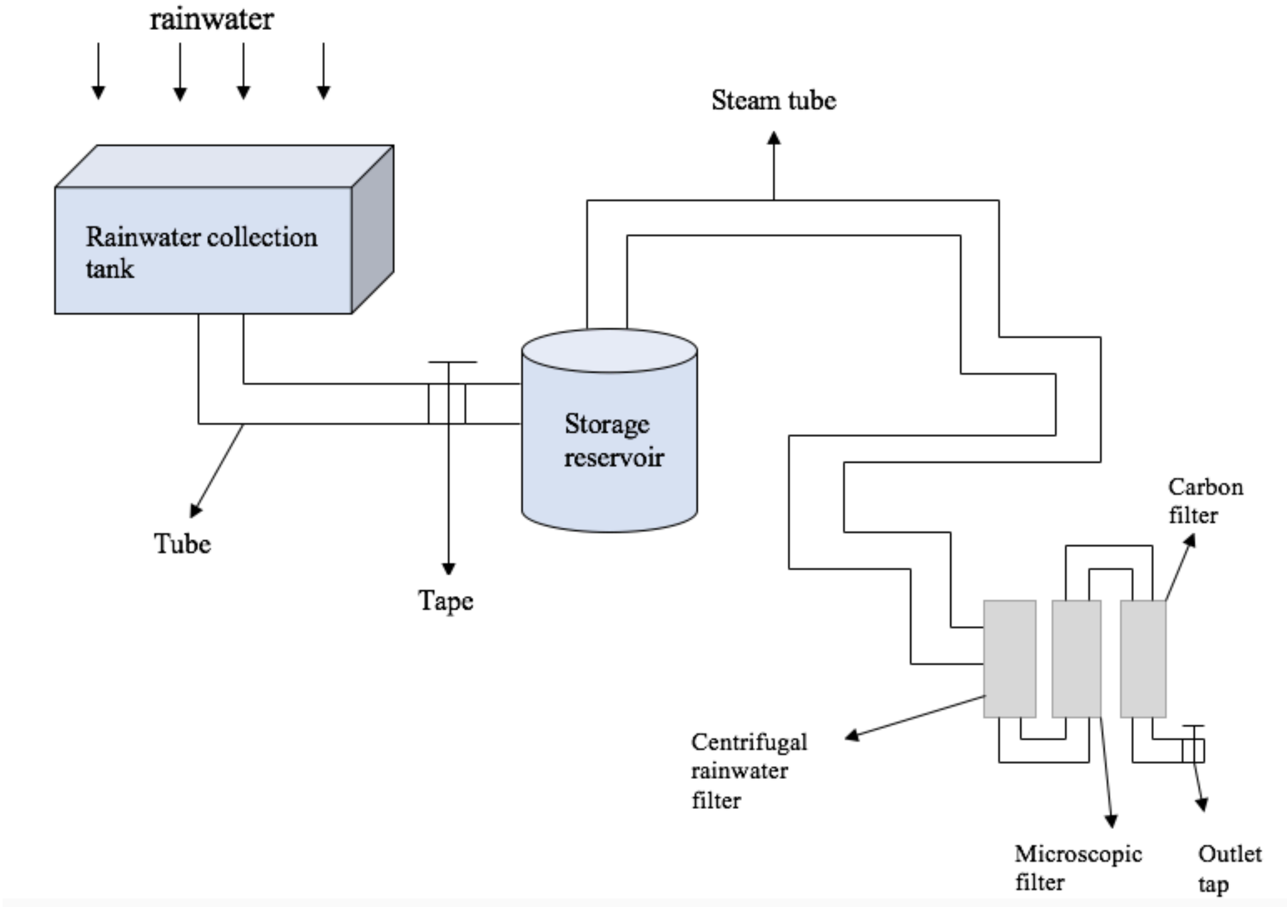
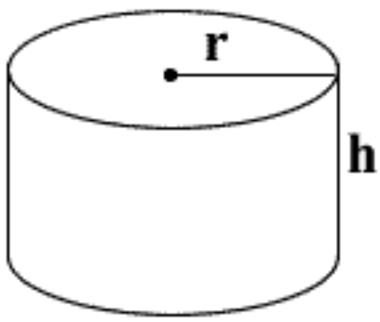


Figure-4.1 Rainwater purification system.

A. Square of Cylinder ($S_{cylinder}$)= $2\Pi rh$ (4.1)

But, $V_{cylinder} = \Pi r^2 h$ (4.2)

Where, $\Pi = 3.14$



B. In choosing the appropriate material for the tank, the energy (heat) that goes through the material was considered here. Two materials were considered due to its readiness (Aluminium and Iron).

The table below shows the thermal conductivity of these materials.

Table-4.1 Thermal properties of some metals.

Metals	**Thermal conductivity (W/m*K)**	**Electrical Conductivity(S/m)* 10^6**	**Electrical resistivity (ohm*m) *10^{-8}**
Aluminium	237	36.9	2.7
Brass	150	15.9	8.5
Copper	401	58.5	8.9
Iron	80	10.1	7.9

From the table above, Aluminium and Copper have high thermal conductivities but Aluminium was chosen for the purpose of this project because of how cheap Aluminium is compared to the other materials. The main idea is to have a less expensive but equally effective material that will serve its purpose and can be used universally.

Aluminium = 237W/m × K

Note that; K = °C + 237 (4.3)

C. The average number of people in a family is 5 people. One family uses 10L per day of water. They need a total of 100L in stock.

D. Checking for tank size;

$1L = 0.001m^3$

$100L = 0.1m^3$

From equation (2);

$$V_{cylinder} = \Pi r^2 h$$

$0.1 = 3.14 \times 0.25^2 \times h$, $h = \frac{0.1}{3.14 \times 0.25^2} = 0.51m$

Tank size;

$h = 0.51m$

$r = 0.25m$

$d = 0.5m$

where, h- height; r- radius; d- diameter

E. Time

$$T = 0.00117 \times V \times (t_k - t_n) / W \quad (4.4)$$

Where, V is volume (L); t_k is final temperature (°C); t_n is initial temperature (°C); W is power of heating (kW)

$T = 0.00117 \times 100 \times (100 - 45) \times 1.04 = 6.44$ hours

$W_{energy\ of\ sun} = 1350\ w/m^2 = 1.3\ kW/m^2$

$S_{cylinder} = 2 \times 3.14 \times 0.25 \times 0.51 = 0.8m^2$

$W = 1.3 \times 0.8 = 1.04$ kW

F. Albedo

Albedo is a non-dimensional, unit less quantity that indicates how well a surface reflects solar energy. Albedo varies between 0 and 1. Albedo commonly refers to the "whiteness" of a surface, with 0 meaning black and 1 meaning white. Absorbed solar energy can be used to heat the surface or, when sea ice is present, melt the surface. A value of 0 means the surface is a "perfect absorber" that absorbs all incoming energy. A value of 1 means the surface is a "perfect reflector" that reflects all incoming energy. Albedo generally applies to visible light, although it may involve some of the infrared region of the electromagnetic spectrum. You understand the concept of low albedo intuitively when you avoid walking barefoot on blacktop on a hot summer day. Blacktop has a much lower albedo than concrete because the black surface absorbs more energy and reflects very little energy [49].

$A_{snow} = 0.9$

$A_{coal} = 0.04$

Black, rough and painted (material surface) = in accordance, $W_{sun} = 4\%$

$W_{sun} = 1.3kW/m^2 - 0.052kW/m^2$

$W_{sun} = 1.24\ kW/m^2$

Where, W_{sun} is energy from the sun

From equation (4),

$$T = 0.00117 \times V \times (t_k - t_n) / W_{input} \quad (4.5)$$

$$W_{input} = W_{sun} \times S_L\,(1\text{-}A) \quad (4.6)$$

$$T = \frac{0.00117 \times V\ (tk - tn)}{Wsun \times Sl\ (1 - A)},$$ if $t_k = 100°C$, $t_n = 45°C$

$V = 0.1m^2$

$W_{sun} = 1350W/m^2$

Note, $0.04 < A < 0.02$

Then, change step for A = 0.02

Table 4.2 shows the calculated heating time and albedo (A).

Table-4.2 Calculated heating time and albedo

Heating time (hrs)	6.44	6.57	6.87	7.03	7.19	7.36	7.54	7.73
Albedo (A)	0.04	0.08	0.10	0.12	0.14	0.16	0.18	0.20

Below is a graph showing the representation of data above which clearly depicts the raise of heating time as albedo also increases.

A graphical statistic of albedo with corresponding heating time.

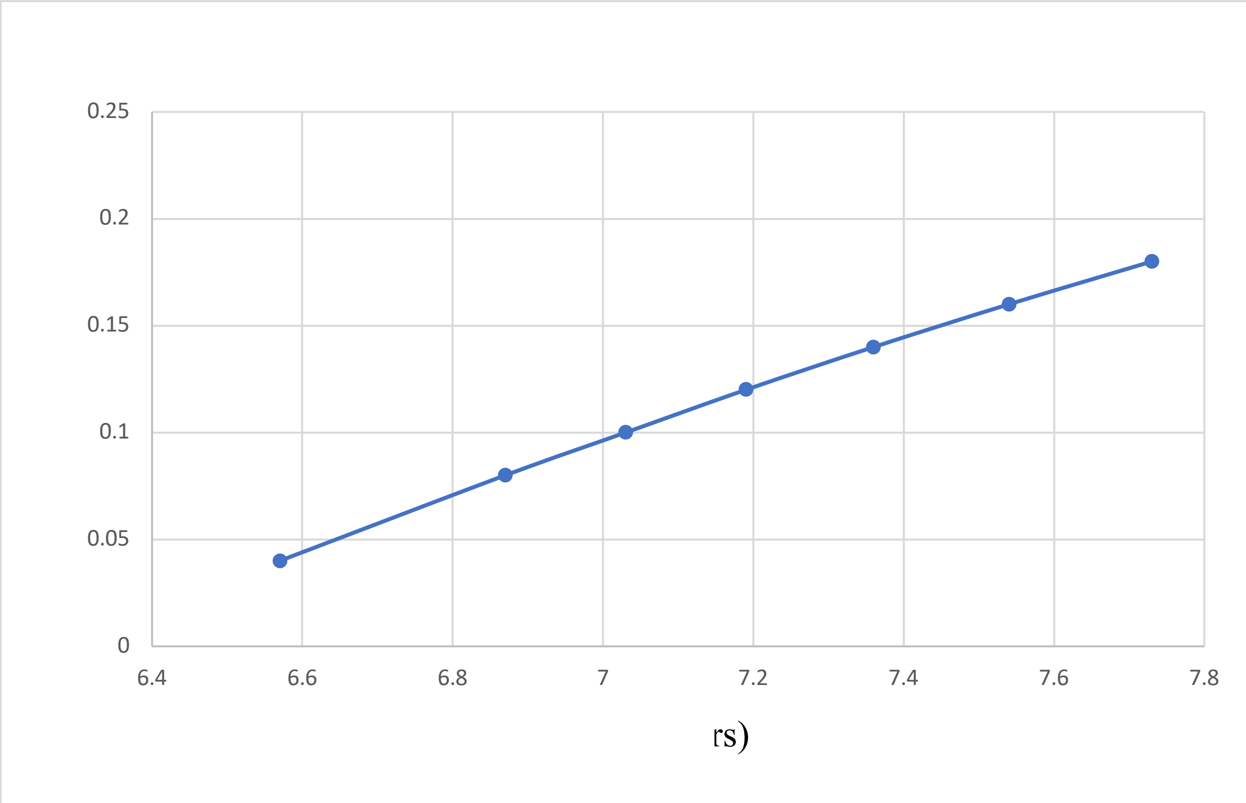


Figure-4.2 Graph of albedo with corresponding heating time

Q = rm, r= constant for steam making

m= mass

but, r_{water}= 2258kJ/kg

Q= 2258kJ/kg × 100kg = 225800kJ = 225.8MJ

1W × 1hr = 3600J

225.8MJ = 66.7kW

Therefore, during 66hours, all water will evaporate.

4.1 Conclusion

Rainwater as it is, contains lots of unhealthy components that needs to be treated or purified to improve upon its quality based on the use. This purification system has various filters with different responsibilities to ensure the improvement of the water quality. Also, material used (Aluminium) is readily available in West African regions which will make this system less expensive and affordable for people in these areas.

5. DEVELOPMENT OF STARTUP PROJECT

The following aspects of the startup project are analyzed within this section:

- the content of the idea (proposed);
- possible direction of application;
- the main benefits that the user of the product can receive;
- difference from existing analogues and substitutes.

5.1 Analysis and description of the current solution (product, technology and market.)

This project is about the development of a Rainwater Harvesting System to provide West African regions with safe drinking water and to reduce the negative impact of water pollution on locals in these areas.

In this project, it is of critical importance to focus on how to perform the all parts of the work with a sustainable and realistic approach. Meaning that an approach of participation from the actual beneficiaries and users (West African regions) must be upheld throughout the project.

More specifically the aim of the project is to create a solid base for rainwater harvesting in the area and develop good solutions that are anchored in the region's needs and desires. It is therefore an objective for the developer to get a closer understanding of various West African countries on both technical, economic and on a social level.

The overlying goals of the project may be identified as:

1. Create a project that is in correlation with the literature of designing and developing in marginalized communities as well as taking into close consideration the actual needs of the public.

2. Develop sustainable rainwater harvesting solutions for the people residing in coastal areas in West African regions, to increase their access to water

To attain the goals the following approach is proposed :

- Gain knowledge from existing literature on how to design and work with developing countries.

- Using development methods from several sources and alter the methods to be most beneficial for the project.

- Perform two field trips to the area to see and learn the actual conditions and to identify the overlying issues.

- Investigate how the people who live on the coastal areas in West African regions deal with the current water problem and how it influences their daily life.

- Explore the coastal areas in to identify facilities, possibilities and opportunities for local production and value creation in the society.

- Investigate how the communities may be included in the development of a rainwater harvesting system to ensure long-term commitment and sustainability.

- Perform the steps in the project task list to develop a realistic and sustainable rainwater harvesting system.

Limitations

To create a sustainable and long-term project in a developing country requires time, resources and great local knowledge. None of which is possible to fully exploit during the short time period a master thesis offers. To mention a few influential aspects there are politics, cultural beliefs and traditions, limited and complicated supply chains and great financial limitations. Therefore the project aims to sowing seeds for future development in the community and create a positive effect on the utilization of rainwater harvesting technologies in the area.

5.1.1 Needs analysis for a user demand specification

Creating community development centers in these areas will play a key role in the development and management of the system and has some demands that influence the solution. The following are identified as demands from the center:

-- Possibility for local production of components

-- Give the people a positive view of the development center

-- Should be able to serve a large amount of people fairly quickly

-- The solution must be able to be used in community awareness initiatives and education of the people in rainwater harvesting

-- Solution should be able to be repossessed in case people fail to pay

In the work with developing a personal rainwater harvesting system, a holistic approach giving long term, sustainable results was strived for. The holistic approach takes into consideration all the elements that influences product development in the framework of humanitarian aid and development.

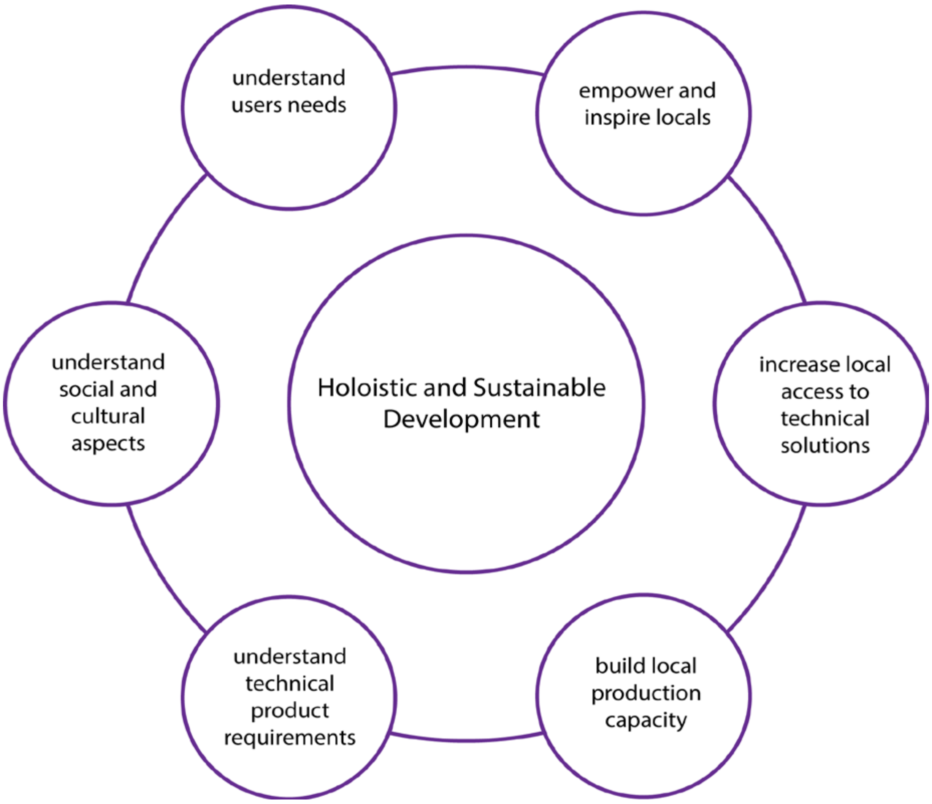


Figure-5.1 Holistic and sustainable development

Figure 5.1 shows what aspects are of central importance in this project:

- Understand users' needs
- Empower and inspire locals
- Increase local access to technical solutions
- Build local production capacity

- Understand technical product requirements
- Understand social and cultural aspects

The demands and views are:

-- Increase in domestic water (with emphasis on drinking water)

-- Cheaper than what is available today

-- Water must be available close to home

-- A large degree of self-made components are desired

-- There should be a range of options as there are great variations in purchasing power in the community.

-- Want a bigger storage tank than what they have today (jerry cans – 40 liter)

-- Possibility to expand the storage size when the economy gets better

-- Self-reliant maintenance to avoid extra cost

Most of the overview from these areas are very general. This may either be because of little knowledge about the technique of this water harvesting system. The general feel is that the knowledge level and familiarity to rainwater harvesting fairly is low and thus the overview reflected more upon their current situation than on the possibilities in the future.

As one of the goals of the project has been to add value to the local communities, participatory design has been an important factor. Participatory design focus on designing in close cooperation with the beneficiaries over a longer period of time to include, consult and empower the user. This is an important aspect of ensuring long term commitment. Hussein (2011) identifies the benefits in a design participation ladder where the highest level of participation empowers the beneficiary to use design methods to develop solutions that can improve quality of life. To utilize the strengths of participatory design in this project has been a priority, however difficulties in achieving this were experienced. The main reason was the lack of time spent with the user, and the share knowledge the developer was able to obtain on the subject. To succeed with participatory design one must first identify the problem together with the user, then the user must be taught design skills which later must be used in real settings to raise their self-belief in their own abilities. This is time consuming and demands a high level of skill from the developer. However even a low level of participatory design is useful to make the beneficiaries aware of the process, they feel included and will recognize the solution when they are later encouraged to invest.

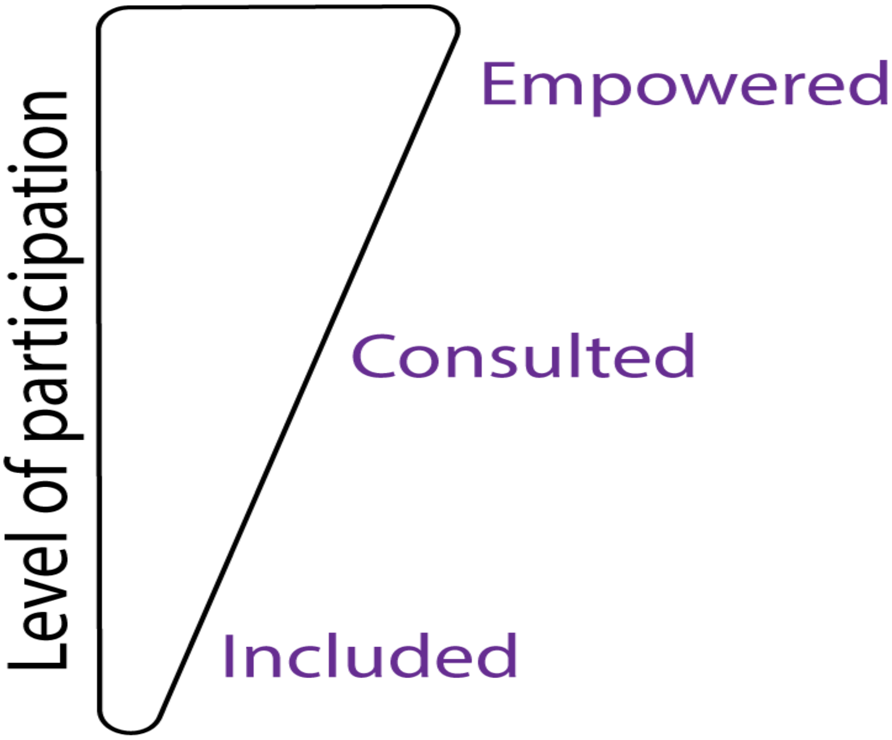


Figure-5.2 Participation ladder

Efforts to including the people living in these areas a part of the project of rainwater harvesting is a must. The developer needs to conduct several interviews with the people including all surrounding areas, to inform and discuss the matter of rainwater harvesting. Finally, a communities will conduct meetings, where solutions and concepts will be shown, encouraging the visitors to share their views and ideas. Within this time, the outcome of these community meetings will be put together as positive feedback for the continuation of the project.

5.2. Elaboration of existing technologies and availability of components and materials

Developing a rainwater harvesting system for the marginalized communities in West African regions requires a model that allows for a large degree of user centered design. Step-vise evaluation of concepts and ideas based on users needs is very important to ensure participation and empowerment of the locals. Also, the chosen model must allow for a great deal of intuition based on human interactions. The model most fit for this project follows the path shown in the illustration below. The arrows represent the direction the development process takes in the pursuit of the best idea, where each part of the model represents a generation of new ideas followed by a reasoning converging towards the best solution determining the new direction. The illustration show that the supposedly good ideas determine the starting direction, however the model encourages to break away from the path most traveled and allows for new approaches to the problem. This fits this project well as there are a number of existing solutions on rainwater harvesting.

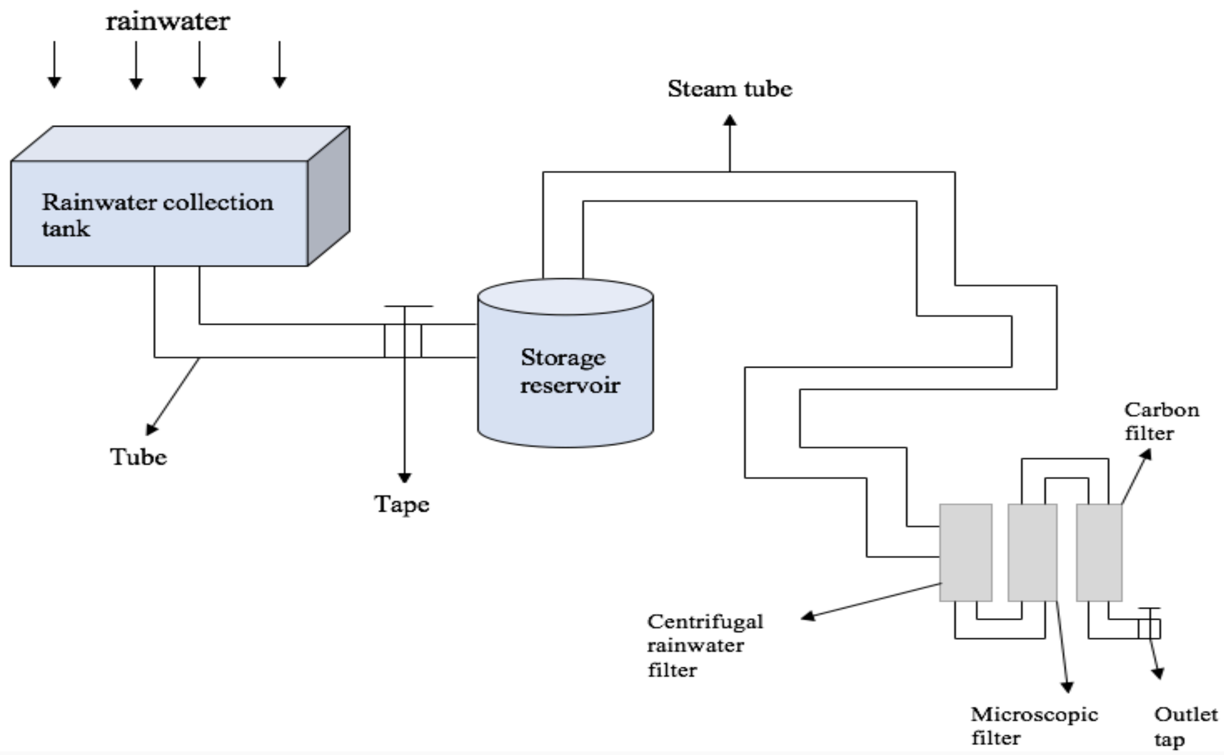


Figure-5.3 Rainwater purification system

The basic principles in roof catchment systems consist of mainly three sub-functions:

1. Catchment surface
2. Delivery system
3. Storage reservoir

Some also include the supply mechanism from reservoirs as a sub-function, but this will not be a focus here.

1 - Catchment surface

This first part of the system is in many ways what gives the technology its name. When there is precipitation the water falls onto a surface that facilitates harvesting and is therefore a crucial part of the system. There is a strong link between the properties of this surface, the intended use of the water and the amount wished to be stored. Is the water intended for human consumption it is important to use a suited surface avoiding pollution and possibly harmful materials.

2 - Delivery system

The delivery system is the mechanisms allowing the water to be transported from the collection area to where the water is stored. In small-scale systems this usually consists of a combination of gutters and pipes. For the effective operation of a rainwater harvesting system, a well-designed and carefully constructed delivery system is crucial because this is often the weakest link.

3 - Storage reservoir

The storage reservoir, or storage unit, is perhaps the most noticeable part of the rainwater harvesting system and is where the water will remain until time of use. This usually involves the highest investment cost, but is generally cheap in operation and maintenance. There are several suitable materials that could be utilized such as cement, mortar, concrete and bricks, or ready-made products as plastic, fiberglass and steel. The storage unit also requires attention to evaporation and pollution minimizing both by the use of covers.

Environmental feasibility depend on the amount of rainfall in the area, the duration of dry periods and the availability of other water sources. The rainfall pattern is very important to determine whether a rainwater harvesting system may be used as either a primary or supplementary supply. Tropical climates with short (one to four month) dry seasons and multiple high-intensity rainstorms provide the most suitable conditions. As a general rule, rainfall should be over 50 mm/month for at least half a year or 300 mm/year to make the technique a suitable option. If other water sources are extremely scarce, the rainwater harvesting may also serve as a great relief even if it is only used during the rainy season. The description fits these regions well as the suspected rainfall here is approximately 900 mm/year and additional water sources are few and hard to come by. The environment also impacts the design of the components as the wind and rainstorms may break the system if not adequately robust. The systems should be tested in the actual, or similar conditions as intended to be installed in.

5.3 Construction and testing of necessary prototypes

Design considerations - Given that the environmental conditions for rainwater harvesting are fulfilled, several other issues needs to be considered to design a successful system. Figure 17 shows important aspects which all must be considered while designing a roof catchment system, both technological and social. The importance of each aspect is different depending on the area and social situation of the project. In West African regions, the needs analysis revealed that the most limiting factor is the economy (budget) and the availability of materials. After these issues are considered, the gutters and tank size may be designed which in turn determines the potential supply of the system. The size of the family and their water usage will show how much of the need is covered by the rainwater harvesting. Subsequently, the realization strategy must be set and lastly the maintenance and management, which is crucial as the knowledge of how to do this properly is missing in the area.

In other words it is most appropriate to first cover the physical issues, and then see how much of the water needs are met. Naturally, all aspects influence each other and must be investigated simultaneously.

In addition to the mentioned issues, aspects like water quality, safety and market demand must be taken into consideration.

- Water quality

Rainwater is generally safe and unpolluted before it hits the catchment surface, especially in some areas of West African regions. However the components of the system may contaminate the water if they are of hazardous materials or if the surfaces are not adequately cleaned. An important safety factor is to let the first water clean the system before it enters the tank. This is called “first flush” and must be facilitated for in the system by for instance letting the delivery system be divertible or allow for blocking of the water flow. Other important measures towards better quality are filters and reservoir covers.

- Safety

Safety is always an important consideration, and especially where kids run around and may harm themselves on system components. If large tanks are used there must be adequate safety railings or locks on openings. If no such thing is possible the system shall not be taken to use.

- Market demand

When designing a rainwater harvesting system the market demand is important, not to offer something users do not want. This may apply to areas where earlier projects have failed and left users skeptic to certain solutions. It must be stressed that this is a more important factor than some may realize, and a perfectly good system may be un-sellable if user and market is not considered.

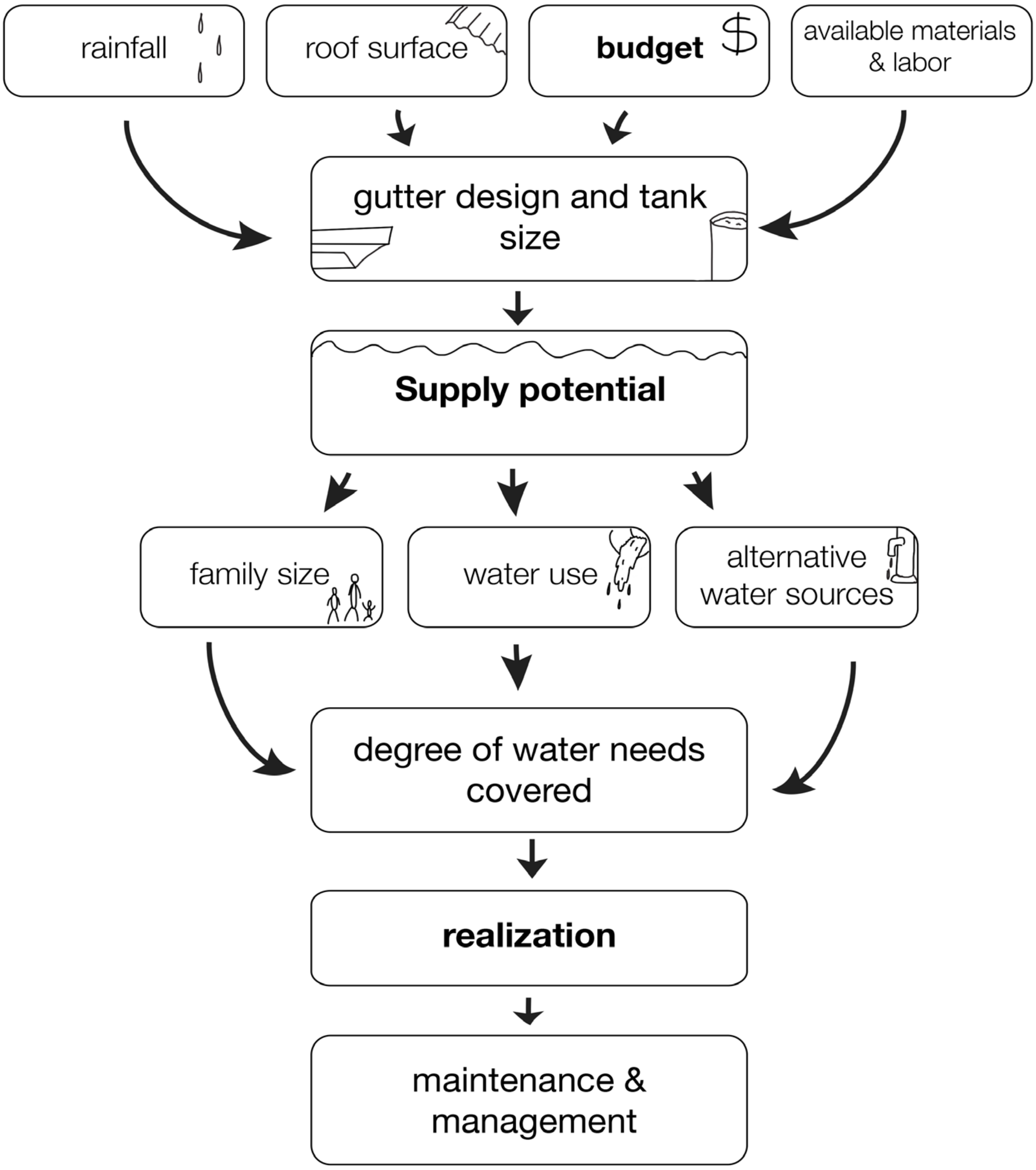


Figure-5.4 Design considerations

When calculating how much water a roof catchment system may supply, a number of factors come into play. The most decisive are the amount of rainfall and the catchment surface.

The potential supply is given by: Supply = rainfall x projected area x run-off coefficient

S = R x A x Cr (5.1)

The supply is given in m^3, the rainfall is given in m, the area in m^2 and the run-off coefficient is a pre-determined constant (how effective the roof surface leads water) without unit.

The supply can then be set up against the water needs of the family to see how many days the collected water may last.

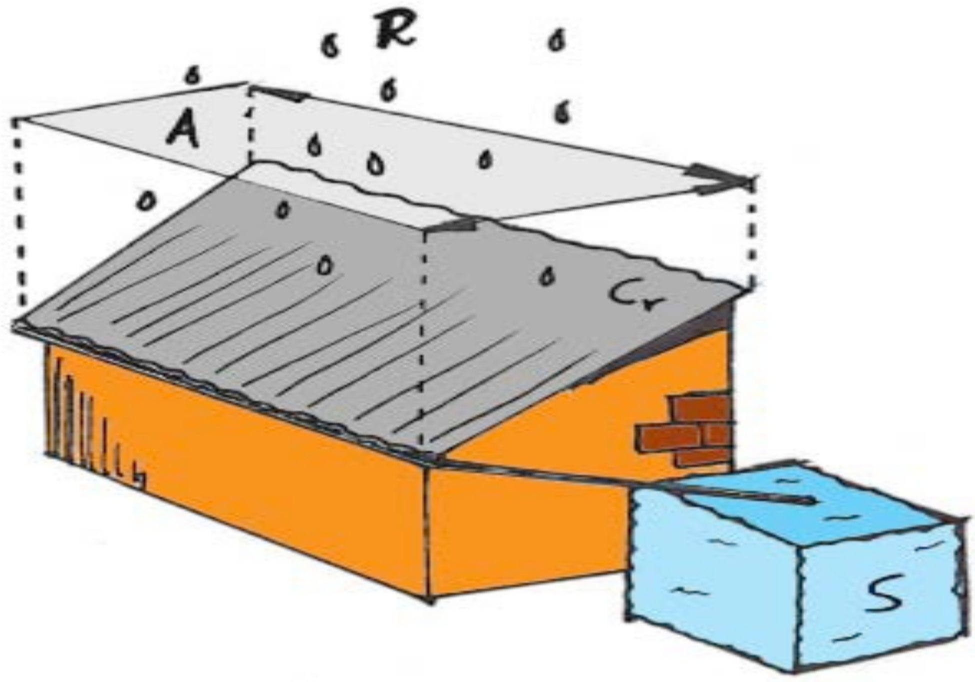


Figure-5.5 S = R x A x Cr

Example

During one week it rains in total 50 mm on a roof of aluminium sheet (Cr = 0.8) measuring 15 m2. The amount of rainwater that may be collected is:

S = 0,050 m x 15 m2 x 0.8 = 0.6 m3 = 600 dm3 = 600 liter 600 liters of storage is a rather large sized tank given the financial difficulties in some areas of West African regions, and the water should therefore be used right away if there is expected more rain to come later (for instance in the beginning of the rain season). So how many days does the collected water save them from going to the river to get water? Take an average family of six people, who based on interviews collect about 80 liters of water per day.

Coverage = 600 liter / 80 liter = 7.5 days.

So, with a rather small home (3 by 5 meter) the family can collect 600 liters, which saves them from going to the river during the following week. This may have a big impact on the welfare of the family.

Actual supply potential and storage size

The optimal storage size for any given household is determined by the potential of the catchment area, and not driven by the need of the family. This may be useful in order to see what storage capacity the families should aim for, so they do not invest in a tank that is too large for their catchment surface. Given that people also use water during the rainy season, the usage must be taken into consideration.

The calculations aim to see where the discrepancy between water use and water supply is at its greatest.

Another family, also with six members needing 80 liters per day, has two suitable buildings giving a total of 28 m^2 for rainwater catchment. The tank size demand of this family will be calculated in this example.

Calculate the potential supply for each month using equation (1). Set up a cumulative supply by step-vise adding the amounts throughout the year. In the same manner calculate the monthly- (in this case: 80 liter x 30 days = 2 400 liter) and cumulative demand.

Advantages and disadvantages

When considering the possibility of using roof top catchment systems for domestic supply, it is important to consider both the advantages and the disadvantages. Even if it has been concluded that this technique is the best option for these areas, one has to be aware of the disadvantages not to get unfortunate results and disappointed community members.

A decision based on the evaluation, pros and cons and intuition took the following reservoirs further into prototyping and testing.

-- Cemented oil drum

-- Water pot

-- Blue drum

-- Black tank

The jerry cans were excluded because of the small sizes available (40 liter max) and are therefore seen as an addition only, not a main reservoir. The water pot was included because the developer wanted to explore its possibilities further.

5.4. Evaluation and presentation of results and methods, particularly in regard to continuation of the project.

The demand stating no exclusions gives the necessity of separating into two systems. Not all inhabitants have suitable roofs; as for instance thatched roofs are not usable for harvesting. Therefore separation into "Roof top systems" and "Independent systems"

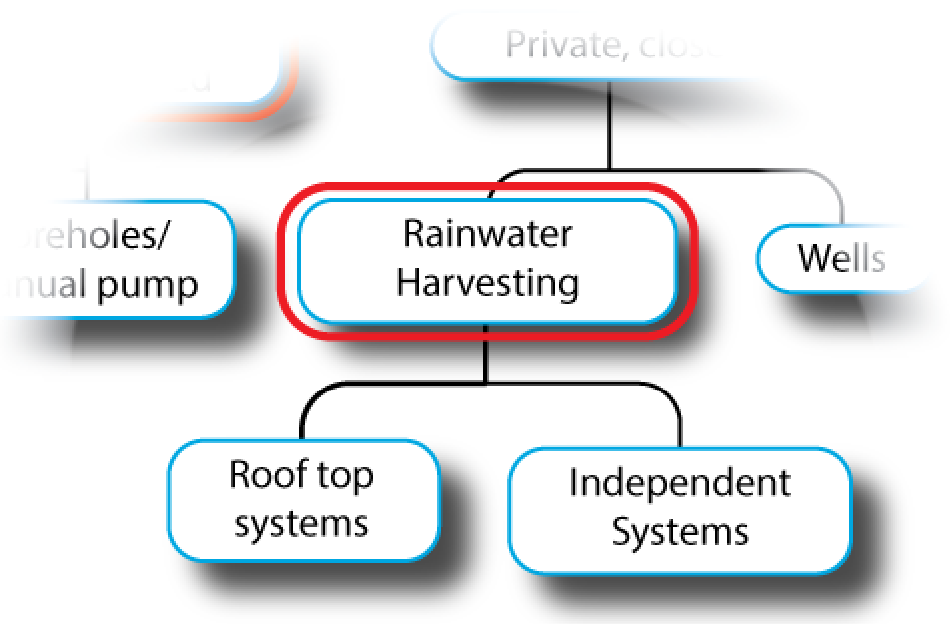


Figure-5.6 Separation

The development process is structured as follows:

1. A number of concepts are developed with basis in the product demand specification (PDS).The concepts are limited within the predetermined demands such

as adequate water quality, possibility of filters and covers etc. but ranges between the measurable demands such as cost, durability, possibility of local production etc.

2. The concepts are thereafter briefly presented with pictures.

3. An evaluation is performed on opposing concepts based on the measurable product demands. Note that not all measurable demands are relevant for all concept ranges, e.g. safety and multipurpose is not included in “delivery system” evaluations.

4. The concept gains the scores 0, 1 or 2 on each demand, which is multiplied by the weight of the demands (for instance cost is weighted more than status). The weighting is different for each concept range, and is shown in doughnut charts. The total sum is then presented in a chart where the concepts are compared to a maximum sum of 200. Only the results are presented in the text, whereas the complete evaluation may be seen in the appendix. Note that the results are indicative since the points given are always debatable and is only a tool in finding the best solutions.

5. Lastly a conclusion is made based on the evaluation, pros and cons and general intuition, determining what concepts are to be brought further into prototyping and testing.

Evaluating the concepts give an indication on what may be useful to bring further into testing and realization.

For the delivery system the demands 1.1, 6.1, 6.2, 7.1, 7.2, 8.3 and 9.1from the PDS are seen as decisive factors as seen in Figure 5.7.

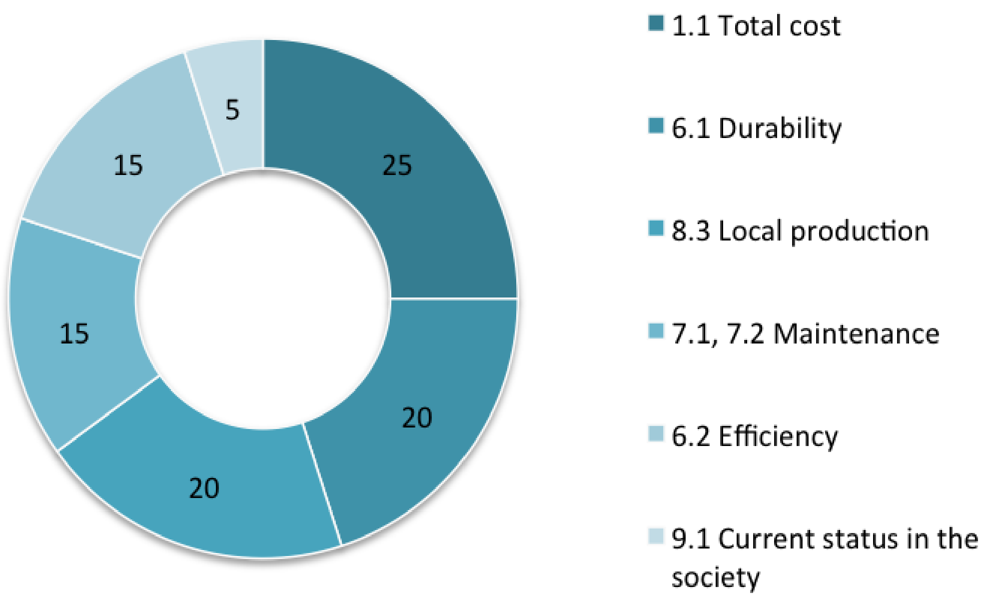


Figure-5.7 Delivery system weighting

Conclusion:

The investigations and evaluation of the delivery system gave some interesting results and the following concepts are taken further into prototyping and testing.

-- Sisal-jerry can

-- Bent aluminium sheet (jerry-can drop outlet)

-- Flat aluminium sheet (jerry-can drop outlet)

Given the focus on the less affluent, smaller reservoirs seem to be most fitting. Smaller reservoir may have a higher cost than a liter, but the introduction cost, which is often the limiting factor, is lower. Tanks may be constructed above and below ground, but the impact on the compound, installation time and cost makes this option seem less as an opportunity in West African regions.

The main focus has been to develop the rainwater harvesting system however other fundamental needs have always been in mind. Lack of data on rain intensity and the potential in harvesting techniques was also focused on while developing the system. In addition there is a great need for increased knowledge about the techniques to fully exploit its potential. The three needs/solutions are intertwined and must work together to optimize the total effect of rainwater harvesting.

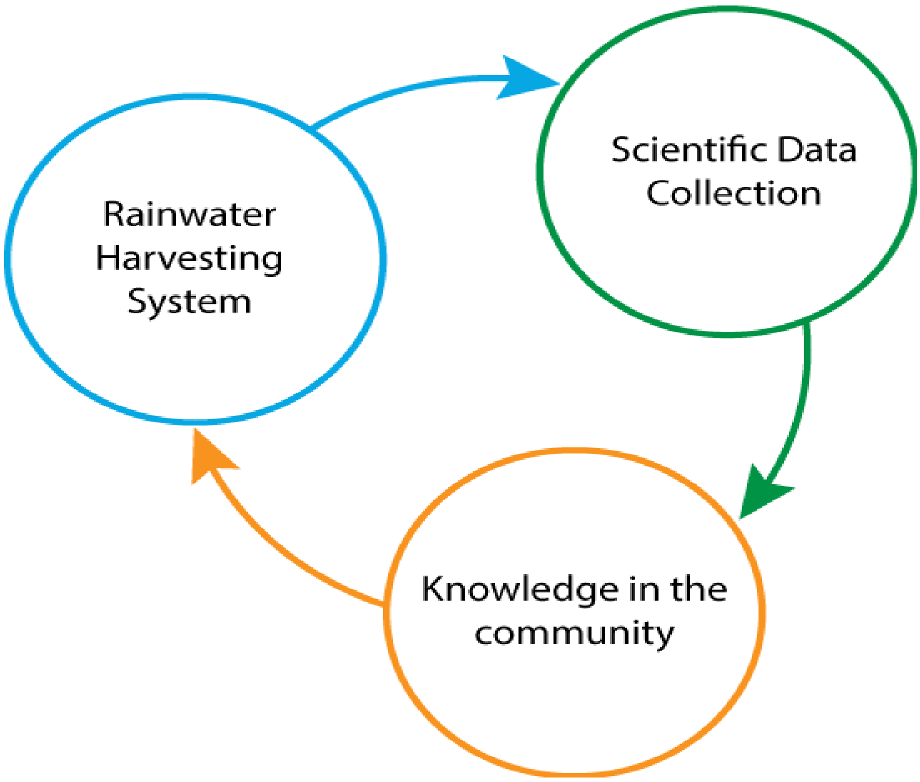


Figure-5.8 Solution circle

- Data collection, Rainwater harvesting test unit

A rainwater harvesting test unit therefore will be constructed in these areas upon identifying the needs. The unit will be developed using local knowledge and local manpower, and the outcome of a participatory design process involving the developer and the staff members at these center. The idea of a rainwater harvesting test unit was adapted from the University of Gaborone, Botswana, where they perform roof catchment studies on such a unit.

The test unit is equipped with a 3 000-liter polyethylene black tank and an aluminium sheet roof surface measuring 6.4 m^2 effective catchment area. Self-made aluminium sheet gutters fastened with wires directly onto the roof functions as delivery system.

The initial purposes of the unit are:

-- Perform rainwater harvesting data collection

-- Educate the community on rainwater harvesting potential

-- Demonstrate proper installation and maintenance of systems

Data collection

With the test unit the development center may now get some most needed data on how much water one is able to collect. Studying the local potential of rainwater harvesting is important to provide the community, or other involved parties, with accurate information. The development center may now give advice to buyers about reservoir sizes and gutters, avoiding unnecessary expenses for the beneficiary.

The data will be used to:

-- Measure amount of rain that may be harvested during each rain showers

-- Calculate weekly supply of water from harvesting, seeing if the families' needs are covered.

-- Measure total harvested water during the rainy season

-- Advising community members on what reservoir size they need

The following steps shall be undertaken to complete successful measurements:

1. Acquire or make a rain gauge

2. Place the gauge in a location away from buildings and trees. This is to avoid water splashing into the gauge, or obstacles hindering rain to enter the gauge. Approximately 10 meter clearance in every direction is advised. Fasten the gauge firmly to a stand so the gauge does not fall in heavy winds.

3. Create a data sheet (spread sheet or paper) noting the date, time of measuring, and the amount of rain (in millimeter or inches).

4. Do measurements every day at the same time. Usually mornings are the most convenient.

Important: Do measurements even if there has been no rain to create serious data collection.

As shown in the technology chapter, rainwater harvesting is more than just run-off from roofs. There is also run-off from land, hills and valleys. In semi-arid areas this run off is often not utilized, as seasonal rivers and streams carries away the water instantly. This is one of the big problems with desertification, since there are no roots or plants to stop water from escaping.

After every major step of the development process make sure to evaluate the results. Without a proper evaluation it is impossible to now the impact of the solutions and to determine the next step in the process. Step-vise go through the different phases of the project and discuss what went well, what went according to plan and what may have been done differently. Do this in a holistic view, where impacts in all aspects of the project are evaluated. Write down the positive and negative effects of the solutions so that they may be maximized or minimized in the future.

5.5 Conclusions to the chapter

1. According to the preliminary assessment, the market is attractive for entry. Exist demand for the deployment of quality drinking water in the mentioned region. There is a high possibility of commercialization of the project on the market.

2. The product is unique in its field. Competitors in the national market, minimum quantity and lower quality of services. For further research, development and testing of goods need to involve highly qualified scientists and engineers.

3. For the market implementation of the project, it is advisable to choose an alternative - search scientific and technical resources, attracting investors, creating advertising, interaction with consumers.

CONCLUSION

Based on the research, these were the following conclusions;

1. An information-analytical system was developed taking into account the issue of pollution and degradation in coastal region in West Africa.
2. There was the development of a rainwater purification system.
3. Climate change has a significant effect on the coast. This includes water pollution, erosion and flooding as lasting effects on the West African regions.
4. Various types of waste materials are deposited on the coastal areas through several means including anthropogenic, artificial or mechanical sources amongst few.
5. The implementation of this proposed purification system as well as the developed information-analytical system will benefit people living in these regions, and in a broader view, it will help improve upon the GDP of the economy.

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