UNIVERSITY FOR DEVELOPMENT STUDIES

# EFFECTS OF FLOODS ON THE JAMBUSIE WATER TREATMENT PLANT IN THE WA WEST DISTRICT OF THE UPPER WEST REGION OF GHANA

ALHASSAN ALI

2022

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**UDS/MEM/0012/18**

**A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENT AND RESOURCE STUDIES, FACULTY OF INTEGRATED DEVELOPMENT STUDIES, UNIVERSITY FOR DEVELOPMENT STUDIES, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN ENVIRONMENT AND RESOURCE MANAGEMENT**

**APRIL, 2022**

# DECLARATION

**Student**

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere.

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I hereby declare that the preparation and presentation of this thesis was supervised per the guidelines on supervision of the thesis laid down by the University for Development Studies.

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## ABSTRACT

Water safety and quality are fundamental to the well-being of humans, and hence providing access to safe water is one of the most effective ways of promoting good health. Contaminated water requires appropriate treatment to remove disease-causing agents. The study examined the effects of floods on water supply from the Jambusie Water Treatment Plant in the Wa West District of the Upper West Region of Ghana. The study adopted a cross-sectional design. The mixed-method approach (quantitative and qualitative) was adopted. Questionnaires, interview and observation guides and content analysis were the main instruments used in collecting data for the study. The study revealed that floods had effects on the water treatment plant. Again, the research found that high levels of physico-chemical properties were found in the flood water during the rainy season. These physico-chemical elements have negative consequences on water treatment. The study further showed that before the rains, the nephelometric turbidity unit could range from 40NTU to 120NTU, and increased to 121NTU and 1000NTU during floods. The results also showed that more chemicals are used to treat raw water during the rainy season, which increases the cost of water production. Crop farming, illegal mining, open defecation, animal rearing, fishing, and felling of trees were found to be the main activities affecting water treatment at the Jambusie Water Plant. The study concludes that floods had effects on the water treatment plant and that physico-chemical properties contaminate the raw water during floods. The research, therefore, recommends that the Ghana Water Company Limited (GWCL) should ensure that a well-engineered drainage system is constructed at the facility. GWCL should also ensure that there are no stock-outs of chemicals and parts. GWCL should collaborate with relevant stakeholders such as the Water Resources Commission (WRC), Environmental Protection Agency (EPA), and the Ghana Police Service to check activities such as illegal mining and farming that could negatively impact on the quality of raw water.

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# DEDICATION

I dedicate this thesis to my family.

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## ABBREVIATIONS/ACRONYMS

| | |
|---|---|
| BC | Before Christ |
| CDC | Centre for Disease Control and Protection |
| CEDAW | Convention on the Elimination of all Forms of Discriminations Against Women |
| DES | Department of Environmental Services |
| EPA | Environmental Protection Agency |
| FAID | French Aid for International Development |
| FDEP | Florida Department of Environmental Protection |
| GDWQ | Guidelines for Drinking-Water Quality |
| GPRS | Ghana Poverty Reduction Strategy |
| GRCS | Ghana Red Cross Society |
| GSS | Ghana Statistic Service |
| GWCL | Ghana Water Company Limited |
| HU | Hazen Units |
| ICOLD | International Commission on Large Dams |
| IPCC | Intergovernmental Panel on Climate Change |
| IRIN | Integrated Regional Information Network |
| IRWL | International Rivers Water-Life |
| ISO | International Organization for Standardization |
| JWTP | Jambusie Water Treatment Plant |
| MDGs | Millennium Development Goals |
| MPCA | Minnesota Pollution Control Agency |
| MW | MegaWatt |
| NADMO | National Disaster Management Organization |

| | |
|---|---|
| NEPAD | New Partnership for Africa's Development |
| NGOs | Non-Governmental Organizations |
| NWDA | National Water Directorate of Angola |
| Ph | Potential of Hydrogen |
| PoU | Point-of-Use |
| SDWA | Safe Drinking Water Act |
| SONABEL | Société Nationale d'Electricité |
| SSA | Sub-Saharan Africa |
| TSS | Total Suspended Solids |
| UNEP | United Nations Environment Programme |
| UNICEF | United Nations International Children Emergency Funds |
| WHO | World Health Organisation |
| WRC | Water Resource Commission |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the Study

Drinking water sources can become contaminated, causing sickness and diseases from waterborne germs, such as Cryptosporidium, Escherichia Coli (E. coli), Hepatitis A, Giardia intestinalis, and other pathogens (Centre for Disease Control and Protection [CDC], 1999). Despite the abundance of water, especially in the rainy seasons, water quantity and quality are often poor (Florida Department of Environmental Protection [FDEP], 2008). Africa as a whole may not reach the Sustainable Development Goal (SDG) of its drinking water target 6.1, which is to achieve access to safe and affordable drinking water. The United Nations report in 2018 on water and sanitation states that worldwide, 844 million people have no access to drinking water from improved sources. Sub-Saharan Africa (SSA) accounts for more than a third of that number, with about 330 million people without access to safe drinking water. Although the proportion of people in sub-Saharan Africa using improved sources of drinking water increased by 14 percent from 1990 to 2008, only 60 percent of its population had such access by the end of that period (World Health Organization [WHO] and United Nations International Children Emergency Funds [UNICEF], 2010). Africa's progress towards achieving the SDG drinking water target is slow and uneven, because one of the hindrances is the pollution of water bodies by either natural or man-made sources (WHO & UNICEF, 2010). Oyeleke and Instifanus (2008) indicate that water bodies are polluted, and such water bodies serve as sources of drinking water. Water suppliers are therefore expected to conform to certain allowable limits of substances of physical, chemical, and biological interest which can affect humans' health (World Health Organization [WHO], 2011). The implication of this is that some of these water bodies which are polluted and serve as sources of drinking water require huge financial outlays to reduce harmful substances to permissible limits to make them safe and fit for human consumption.

Changes in the amount, intensity, and frequency of rainfall directly affect the magnitude and time of runoff, floods, and drought (Cubasch et al., 2001 as in Ifabiyi & Ashaolu, 2013). The WHO (2011), however, indicates that the quality of drinking water is a great determinant of environmental health. Hence, water safety is a foundation for the prevention and control of waterborne diseases. For instance, the physico-chemical and bacteriological quality of water for consumption and other socio-economic activities is considered to be one of the concerns for the general public and water suppliers. However, water for most reservoirs comes from dams, and some of these dams take their source from rivers. For instance, the Kpong Water Supply takes its source from the Volta River (Ntiamoa-Baidu, Ampomah, and Ofosu, 2017) while the Jambusie Water Treatment Plant (JWTP) takes its source from the Black Volta, which is linked to the Ziga Dam in Burkina Faso (GWCL, 2018).

A dam can store all or part of floodwaters depending on the size of the reservoir. However, the determination of environmental flood flows is a management constraint for dam managers. The control of flood flows by the dams in the Black Volta Basin, the White Volta Basin, and the Oti Pendjari Basin is of growing concern. These parts of the rivers lie downstream of control facilities but are not particularly representative of wetlands and flood plains, which tend to be found in the upper parts of the three sub-basins. This means that floodwaters caused by heavy and frequent rains represent a high risk in these portions. In recent times, spillage of water from dams during high waters due to intensifying rains has caused transboundary damage further downstream (Amidou, Terrasson, Citeau, & Balique, 2018). The rainy season cause floods that affect water bodies, including the JWTP, which transmits 16,500m$^3$/day to the Wa Township and its surrounding communities (GWCL, 2018). As a result of the effects of the2007, 2013, 2018 dam spillages from the Burkinabe authorities from the Bagre Dam which flowed through the Ziga Dam, to the Black Volta, the excess waters have always flooded downstream water bodies. Many of these water bodies suffer serious water quality deterioration due to reduced oxygenation and dilution of pollutants of stagnant reservoirs when compared to fast-flowing water and flooding of biomass; especially, from forests, underwater decay, and reservoir stratification. However, Ghana and Burkina Faso have not done much to reduce this annual occurrence. The question that has given rise to this research is how is the Jambusie Water Treatment Plant taken care of during floods which subsequently affect the supply of water in terms of operational cost, water treatment, and general maintenance of the facility?

According to the National Oceanic and Atmospheric Administration (2021), flooding occurs when a land which is usually dry gets inundated as a result of the overflow of water. Flooding can also be defined as the submerging of dry lands by overflowing water (Casanova and Brock, 2000). Several different weather conditions can cause extreme rainfall in a region. Tropical cyclones form in some tropical and subtropical areas, usually in the summer and fall. When they appear in the Atlantic Ocean or the northwest part of the Pacific Ocean and reach a certain intensity, they are called hurricanes. Tropical cyclones can produce huge amounts of rain, causing flooding and flash flooding once the storm reaches land (Camargo et. al. 2010). They can also send a rush of water from the ocean onto coastlines in an event called a storm surge. Also, strong atmospheric rivers can deliver enormous amounts of rain and snow in California, the Pacific Northwest and Alaska, especially during the winter months. This can lead to serious flooding and mudslides.

Flooding is caused by atmospheric condition which results in heavy rains or speedy melting of snow and ice. It is further explained that geography can also make an area more likely to flood (DU et. al. 2010). For example, areas near rivers and cities are often at risk of flash floods. The incidents of poor drainage facilities and removal of flood defense systems are a probable cause of flooding. Furthermore, construction of roads, buildings, parking lots and other infrastructure can increase run off which has the potential of causing floods (Douglas et. al. 2008). According to Karley (2009), dam spillage is another cause of floods in many parts of the world especially Africa. This happens when the dams are filled beyond their holding capacity as a result of heavy rains. The spillage of the excess water from a dam in order to enable the dam maintain its integrity usually results in flooding at the catchment areas of the river which was dammed or the downstream environments of the dam.



### 1.2 Problem Statement

Water is the lifeblood of the planet, and the state of this resource affects all-natural, social, and economic systems (Ifabiyi and Ashaolu, 2013). It serves as the fundamental link between the climate, human society, and the environment

(United Nation Water, 2010). Hence, rainfall appears to be one of the most critical meteorological factors on earth that sustain the natural environment and human life thus, making it a most vital ecological factor.

In considering the Intergovernmental Panel on Climate Change (IPCC) report, Cubasch et al (2001) argued that changes in the total amount of rainfall and its frequency and intensity directly affect the magnitude and timing of run-off and the intensity of floods. They stressed that floods can have major impacts on water resources, affecting both ground and surface water quality for domestic and industrial uses.

The Volta River basin serves as a source of raw water for the JWTP. Human activities such as livestock rearing, use of agrochemicals for farming, open defecation and illegal mining along the Black Volta renders the water unsafe for drinking and other uses. The situation is aggravated by heavy rains and its attendant flooding which releases substances of physical, chemical, and bacteriological contaminants into the water treatment plant which must be removed to make the water wholesome for drinking. Flooding, whether caused by an act of God or man (artificial) has its consequences. As a result of the flooding due to heavy rains, Burkina Faso is often forced to spill the Bagre and Ziga Dams into the Black Volta Basin. The annual spillage often increases the volume of water surrounding the Water Treatment Plant at Jambusie. This study seeks to establish the impacts of these occurrences on the JWTP in terms of how it affects the facilities and water treatment as well as the cost implications.

A preliminary visit to the water treatment plant at Jambusie during the rainy season revealed several rainfall-related factors which have the likelihood of affecting water treatment at the facility. For instance, it was observed that the colour of raw water at the time was brownish which occurred as a result of pollutants and contaminants carried by surface run-off into the river basin. The raw water intake (facility) which is located about one kilometer away from the treatment plant faces challenges as a result of erosion which carries silt into the river with the potential of making the river shallow. The facility gets affected by the upsurge of water during the rainy season. Besides, the river bed has almost silted up due to the floods which carry silt into the river. The only access road between the treatment plant and the intake facility gets flooded as a result of flooding caused by rains. These and other related rainfall factors indicate that the water treatment plant at Jambusie could be facing some challenges during the rainy season. It is thus, perceived that flooding increases the cost of operations especially, the infrastructure and treatment of the raw water for consumption.



There are a plethora of studies on the rainy season and its effects on water supply systems. For example, Ifabiyi and Ashaolu (2013); Amuquandoh (2016); Chimber & Kansuk (2019); NADMO (2010); Atoaba (2011), and Ghana Red Cross Society [GRCS] (2019) have researched into rainy season and flooding and their effects on water supply systems. However, their studies were limited in scope and could not be generalized to cover all water supply systems especially, the Jambusie Water Treatment Plant. Besides, these researchers concentrated on the spillage and rainfall variability and their impact on public water supply systems. For this reason, this research examines the effect of flooding on the supply of water to the Wa Municipality from the Jambusie Water Treatment Plant in the Wa West District of the Upper West Region of Ghana.

## 1.3 Research Questions

How does flooding affect water production and the facilities at the Jambusie Water Treatment Plant in supplying water to the Wa Municipality of the Upper West Region of Ghana?

### 1.3.1 Specific research questions

The gap as identified in the study leads to the following specific research questions:

i. How are the water treatment processes at the Jambusie Water Treatment Plant affected by the flooding of the facility?
ii. Which parts of the infrastructure at the Jambusie Water Treatment Plant is affected by flooding and how are they affected?
iii. What are the cost implications of flooding on water treatment at the Jambusie Water Treatment Plant?

## 1.4 Research Objectives

The main research objective the study seeks to address is to examine the effect of flooding on water supply from the Jambusie Water Treatment Plant to the Wa Municipality of the Upper West Region of Ghana.

#### 1.4.1 Specific research objectives

The study specifically sought to:

i. Assess the effects of flooding on water treatment at the Jambusie Water Treatment Plant.

ii. Investigate the effects of flooding on infrastructure at the Jambusie Water Treatment Plant.

iii. Determine the cost implications of flooding on water treatment at the Jambusie Water Treatment Plant.

### 1.5 Significance of the Study

The study acknowledges the fact that some research work has been done on the effects of flooding on the quality of water sources (Ifabibyi & Ashaolu, 2013; Amuquandoh, 2016; Chimber & Kansuk, 2019; NADMO, 2018; and Atoaba, 2011). These studies focused on flooding as a result of the spillage of the Bagre Dam in Burkina Faso with its devastating effects on communities along the Volta basin. The current study, however, contributes to the literature by examining the effects of floods on the Jambusie Water Treatment Plant which supplies water to the Wa Municipality. It is important to note that the production of good drinking water is very crucial to the Wa Municipality which hitherto, relied on groundwater from boreholes. Thus, a study of this kind is very significant as it examines the factors which are likely to increase the cost of water production at the JWTP.

This study would also serve as a tool for designing appropriate procedures and policies that would advance Ghana's development agenda especially in the Wa

Municipality where the provision of water is limited to a few areas. The study would spell out measures to cater for the devastating effects of the floods which occur annually at various parts of the country with special focus on water treatment and water treatment infrastructure as in the case of JWTP which supplies water to the Wa Municipality.

## 1.6 Scope of the Study

The study considered the flooding and the JWTP in the Upper West Region of Ghana. The JWTP was chosen because it is the only plant in the region that processes surface water and distributes it to the Wa Municipality. The study took a critical look at some conceptual issues such as coagulation, flocculation, sedimentation, filtration, and disinfection. A conceptual framework has been constructed to illustrate and explain the entire thematic area of the study. Theoretically, the study was guided by the water treatment concept and the regulations governing water treatment.

## 1.7 Limitation of the Study

In every scientific research, plans are often put in place to ensure that the objectives set for the study are achieved through empirical means. However, there are times the plans put in place to realize the objectives of a study may be impeded by some unforeseen circumstances. For this particular study, the researcher was unable to widen the scope of the study to cover the dry season due to time constraints and the cost involved in carrying out an academic study of this kind. Thus, the concentration was during the peak periods of the flooding.

Secondly, language served as a barrier as the researcher does not understand or speak the Brifo Language. Consequently, research assistants were recruited to assist in the data collection process.

### 1.8 Organization of the Study

The study is organized into five chapters with chapter one comprising background of the study, problem statement, main and specific research questions, main and specific research objectives, the significance of the study, the scope of the study, and organization of the study. Chapter two consists of the literature review and conceptual issues, whilst chapter three is composed of the research methodology, research design, data collection techniques, and data analysis. Chapter four presents the results and discussions and chapter five consists of the summary, conclusions, and recommendations.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Conceptualization of Concepts

Conceptualization is a careful definition of the concept to be measured based on theories and the views of other researchers (Agyapong and Adam, 2019), whiles the term concept refers to the end product of conceptualization. In other words, the concept could be a word or complex set of events or ideas referred to by the word. A concept can be a word or symbol used to represent a meaningful whole (Sequeira, 2014). Hence, the conceptual definition must present the meaning of the construct under study in a clear, unambiguous, and specific way.

### 2.1.1 Water colour

Generally, coloured water has an adverse effect on human health and the aquatic environment. As pure water does not possess any kind of colour, water that has colour may provide evidence that there is some form of contamination. All kinds of particles - organic matter, algae, sediments, dissolved minerals, or other artificial chemicals have harmful effects on humans and aquatic health (State Water Resources Control Board & Clean Water Team, n.d.). Also, dissolved and particulate materials in water can cause coloration. Thus, slight coloration is measured in Hazen Units (HU).

Impurities can colour the water as well, for instance, dissolved organic compounds called tannins can result in dark brown colours, or algae floating in the water (particles) can impart a green colour" (International Organization for Standardization, [ISO], 1973:2211).

Testing for colour can be a quick and easy test that often reflects the amount of organic materials in the water, although certain inorganic components like iron or manganese can also impact the colour of the water. Water colour can also be influenced by a number of factors: some colours occur naturally; some may be human-induced or may result from a combination of circumstances. For instance, heavy rain events are known to wash organic substances into the water where they dissolve and act as a dye; seasonal algae blooms can result in such high concentrations of algae that the water becomes tinted with the coloration of the algal cells; or wind events may stir up fine particles off the bottom, re-suspending them into the water column. Colour may also be the result of inorganic materials (e.g., clay particles, etc.) from storm-water runoff or shoreline erosion (Florida LakeWatch, 2017).

Also, suspended and dissolved particles in water influence the colour. Suspended material in water bodies may be a result of natural causes and/or human activity. Transparent water with a low accumulation of dissolved materials appears blue and indicates low productivity. Dissolved organic matter, such as hummus, peat, or decaying plant matter, can produce a yellow or brown colour. Some algae or dinoflagellates produce reddish or deep yellow waters. Water-rich in phytoplankton and other algae usually appears green. Soil runoff produces a variety of yellow, red, brown, and gray colours (State Water Resources Control Board & Clean Water Team, n.d.).

The colour of water varies with the ambient conditions in which that water is present. While relatively small quantities of water appear to be colourless, pure water has a slight blue colour that becomes a deeper blue as the thickness of the observed sample increases. The blue hue of the water is an intrinsic property and is caused by selective absorption and scattering of white light (Tembhekar, 2008). Dissolved elements or suspended impurities may give water a different colour. Water colour can reveal physical, chemical, and bacteriological conditions. In drinking water, green can indicate copper leaching from copper plumbing and can also represent algae growth. Blue can also indicate copper or might be caused by the siphoning of industrial cleaners in the tank of commodes, commonly known as back flowing. Reds can be signs of rust from iron pipes or airborne bacteria from lakes among others. According to Braun and Smirnov (1993), water has an intrinsic colour, and that this colour has a unique origin. This intrinsic colour is easy to see. Water owes its intrinsic blueness to selective absorption in the red part of its visible spectrum. The absorbed photons promote a transition to high overtone combination states of the nuclear motions of the molecule i.e., to highly excited vibration. The intrinsic blueness of water is the only example from nature in a colour that originates from vibrational transitions.

Accurate documentation of water colour is important as it indicates the source of water and pollutants. Water colour is referred to as apparent colour and true colour based on the type of solid material present in it. Apparent colour is the colour of the whole water sample and consists of colour due to both dissolved and suspended components. The true colour is measured by filtering the water sample to remove all suspended material, and measuring the colour of the filtered water, which represents colour due to dissolved components (State Water Resources Control Board & Clean Water Team, n.d.).

### 2.1.2 pH

The pH level of drinking water is a measure of how acidic or basic it is – pH is related to the hydrogen ions in water and stands for "Potential of Hydrogen" (NOVA SCOTIA Environment, 2008). The pH concept was first introduced by a Danish Chemist Søren Peder Lauritz Sørensen at the Carlsberg Laboratory in 1909 (Sørensen, 1909), and revised to the modern pH in 1924 to accommodate definitions and measurements in electrochemical cells. The notation first had the H as a subscript to the lowercase p, like this pH. However, the exact meaning of the p in pH is disputed, as Sørensen did not explain why it was used (Francl, 2010). Sørensen, however, describes a way to measure it using potential differences, and it represents the negative power of 10 in the concentration of hydrogen ions. Thus, Carlsberg Laboratory was French-speaking, German was the dominant language of scientific publishing, and Sørensen was Danish. He also used "q" in much the same way elsewhere in the paper. So, the "p" could stand for the French puissance, German potenz, or Danish potent, meaning "power", or it could mean "potential". He might just have labeled the test solution "p" and the reference solution "q" to identify them because, the letters were often paired (Myers, 2010), which implies that there is little to support the suggestion that "pH" stands for the Latin terms pondus hydrogenii (quantity of hydrogen) or potentia hydrogenii (power of hydrogen). However, NOVA SCOTIA Environment (2008) opines that pH is related to the hydrogen ions in water and stands for "potential of hydrogen".

The first electronic method for measuring pH was invented by Arnold Orville Beckman, a professor at the California institute of technology in 1934 (origins:

birth of the ph meter, n.d). it was in response to local citrus grower Sunkist who wanted a better method of testing the pH of lemons picked from nearby orchards (Tetrault, 2002). pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, $a_{H}+$, in a solution

(Covington, Bates, & Durst, 1985).

For Instance, in a solution with a hydrogen ion activity of $5\times10^{-6}$ (at that level, this is essentially the number of moles of hydrogen ions per liter of solution) there is $\mathrm{pH} = -\log_{10}(a_{\mathrm{H}^+}) = \log_{10}\left(\frac{1}{a_{\mathrm{H}^+}}\right)$ $1/(5\times10^{-6}) = 2\times10^{5}$, thus such a solution has a pH of $\log_{10}(2\times10^{5}) = 5.3$. For example, based on the facts that the masses of a mole of water, a mole of hydrogen ions, and a mole of hydroxide ions are respectively 18g, 1g, and 17g, a quantity of $10^{7}$ moles of pure (pH 7) water, or 180 tonnes ($18\times10^{7}$g), contains close to 1g of dissociated hydrogen ions (or rather 19g of $H_3O^+$ hydronium ions) and 17 g of hydroxide ions. It is important to note that pH depends on temperature. For instance, at 0 °C, the pH of pure water is 7.47. At 25 °C, it is 7.00, and at 100 °C, it is 6.14. As indicated by WHO (2003), the pH of water is a measure of the acid-base equilibrium and, in most natural waters, it is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An increased carbon dioxide concentration will therefore lower pH, whereas a decrease will cause it to rise. The temperature will also affect the equilibria and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C. In water with a buffering capacity imparted by bicarbonate, carbonate, and hydroxyl ions, this temperature effect is modified (1). The pH of most raw water lies within the range of 6.5 – 8.5 (1). pH is measured on a scale from 0 to 14. A measurement below 7 means the water is acidic whiles

7 above means the water is basic or alkaline. Also, a measurement of 7 is neutral. A pH of less than 6.5 may contribute to the corrosion of pipes and fixtures. How corrosive the water is also dependent on other factors, such as alkalinity, water temperature, total dissolved solids, and hardness. Further, a pH of less than 6.5 is not a health risk in itself; however, corrosive water can dissolve metals, such as lead, cadmium, zinc, and copper, present in pipes. This may lead to increased concentrations of these metals in drinking water, which can cause health concerns (NOVA SCOTIA Environment, 2008).

Indicators may be used to measure pH, by making use of the fact that their color changes with pH. Visual comparison of the color of a test solution with a standard color chart provides a means to measure pH accurately to the nearest whole number. More precise measurements are possible if the color is measured spectrophotometrically, using a colorimeter or spectrophotometer. The universal indicator consists of a mixture of indicators such that there is a continuous color change from about pH 2 to 10. Universal indicator paper is made from absorbent paper that has been impregnated with a universal indicator. Another method of measuring pH is using an electronic pH meter.

### 2.1.3 Turbidity

Turbidity in water is a measurement of how cloudy or murky the water is (Minnesota Pollution Control Agency [MPCA], 2008). Turbidity is an extremely useful indicator that can yield valuable information quickly, relatively cheaply, and on an ongoing basis. Measurement of turbidity is applicable in a variety of settings, from low-resource small systems to large and sophisticated water treatment plants. Turbidity, which is caused by suspended chemical and biological particles, can have both water safety and aesthetic implications for drinking-water supplies. The sources of turbidity are diverse, and many of the constituent particles (e.g. clays, soils, and natural organic matter) are harmless. Turbidity itself does not always represent a direct risk to public health. For instance, high turbidity in source waters can harbour microbial pathogens, which can be attached to particles and impair disinfection. It, however, indicates the presence of pathogenic micro-organisms and can be an effective indicator of hazardous events throughout the water supply system, from its catchment to the point of use. For example, high turbidity in filtered water can indicate poor removal of pathogens, and an increase in turbidity in the distribution systems can indicate the sloughing of biofilms and oxide scales or ingress of contaminants through faults such as mains breaks.

However, low turbidities in drinking water are a proven indicator of pathogen removal of drinking water safety. Incidents of high turbidity are associated with several outbreaks of disease (Hrudey & Hrudey, 2004; Mann et al., 2007). However, a directly proportional relationship between the removal of turbidity and pathogens has not been demonstrated (Health Canada, 2012). Besides, investigations of potential links sbetween levels of turbidity in drinking water and rates of endemic gastrointestinal disease in communities have produced mixed results. Studies have shown a relationship between turbidity and endemic disease but others have not (Mann et al., 2007; Tinker et al., 2010; Beaudeau, 2014). Though correlations may exist in individual drinking-water supplies, a uniform relationship has not been established.

### 2.1.4 Nitrate

Nitrate is a naturally occurring ion that is part of the nitrogen cycle. The nitrate ion ($NO_3$) is the stable form of combined nitrogen for oxygenated systems. Although chemically unreactive, it can be reduced by microbial action. Nitrate is used mainly in inorganic fertilizers. It is also used as an oxidizing agent and in the production of explosives, and purified potassium nitrate is used for glass making. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including the excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and the oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (WHO, 2011). The presence of high or low water tables, the amount of rainwater, the presence of other organic material, and other physicochemical properties are also important in determining the fate of nitrate in soil (Van Duijvenboden & Loch, 1983; Mesinga, Speijers & Meulenbelt, 2003; Fewtrell, 2004; Dubrovsky & Hamilton, 2010).

### 2.1.5 Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids. It measures the presence of carbon dioxide, bicarbonate, carbonate, and hydroxide ions that are naturally present in water. At normal drinking water pH levels, bicarbonate, and carbonate are the main contributors to alkalinity. Alkalinity measures the concentrations of bicarbonate, carbonate, and hydroxide ions and is expressed as an equivalent concentration of calcium carbonate (CaCO3). When choosing a treatment system to minimize corrosion, one should consider both the pH and alkalinity of water, since alkalinity is a measure of the buffering capacity of water – its ability to resist sudden changes in pH and maintain the system according to the guidelines to ensure a continued supply of safe drinking water because, chemical feed treatment systems require very careful operation and maintenance (NOVA SCOTIA Environment, 2008). Alkalinity is a measure of the presence of bicarbonate, carbonate, or hydroxide constituents. Concentrations less than 100ppm are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400ppm. A minimum level of alkalinity is desirable because it is considered a "buffer" that prevents large variations in pH.

Alkalinity is not harmful to humans. Moderately alkaline water – less than 350mg/l, in combination with hardness, forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. Many public water utilities employ this practice to reduce pipe corrosion and to increase the useful life of the water distribution system (Illinois Department of Public Health, n.d.).

High alkalinity – above 500mg/l is usually associated with high pH values, hardness, and high dissolved solids and has adverse effects on plumbing systems, especially on hot water systems – water heaters, boilers, heat exchanger, and so on – where excessive scale reduces the transfer of heat to the water, thereby resulting in greater power consumption and increase costs.

Water with low alkalinity – less than 75mg/l – especially some surface waters and rainfall, is subject to changes in pH due to dissolved gasses that may be corrosive to metallic fittings (Illinois Department of Public Health, n.d.).

## 2.2 Historical antecedents of Dam and Rainfall

A dam is a barrier that stops or restricts the flow of water or underground streams. A large dam is a dam with a height of 15 metres or more from the foundation. If dams are 5 – 15 metres high and have a reservoir volume of more than three million $m^3$, they are also classified as large dams. Using this definition, there are more than 45,000 large dams around the world, almost half of them in China. Most of them were built in the 20th Century to meet the constantly growing demand for water and electricity (International Commission on Large Dams [ICOLD], n.d). Rainfall and dams have a connection as dams cannot get full of water without rain.

Reservoirs created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability. Hydropower is often used in conjunction with dams to generate electricity. A dam can also be used to collect water or for the storage of water which can be evenly distributed between locations. Dams generally serve the primary purpose of retaining water, while other structures such as floodgates or levees (also known as dikes) are used to manage or prevent water flow into specific land regions (Günther, 1986).

The earliest known dam is the Jawa Dam in Jordan, dating to 3,000 BC. This gravity dam featured an originally 9 metre-high (30 ft) and 1 metre wide (3.3ft) stone wall, supported by a 50 metre wide (160 ft) earth rampart. The structure is dated to 3000 BC (Günther, 1986).

In Africa, dams have been constructed for various purposes. As indicated by International Rivers Water-Life (IRWL) (2010), dams are often the largest water and energy investment in Africa. Yet, African citizens rarely have access to critical information about these projects. Citizens have the right to hold their governments accountable for the decisions they take and the use of public funds. The African Dams Briefing (2010) was intended to assist African and international civil society in holding their government officials accountable by providing greater transparency about dam projects, project decision-making, and companies and donors involved in specific dams. Every large dam poses economic, social, and environmental impacts.

In that briefing, dams can increase a country's debt burden, displace whole communities, destroy livelihoods, alter ecosystems, and increase disease, which is often the result of high rainfall (IRWL, 2010). Dams can also fall far short of achieving their objectives, especially in a warming world. Climate change and increasingly erratic rainfall can reduce energy and water benefits from dams and increase the risks of floods.

The IRWL (2010) has outlined the construction of dams in some African countries as follows:

The Angolan government in 2008 outlined plans to increase production capacity by at least 1,250 Mega Watt (MW) by 2016. In 2014, the government increased the production capacity target to 7000 MW, however not specifying a deadline. The increased production capacity was to be achieved by the construction of 5 new dams on the Cuanza River. To achieve this objective, the National Water

Directorate of Angola (NWDA) in 2014 recruited consultants, to develop an integrated water resource management plan for the Cuanza River. These developments came about as a result of damage to six hydro dams in Angola. In all, Angola has a number of dams supplying it with water, energy, irrigation, and other needs (NWDA, 2014).

A similar large dam has been constructed in Benin to serve the country's multipurpose needs. An example of such a dam is the Kandadji dam which was started in 2003 and completed in 2011.

In Botswana Dikgatlhong Damhe dam which is the largest in that country has a reservoir size of 400 million cubic meters. The dam provides water mainly in the eastern parts of Botswana, particularly for the Mmamabula coal project and other thermal power generation as well as mining activities in the area (IRWL, 2010).

As part of the country's effort to diversify its energy resources and improve electrification nationwide, Equatorial Guinea undertook the construction of the Djibloho hydroelectric plant in the Continental Region, near the city of Anisok. Synohydro Corporation began construction work of the plant in March 2008 and completed it in October 2012. This project is funded principally by the Government of Equatorial Guinea with assistance from China Exim Bank; it is one of the largest infrastructure investments thus far. This dam is 22 meters high, 274 meters long, and is expected to generate 120MW of electricity. It already offers energy to several areas of the Continental Region such as Mongomo, Rio Campo, Machida, Niefang, Micomesend, Nkue, Bidjabidjan, Ebebiyin, Mengomeyen, Anisok, and Evinayong.

In Burkina Faso, the Bagre Dam was constructed to serve various purposes. Since its construction the Bagre Dam has been renovated and expanded to prevent frequent spillage. However, that has compounded the effects of floods in the Upper East Region of Ghana. The dam was raised by 1.5 meters and the reservoir banks were reinforced, at $18 million provided by the French Aid for International Development. The dam irrigates 30,000 hectares of land and provides 10% of the country's electricity. The dam was originally built in 1994 and underwent a first renovation costing $33 million. Ghana and Burkina Faso already have a Transboundary Committee to oversee the management of the White Volta River Basin. In 2014, the Government of Ghana commissioned siltation studies on the dam. Still, in the same year, the Burkina Faso government had to spill water from the dam due to abnormally high-water levels. Two people died as a result of the water spillage from the dam. No further information about the expansion has been received to date.

In Ghana, several dams including the Kpong, Bui, and Akosombo dams have been constructed to collect water during the rainy season and to provide energy and other water resource needs of the country. The Akosombo Dam was originally built in 1960. Its reservoir, Lake Volta is the world's largest man-made lake and flooded 4% of Ghana's landmass. The flooding to create the Lake Volta reservoir displaced many people and had a significant impact on the environment and public health. The original purpose of the Akosombo Dam was to provide electricity for the aluminum industry. Akosombo’s installed capacity increased from 912 MW to 1,020 MW during a retrofit in 2006.

The literature reveals that most of the dams constructed in Africa have had some form of financial support from banks, especially, the World Bank. It does appear that the construction of many dams in Africa has had some opposition from the communities they are to impact. For instance, the governments of Angola and Namibia jointly plan to build the Baynes Dam with an expected capacity of 600 MW, to be shared equally between Angola and Namibia. The 17 projects were estimated at US$1.35 billion and construction was due to begin in 2017. The Baynes Dam was to affect the indigenous Himba peoples, a nomadic tribe in northern Namibia. Consequently, there was a great deal of opposition from the Himba community against the building of the dam. In 2015, concerns were raised in Nigeria on the possible impact of the dam upstream, on the Kainji and Jebba dams in Nigeria, and further socio-economic impacts that might be apparent. In 2014, the US decided to oppose large dams, through vetoes in international financial institutions, and the Adjarala is one of such dams.

It is therefore not surprising that the spillage of the Bagre Dam has rendered many homeless. The situation seems to be exacerbated as the management of the JWTP had persistently complained about the high cost of treating water for consumption in the Wa Municipality.

## 2.3 Effect of Floods on Water Treatment

Among the various weather events, flooding is the most prevalent, occurring at many places around the world (Douglas et. al. 2008). A water supply source has the potential of getting contaminated due to flooding. Bhateria and Jain. (2016) posited that the source of contamination can be chemicals used in farming activities such as phosphates, nitrates, ammonia, potassium and urea which are washed into the source of water treatment due to the flooding. The presence of these contaminants at high levels requires the use of more chemicals for treatment than would usually be the case. Where the treatment process does not have the infrastructure to treat the pollutant, then an improvised system has to be introduced to treat the water. Another source of contamination caused by the incidence of flooding is run-off from sewage and other polluted sources (Singh and Gupta 2016). The floods which inundate anything within their coverage area, also carry the pollutants, which in this case constitute–microorganism, into the water body and increase the bacterial load which has to be treated to make the water wholesome.

According to Bilotta and Brazier (2008), flooding does not only cause siltation of rivers and other water bodies used for water treatment, but also causes the turbidity of the water to increase, which complicates the way the water will be treated before consumption. Whist the siltation of the water body affects the amount of water available in the river basin for treatment, the increased turbidity also results in the use of coagulants needed to coagulate the water during treatment. The turbidity also causes the excessive production of sludge which increases the water used to flush the sludge and also the amount of water used in washing the filters (Summerfelt et. al. 1997). Animal and industrial wastes are all pollutants that excessive floods can contaminate water bodies with. They introduce organic pollutants into the water which serve as nutrients and cause algal bloom (Bilotta and Brazier, 2008).

In a nutshell, the excess water carrying the contaminants makes it more difficult for water treatment devices to treat the water efficiently and effectively. If there is a contamination at any step of the water flow process, this puts consumers at risk of exposure to dangerous toxins that could result in serious harm such as wound infections, skin rashes, gastrointestinal illnesses, and tetanus. Where the cases are overwhelming, death may occur (Gleick and Palaniappan, 2010).

## 2.4 Effects of Floods on Infrastructure

The progressive changes in environmental conditions are resulting in a worsening occurrence of floods which have various degrees of impact on local communities, towns, and cities (Gutiérrez et. al. 2014). To be able to comprehend the risk of floods from climate change and other factors, the resilience of communities and the impacts on infrastructure have to be studied. Infrastructure in this context includes a number of facilities like roads, utilities, emergency services, buildings, public services, social/cultural institutions and various property level land use (Wood et. al. 2002).

The devastating effects of floods on physical infrastructure cannot be over emphasized. According to McShane (2019), governments over the world are faced with the problem of investing and spending large amounts of money to repair damage that has occurred to roads as a result of floods. The overwhelming nature of such floods washes away these roads and cause cracks to portions of the roads rendering them unmotorable in most instances (Wood, 2002). Floods also cause the weakening of buildings or the development of cracks in most buildings at areas where their occurrence is persistent (Amadi, 2012). On several occasions, buildings that have been found to be in the way of floods have been washed away due to the currents that have been associated with floods. The floods also have the potential to cause the fading of buildings which necessitates persistent repair works. McShane (2019) added that floods expose infrastructure to more risks of structural damage, wearing out, and aging quickly, thus increasing maintenance and replacement costs.



Armah et. al (2010) posited that floods also have large social consequences for communities and individuals. Some of the consequences that can mostly be identified due to the immediate impacts of flooding include loss of human life, damage to property, destruction of crops, loss of livestock, and deterioration of health conditions owing to waterborne diseases. National level flood risk assessments that focus on infrastructure are relatively rare. In 2007, the Federal Emergency Management Agency (FEMA), the federal agency which is tasked with managing the nation's disaster in the USA announced a design guide for improving critical facility safety from Flooding and High Wind (Hu et. al. 2016). Globally, some studies estimate the flood risk of infrastructure focused on specific cities and regions (Thacker, 2017), but such assessments are not as common (Federal Emergency Management Agency, 2007). Other researchers have aimed to understand flood risk in a more detailed manner, with an eye toward infrastructure.

## 2.5 Water treatment in developing countries

Treacy (2019) explains that in developing countries, the priority is to obtain safe water. Waterborne diseases are global issues especially in tropical countries with poor water supplies. This means that the chemical and physical characteristics of water should not be overlooked, but the emphasis on the biological quality of water should be salient. There are two treatment systems in developing countries. These are the central source treatment system and point-of-use treatment (Treacy, 2019).

Wright (2004) noted that the central source treatment system involves water treatment in a central location followed by distribution to the consumer. This is known as a medium- or large-scale treatment. The treatment is similar to conventional treatment used in developed countries. This type of treatment is suitable for urban areas in developing countries (Wright, 2004).

Challenges of network contamination and maintenance of the infrastructure are a large concern (Wright, 2004). Wright explained that treated water can be transported by tankers to rural areas if piped networks are not present in a particular area. Point-of-Use (POU) treatment involves informal sources of treating water at the source which is also known as a small-scale treatment. Risk management in terms of pollution of informal sources such as rainwater, shallow boreholes, and small streams per household is a large concern (Arvai & Post, 2012). These writers suggest that when deciding on which type of POU treatment variables to consider, it should include ease of use, price, time for treatment, and volume of water treated.



### 2.5.1 Processes of water purification

Public water treatment systems use various methods of treating water to provide safe drinking water for society. The method for treating water depends on the nature of raw water and the required standard of water quality. These steps for treating surface water by community water systems are aeration, coagulation and flocculation, sedimentation, filtration, and disinfection. An explanation of the method and steps for treating water is given below.

i. Aeration

Raw water is first collected in large aeration tanks for air to circulate in the water or penetrate it. This is done by cascading it on various levels or pumping it through perforated pipes to introduce the air into the water. Aeration removes bad odours and $CO_2$. It also removes metals such as iron and manganese by precipitating them before their respective hydroxides.

ii. Coagulation and Flocculation

Coagulation and flocculation is the first step in water treatment. Water from the storage tank is placed in a coagulation tank and some precipitating agents such as alum, lime, and so on are added to water and mixed. These precipitating agents form a precipitate of $Al(OH)_3$ when dissolved in water. Suspended solids absorb on the surface of a precipitate, so gradually mass of precipitate becomes heavier and finally settles down. This technique is used to remove very light suspended solids that do not settle by themselves during storage. Furthermore, if negatively charged colloidal impurities are present, they are neutralized by Al+++ ions and settle down.

iii. Sedimentation

The next stage of the water purification process is called sedimentation. Sedimentation is a water treatment process that uses gravity to extract suspended particles from water (Omelia, 1998), by depositing sediments at the bottom of a clarifier of a water treatment plant (Hammer, 1975). It is used for potable water treatment and waste water treatment (Chatzakis, Lyrintzis, Mara, & Angelakis, 2006; Steel & Terrence, 1979). Sedimentation makes particles come together to form flocs of bigger sizes which settle to the bottom of a clarifier (Metcalf & Eddy, 1972; Department of Planning and Local Government, Adelaide & Australia, 2010).



iv. Filtration

Partially clarified water is then passed through a sand gravity filter which removes 98 - 99% of microorganisms and other impurities. Sand gravity water filter: a sand filter is a rectangular tank in which the filter bed is made up of 3 layers; top layer: a fine layer of 1 meter thick; middle layer: 0.3 - 0.5 meter thick layer of coarse sand; and bottom layer: 0.3 - 0.5 meter thick layer of gravel. There is a collection tank at the bottom of the filter bed to collect filtered water (Gaurab, 2018). During filtration filter bed soon gets covered with a slimy layer called the vital layer. The vital layer consists of thread-like algae, diatoms, and bacteria. During filtration, microorganisms present in a vital layer oxidize organic and other matter present in water (Gaurab, 2018). For example, if $NH_3$ is present, it is oxidized into nitrate. The vital layer also helps in the filtration of microbial cells. If the water contains unpleasant odours, activated carbon may be placed in a filter bed that removes bad odours.

v. Disinfection

The filtered water is finally purified by using disinfectants, for example, chlorination. Disinfectant kills pathogenic as well as other microorganisms in water. After disinfection, water is pumped into an overhead tank for subsequent domestic distribution (Gaurab, 2018). The Jambusie Water Treatment Facility goes through a similar process to get the water purification for use in the Wa Township and its environs. Figure 2.1 below shows the steps of the water purification process.

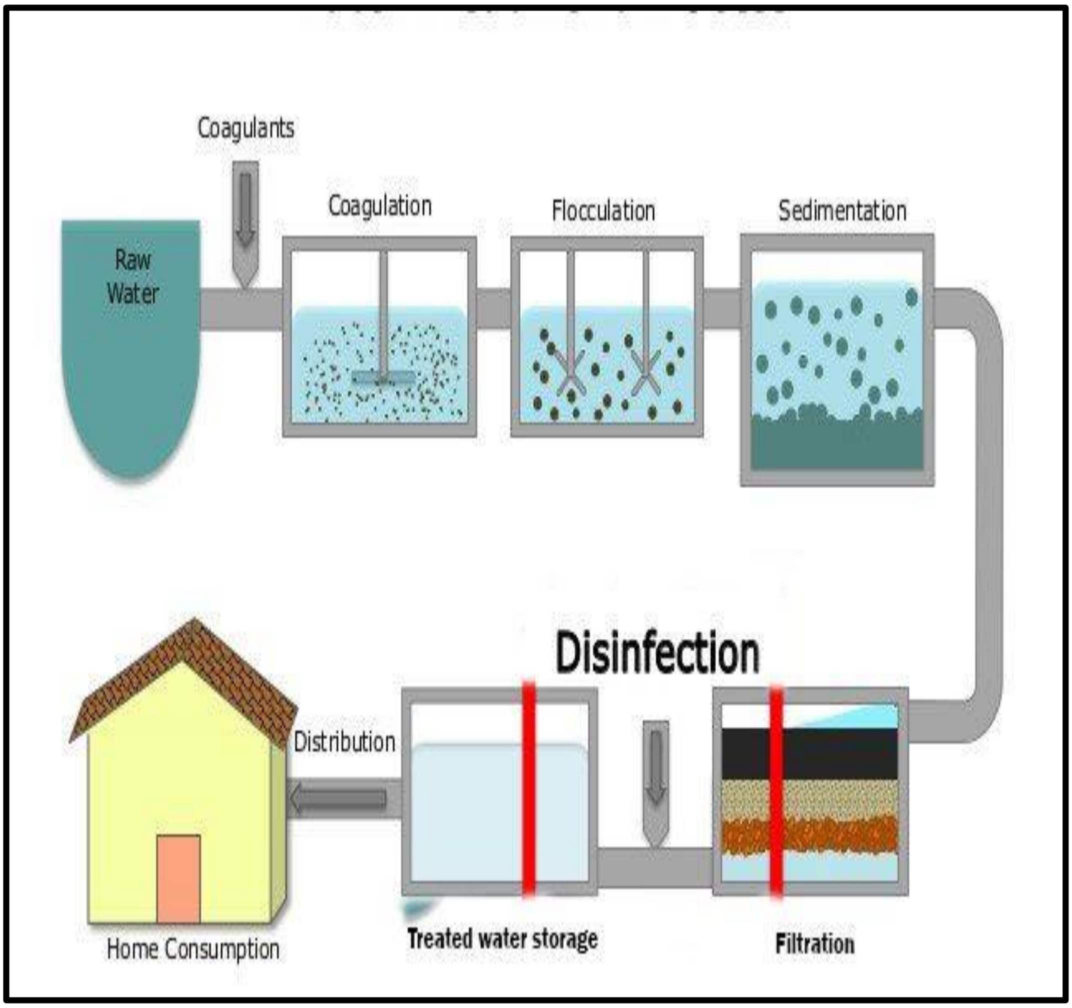



**Figure 2.1: Steps of water purification process**
*Sources*: Adopted from Gaurab, 2018

## 2.6 Municipal Water Systems

This study adopts the definition of the water system by Sparn and Hunsberger, (2015) as including the collection of raw water from surface or groundwater sources, treating it to meet regulatory standards, and delivering potable water to consumers. Raw water generally comes from surface sources which include reservoirs, and rivers.

EPRI and WRF (2013) indicated that water treatment processes vary, but pumping accounts for most of the electricity used in water treatment systems. About 55% – 90% of the total load depends on the level of sophistication of the hydraulic system and treatment process.

In general, there are three pumping systems and these are raw water pumping, in-plant pumping, and finished water pumping (Sparn & Hunsberger, 2015). They are used in every water treatment system. Raw water pumping is needed to deliver raw water to the treatment plant, where it is then pumped through all the processes, and then the finished water is delivered to end-users at a certain pressure (Sparn & Hunsberger, 2015). As noted by Sparn and Hunsberger, various pumps situated along the water system have different degrees of flexibility, depending on the system configuration. There are instances where some systems have to draw their raw water from long distances and then process it for use. An example of such systems can be found in California where raw water is drawn from distant sources throw a series of reservoirs and storage tanks (Sparn & Hunsberger, 2015). At the end of it, all the finished water is pumped to end-users. And in the view of Raucher et al., (2008) the pumping energy required to deliver water to storage tanks is flexible, and many water utilities already wait to pump to storage tanks at night when domestic consumption of electricity rates are lower. This, therefore, suggests that if the Jambusie Water Treatment Plant situated at Jambusie goes through the right processes as outlined above, the cost of treating water for the municipality may be reduced.

## 2.7 Wa Water Supply Expansion Project

Wa is the capital town of the Upper West Region in Ghana. It has a population of 129,689 (Ghana Statistic Service [GSS], 2019). As captured by Ghana Water Company Limited (GWCL) Diary (2020), the existing water supply system is based on groundwater which is made up of 18 boreholes located in three well fields. These boreholes directly pump water to two storage tanks at the site of a central reservoir. The current production stands at 1,832$m^3$/day (0.4MGD) whilst the present estimated water demand is 12,840$m^3$/day (2.8MGD). The current production, therefore, represents only 14% of the current daily water demand.

Further, production from these boreholes has declined considerably over the years due to aquifer depletion and deterioration of the boreholes. As a solution, a more reliable water supply system was planned to meet current and future demand for water. Hence, Messrs Hifab/Sweco Colon was tasked to undertake a detailed feasibility study to develop a water treatment plant along the Black Volta River to supply water to the Wa Municipality (GWCL Diary, 2020).

The Ghana Government through the Ministry of Finance signed a loan agreement with the Korean Exim Bank securing US$55.50 million to undertake a surface water supply project for Wa. Consequently, GWCL signed a contract with Messrs Kolon Pyunghwa Consortium to undertake the works. The project is to meet the water demand of Wa Township and its environs up to the year 2025 (GWCL Diary, 2018).

### 2.8 Water Spillage of the Bagre Dam

The Bagre Dam is a multi-purpose facility on the White Volta, located near Bagre village in Burkina Faso. Whenever water in the dam reaches its maximum level of 235 metres, the excess volumes are spilled by Société Nationale d'Electricité (SONABEL), the power utility authority of Burkina Faso, to prevent the dam from damage. The spilled water often finds its way into the White Volta River, which causes floods in the three regions of the North and the Eastern Region, thereby destroying lives and properties in those areas (Dapatem - Graphic Online, 2018).

For instance, in August 2007, the Ghana Government had to declare a state of emergency in the then three regions of the North thus, Upper East, Upper West, and Northern. Without any notice from the Burkinabe authorities, Ghanaians living in these regions bore the brunt of a devastating spillage (Appiah, 2018).

The National Disaster Management Organization (NADMO) in 2019, called on the public, especially those along the river banks to take precautionary measures as excess water of the Bagre Dam was to be spilled by neighbouring Burkina Faso. The people were cautioned to take their safety seriously, as the water was being spilled. The Vice President, Dr. Mahamudu Bawumia, observed that the spillage of the dam occasioned by Burkinabe authorities over the years has inflicted substantial destruction to farmlands in several local communities in Ghana (GhanaWeb Reports, 2019).

Further, the Director-General of NADMO, Mr. Eric Nana Agyemang Prempeh, indicated that farmlands were consumed by floodwaters and lives were under threat. The NADMO boss said the water level was very high describing the situation as bad (Boadu & Amenuveve, 2018). The water level in 2018 rose to 100 percent, which was compounded by flooding as a result of heavy rains in the North. By estimation, NADMO indicated that over 200,000 people along the White Volta and the Black Volta were expected to be affected by the floods. Hence, NADMO had to issue a flood alert ahead of the opening of the dam and warned residents along the two rivers of the rising water levels in the White Volta and the opening of the dam. They therefore, urged the residents to move their valuables to higher ground for safety.

## 2.9 Measures to Forestall Spillage of the Bagre Dam

Dapatem (2018) indicates that President, Akufo-Addo said taking measures were necessary because the annual flooding causes great loss to human lives and properties. The President noted that the issue should have been dealt with long ago. He also indicated that plans were underway to spend $750 million to construct the Pwalugu Dam. On the part of the Vice President, 25,000 hectares of farmlands were to be used for irrigation purposes. He further said the Pwalugu Dam was to be used for electricity to help improve irrigation farming in local communities in the farming area (Ghana News Agency Reports, 2019).

## 2.10 Challenges in Raw Water Treatment

Sustainable access to safe drinking water and basic sanitation is an important part of the Sustainable Development Goals (SDGs). For most African countries, an extensive effort is needed for the last three remaining years for the achievement of the SDGs, especially in Sub-Saharan Africa. Current practices for water and wastewater treatment in Africa are insufficient to ensure safe water and basic sanitation (Wang et al., 2014).

Municipal water treatment plants usually have shared upstream treatment systems. This suggests that the water is fully treated before being supplied to a distribution system from where it will go on to feed consumers. It is therefore important that the design of any water treatment plant should take into consideration, the site condition including chemical and microbiological analysis of the water to be treated, a risk assessment, and the results of laboratory or pilot-scale tests to determine the effectiveness of the plant/processes and the chemical requirements. This should always be done to ensure that water meant for consumption is wholesome. Since the requirements for treating water differ in different geographical locations, the challenges that may be encountered in treating the water may also differ.

For African countries, Wang et al. (2014) categorize the challenges to water treatment as insufficient infrastructure and poor operation and maintenance. They argued that limited sewer collection is a bottleneck for water treatment in Africa and as such most homes are often not hooked to the water system and the rate of connections is very low. Apart from the above water quality monitoring is often poor in African countries. In most of the laboratories as these writers opined, for water quality monitoring in waterworks, only a few parameters such as turbidity, pH, and alkalinity are monitored. For example, in Nairobi, Kenya although the significance of organic pollutants in drinking water is realized, there are few waterworks monitoring total organic carbons due to lack of instruments. In

Kampala, even though the environmental management agency is aware of the illegal discharge, it is hard to monitor these industries partly due to the lack of an effective management system.

The lack of power supply hinders water treatment to a great extent in Africa. Many treatment plants cannot operate properly due to unreliable power supply (Wnag et al., 2014).

Another major challenge in treating water in Africa is poor operation and maintenance. Some waterworks are facing challenges for the dosage of coagulants when the turbidity is too high or too low. Another challenge for drinking water treatment is algae. Algae may consume more chemicals, clog filters, resulting in a bad smell and cause microcystin, which is toxic and hazardous to human health (Wnag et al., 2014).

At an AMEC water treatment workshop in 2007, a number of challenges were identified for treating water for consumption. These challenges include; water management – collection and storage during peaks, mechanical reliability - backups and contingency plans for upset conditions, cost - availability of skilled labour, operation - lack of trained operators, and technical supervision. The lack of power supply also hinders water treatment to a great extent in Africa. It was found that many treatment plants cannot operate properly due to unreliable power supply systems. Also, water quality monitoring is often poor in African countries. In most of the laboratories for water quality monitoring of waterworks and WWTPs, only a few parameters such as turbidity, pH, and alkalinity are monitored.

### 2.11 Socio-Economic Effects of Water Spillage

Spilling dams have both positive and negative consequences for the dam that is spilled and the communities or inhabitants of the areas where the water runs to. More often than not water in a dam may be spilled to prevent the dam from being damaged when its capacity is exceeded by surface run-off.

The annual spillage of the Bagre Dam by Burkinabe Authorities, for example, is often associated with the dangers of flooding for farmers and residents along the White Volta (Dapatem, 2018). Media reports indicate that nearly 266,000 people in the Northern, North East, Savanna, Upper East, and Upper West regions of Ghana were affected, with 22 people reported dead. Over 11,000 homes were destroyed and more than 12,000 hectares of farmlands were destroyed in the Upper East Region (Integrated Regional Information Network (IRIN) (2016). The reports show that in various years, the opening of the flood gates of the Bagre Dam has always contributed to floods in Northern Ghana with attendant consequences, especially in the immediate communities around the White Volta River banks and its tributaries, including communities in the Talensi, Binduri, Bawku West Districts, and the Bawku East Municipality.

Records show that the spillage of the Bagre Dam can be described as an event. For example, current records indicate that for the years 2016, 2018, and 2019 the Dam was spilled and the spillage came with the associated effects on the communities.

The disruption to the agricultural industry which is the mainstay of the rural communities, in particular, led to a loss of livelihoods and subsequently affected the food security situation of the communities. Other effects as a result of the spillage included damage to infrastructure which also caused long-term impacts, such as disruptions to access to potable water, electricity, transport, education, and health care. Trade between the communities and their Burkinabe counterparts is normally affected by the floods as traders in the communities are unable to cross the river by canoes to trade (IRIN, 2007).

Considering the above literature, the spillage of dams has deadly consequences on the affected communities, and there is an urgent need for Ghana and Burkina Faso to work assiduously to address this annual canker.

### 2.12 Conceptual Framework

A conceptual framework is the researcher's understanding of how the particular variables in his/her study connect. Thus, it identifies the variables required in the research investigation. It is the researcher's "map" in pursuing the investigation (Regioniel, 2015). A framework is a research tool intended to assist a researcher to develop awareness and understanding of the situation in research as well as to ensure that the researcher did not stray from the original agenda (Guba & Lincoln, 1989) as in (Nurshahirah, Nolila, Nitty, & Zaiton, 2015). The reasoning is to assist the researcher organise his/her thoughts, and explain the relationship between interconnected concepts.

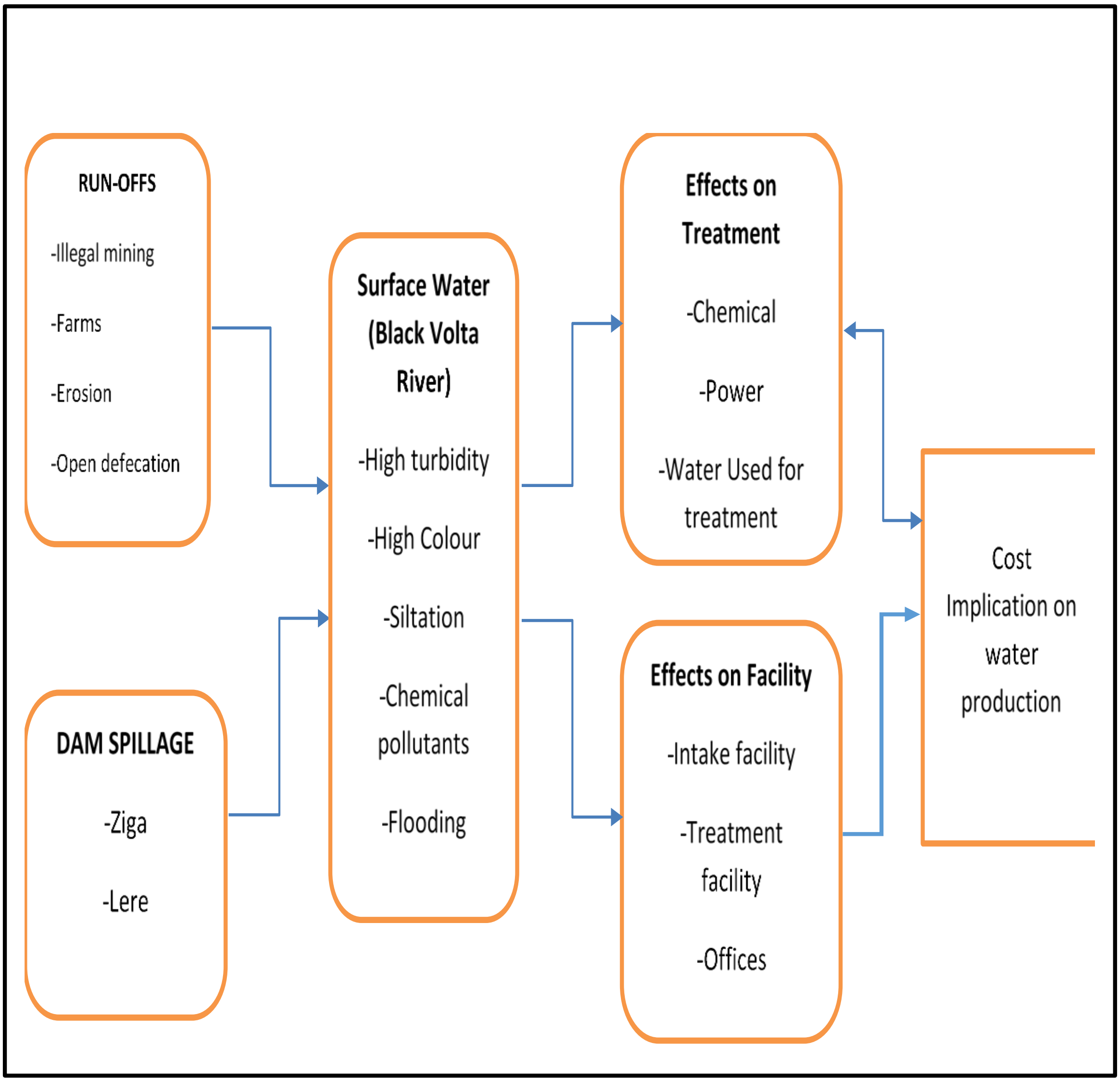



**Figure 2.2: Depicts rainfall and its activities on water facility and cost of production. Along the river bank a number of activities including illegal mining, farming,**
*Source:* Author's Construct, 2020

During the flooding, there are run-offs from illegal mining sites, farms, and places where open defecation is practiced. This run-off water carries these contaminants from the illegal sites, farm sites, and feces into the raw water. Also, the run-off water leads to erosion of the top-soils into the Black Volta. Besides, the run-offs lead to erosion within the catchment area of the river which leads to the siltation of the river and decreases its water holding capacity.

The run-offs from the illegal mining sites and farms carry the top soils which are eroded into the water body causing high turbidity and discoloration of the raw water. Further, chemicals used at the illegal mining sites and farms are washed into the river leading to the pollution of the water body by the harmful chemicals which endanger human health.



Also, in the flooding, the downpour leads to the spillage of dams that reached their maximum capacity. This is the case of the Bagre and Ziga dams which are dams that empty into the Black Volta River. The spillage of these dams can result in the washing of silt and chemicals into the river as well as flooding of the catchment area of the river leading to the pollution of the river.

The effects of these incidents on the Black Volta River have a direct effect on the treatment of water from the river and the facilities of the plant. The incidence of high turbidity and microbial pollution leads to an increase in chemical usage for water treatment. Also, the increase in pollution leads to an increment in power consumption as a result of the increase in the use of the back-wash pumps and the air-compressors which are used to wash the frequently choked filters. The regular washing of the filters and the increase in dislodging of the clarifiers also lead to an increase in the water used for treatment.

Further, the intake facility is inundated by flooding during the flooding as the river level increases and sometimes overflows its banks. This leads to erosion of the structure defense mechanism and aesthetic works of the facility. These effects can be experienced at the treatment facility, the administrative blocks, and the residence of the workers.

Hence, the associated increase in chemicals for the treatment of water, the power to run the machines, and the water used during the treatment of water as well as the funds needed to maintain the infrastructure at the headwork leads to an increase in the total cost of treating water. This cost implication increases the cost of treated water to consumers.

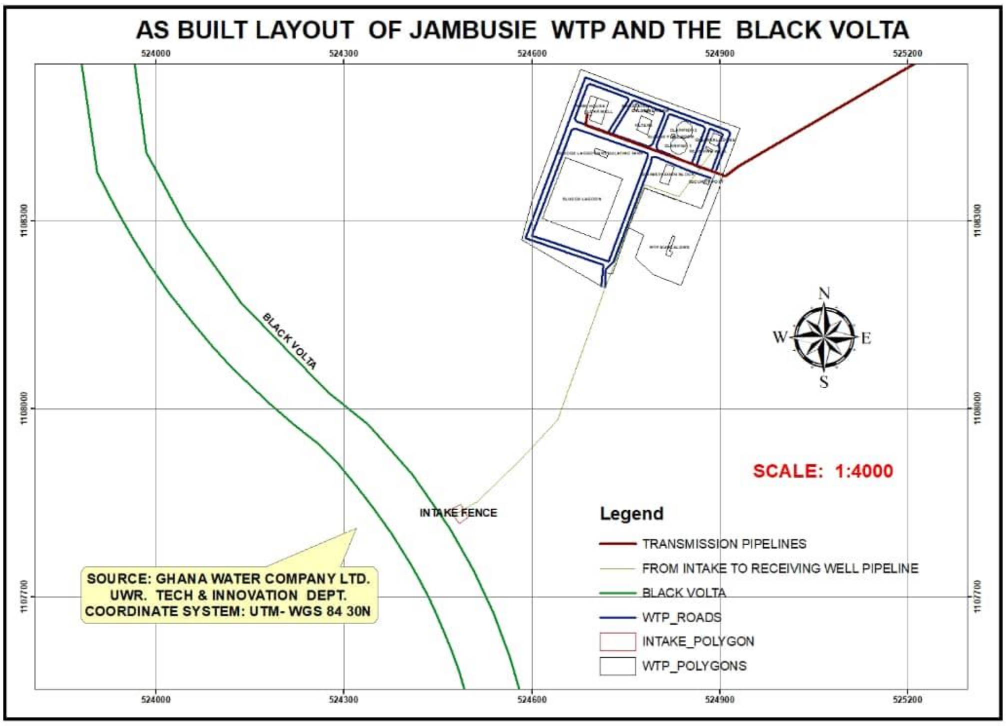
# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Introduction

Having a method is very critical in every aspect of life as it provides the principles upon which an objective can be achieved. A method can be described as an established principle or rule by which a set target can be achieved (Gyelaa, 2016), hence choosing an appropriate working method often creates room for a successful pursuit of every endeavour. This chapter provides the framework by which information was gathered, codified, synthesized, and analyzed towards achieving the objectives of the study. This was informed by the relation to factors of relevance, convenience, reliability, and cost efficiencies.

## 3.2 Profile of the Study Area




Source: Adopted from GWCL (2020).

### 3.2.1 Location and size of the study area

The Jambusie water treatment plant which supplies water to the Wa Municipality of the Upper West Region is located The Wa West District is one of the eleven (11) districts in the Upper West Region of Ghana with its capital as Wechiau. It was carved out of the Wa Municipality and made an autonomous district by L.I 1746 in 2004. The District shares boundaries with Sawla-Tuna-Kalba District to the South, Wa Municipal to the East, Nadowli District to the North, and the West with Burkina Faso.

The surface water source which is treated and supplied to the Wa Municipality is located at Jambusie. Jambusie and its catchment area is a zone in the Wa West District. The zone is made up of four communities; namely Buka, Mwabasi, Baliesare and Jumbusie with a total population of 2,582. The zone shares boundaries to the north with Gonjolo, to the south with Nyorse, to the east with Konduoni, and to the west it is bounded by the Black Volta.

The people in the zone are Dagaabas and Brifos. The main occupation of the people in the area is farming, fishing, pito brewing, and livestock production. The average household size in the zone is 7.0 persons per household.

## 3.3 Research Philosophy

### 3.3.1 Pragmatism

The core ideas of pragmatism emerged from talks at Harvard's 'Metaphysical Club' around 1870. Pragmatism began as a philosophical movement in the late 19th and early 20th centuries and focused on the practical ramifications of social reality. Its origins can be traced back to academic skepticism about the possibility of complete knowledge or truth being achieved through positivist scientific practice (Ormerod, 2006). The work of Charles Peirce, William James, and John Dewey is credited with launching the first wave of pragmatism, known as "classical pragmatism." When Peirce (2014) looked into the meaning of a notion, he found that it was closely tied to its experiential effects. In 1878, he defined the 'pragmatic maxim,' as a rule for clarifying the content of concepts.

By emphasizing the personal and subjective components of meaning, James (2010) expanded on Peirce's work. He stated that when the pragmatic maxim is applied to philosophical discussions, it generally discloses hidden and significant issues that are at stake, rather than demonstrating that they are devoid of meaning. The pragmatic maxim, for James, was a doorway into how individuals think, generate ideas, experiment, and form new habits (Ormerod, 2006). Pragmatism went beyond the individual, psychological world with Dewey, emphasizing both individual and shared human experience. All human experience, according to Dewey, requires some level of interpretation - interpreting facts and beliefs leads to action and reflection. The actions lead to new ways of knowing and acting (Morgan, 2014a).

In Dewey's opinion, if studied carefully and methodically, this dialectic interpretation process may reveal social realities more clearly than philosophical methods that assumed human behavior and activity existed independently of cognition. Understanding inquiry as experiencing, knowing, and doing, he argued, presented a more dynamic perspective of social life. “Because we live in a world in process, the future, while continuous with the past, is not its bare repetition” (Dewey, 1929: 40). As a result of Dewey's work, the classical pragmatism movement reached its pinnacle and was adopted by all branches of philosophy, as well as psychology, education, and politics (Morgan, 2014b).

The Pragmatism philosophical stance falls within the context of this study because it relates to the parts of the research that deal with the conceptualization of floods and interpreting its effects in relation with the research objectives which will lead to reflections and actions. The actions will result in new ways of knowing and acting to forestall the occurrence of floods.



## 3.4 Methodology

### 3.4.1 Research Design

This study sought to assess the effects of flooding on the supply of water from the Jambusie Water Treatment Plant to the Wa Municipality. This, therefore, requires the collection of information on the plant, infrastructure, and water from the workers, hence the study employed a cross-sectional design, which means that data were collected at one point in time from the workers of the Ghana Water Company Limited. This was done while keeping in mind the different types of designs in research, which include experimental, longitudinal, cross-sectional, case study among others. Each would usually be adopted based on the research objectives. It is instructive to note that the study employed a cross-sectional design. Cross-sectional design involves the collection of information from any given sample of population elements only once. They may be either a single cross-sectional or multiple cross-sectional. Betensky et al (2003) indicate that cross-sectional designs have three distinctive characteristics: no time dimension, reliance on existing differences rather than change following intervention; and groups are selected based on existing differences rather than random allocation.

Data collection tools that helped in achieving this were the questionnaire, key informant interviews, documentary analysis obtained from the plant as well as the use of personal observation on the infrastructure, and the colour of the water. The use of chemicals in the water treatment was also considered, especially from the documents of the JWTP with the questionnaire where some questions were arranged in the same order in the close-ended format to enable cross-comparison of responses across respondents. The reason was to generate qualitative data to re-enforce other information collected with other tools.

The study employed the cross-sectional design because data was collected and analyzed at one point in time. The reason was to draw inferences from the plant, water, and cost implications on the infrastructure.

### 3.4.2 Research Approach

Cresswell (2007) indicates the importance of illustrating the research approach as an effective strategy to increase the validity of social research. There are different research approaches. The major approaches as is explicit in literature are quantitative and qualitative. There is however a third research approach known as the mixed approach.

The instrument of a questionnaire that contained both closed-ended and open-ended questions was used to collect quantitative data.

The mixed-method approach is a combination of quantitative and qualitative approaches. As Creswell (2009) explains with the development of and perceived legitimacy of both qualitative and quantitative research in both the social and human sciences, mixed methods research, employing the combination of quantitative and qualitative research approaches has gained popularity. Mixed methods often create an avenue for the researcher to make use of the strengths of both quantitative and qualitative approaches. Considering the merits of using the mixed method approach and also taking into account the research objectives, both quantitative and qualitative approaches were employed.

Quantitative research is based on collecting numerical data (Agyapong & Adam, 2019). In this type of research as explained by these writers, statistical models are constructed to analyze and explain data collected. Some of the tools used for this type of research include a questionnaire.

Qualitative research, on the other hand, is subjective and seeks to describe or interpret whatever is being researched. Instead of numbers, this type of research provides data in the form of words or visual representations. It relies on the researcher to observe, record, and analyze what happens (Agyapong & Adams, 2019).

Also, an interview was conducted with some key persons in the Ghana Water Company Limited to further collect qualitative data. Personal observation was done on the plant and the water infrastructure. Thus, a visit to the plant allowed the researcher to collect data employing picture taking. All these were means of collecting data qualitatively. The reason for employing this research approach was to collect both quantitative and qualitative data to re-enforce the information collected.

### 3.4.3 Sources of Data

As noted by Agyapong and Adams (2015), the sources of data define the roots from which a researcher gathers his or her data. Data are the qualitative and quantitative variables, belonging to a set of items Thus, data was collected from primary and secondary sources using the mixed method of data collection (Creswell, 2009):

### 3.4.4 Primary Source

Primary data was sourced from the staff of GWCL and the management of the Jambusie water treatment plant using questionnaires and interviews.

Primary data has been explained as the data collected from the source first-hand by the researcher. It is data that is originated for the first time by the researcher through direct efforts and experience to address his research problem. It is also known as first-hand or raw data (Agyapong & Adams, 2019). Primary data collection is quite expensive, as the research is conducted by the organization or agency itself, which requires resources like investment and manpower. The data collection is under the direct control and supervision of the investigator. Some of the sources of primary data include: questionnaire, interview, observation, and experiments.

### 3.4.5 Secondary data

Secondary data are data that have been sourced and processed by other persons or researchers and they may be published or unpublished. They can be termed second-hand data since they have been used by others. Secondary data can be sourced from books, theses, journals, and many more. Such data are cheaper and more quickly obtainable than the primary data and also may be available when primary data cannot be obtained at all. Secondary data for this study was obtained from the dairy of Ghana Water Company, and journals.

## 3.5 Sampling

### 3.5.1 Target Population

The first group of respondents in the population was the management of the Jambusie Water Treatment Plant. These individuals formed part of the study population because they were deemed to be people who had adequate knowledge of the subject under study.

The second group of respondents was the workers of the Ghana Water Company who are key stakeholders in the running of the Jambusie Water Treatment Plant.

Target population is an important part of every research as it is based on it that the analysis of the data collected is made. The population of the study could be the people, inanimate objects such as tables and chairs, markets. According to Agyapong and Adam (2019:149), the population is the collection of objects and/or individuals who have uniquely identifiable characteristics. In their view, the population is the universal set which research pertains to and is carried for.

Also, in the view of Mugenda and Mugenda (2003), the target population refers to all conceivable units of analysis with a common characteristic that conforms to a given specification. The writers explain that the target population could be the entire group of individuals, events, or objects possessing peculiar features that fit the inquiry. Hence, the workers of the JWTP was the right target population to help collect the needed information.

### 3.6 Sample and Sampling Techniques

In research, there are two major types of sampling techniques: Probability and non-probability sampling. Non-probability sampling is the type of sampling where the researcher knows the exact possibility of selecting members of the population. Probability sampling, however, is the type of sampling where the chance of being included in the sample is not known. It is a sampling technique in which every unit of the population have equal chance of being selected or where the probability of selection cannot be accurately determined (Showcat & Huma, 2017 cited in Gyelaa, 2019). Unusually, units are selected based on certain non-probability criteria, such as quota or convenience. Since selection is non-random, non-probability sampling does not allow the estimation of sampling errors and may be subjected to a sampling bias. Thus, the researcher determines what he thinks is the representative unit of the group (Twumasi, 2001). Some examples of non-probability sampling techniques include convenience, quota, purposive, and snowball sampling techniques.

Purposive sampling was adopted to select the Management of the Plant (Key informants), and the Staff of GWCL. The justification for the adoption of purposive sampling techniques was that it yields considerable results in realistic/qualitative research where the focal point is on qualitative description rather than quantification and statistics (Grnnel 1993 cited in Gyelaa, 2016).

Also, considering the small nature of the population and the fact that all the sampling units were relevant to the study, the researcher conducted a census instead of using a statistical formula to get the sample size. In the view of Agyemang and Adams, (2019) where the population of a study is less than two hundred (200), it is usually better to conduct a census. The summary of respondents is shown in the Table below.

**Table 3.1 Summary of Respondents for the Survey**

| Category of Respondents | Target Population |
|---|---|
| **Key informants** | 5 |
| **Staff of GWCL** | 40 |
| **TOTAL** | **45** |

*Source:* Authors Construct, 2020

Considering the whole or part of the population to be studied is very important in every scientific study. There are times when it becomes possible to study the entire population in which case the research would be conducting a census. However, contacting every research participant in some cases becomes cumbersome or impractical. In such circumstances, studying a representative or sample of the population using scientific procedures makes the study realistic. The sample of a study can be described as the study population which is a representation of the whole. Agyapong and Adam (2019) view a sample as the subset that represents the population for statistical study, and the findings from the sample are used as the basis for estimating or predicting the characteristics of the population.

Bhattacherjee, (2013 cited in Gyelaa, 2019) noted that sampling is the statistical process of selecting a subset (called a "sample") of a population of interest to make observations and statistical inferences about the population. Social science research is generally about inferring patterns of behaviours within specific populations. Agyapong and Adam (2019) on the other hand explain that sampling is the scientific way of selecting out of the population a representative subset for research work. They posit that scientific sampling should follow certain methods and distribution to ensure that the samples represent the target population as accurately as possible. Sampling is very crucial as it enhances the selection or determination of adequate respondents from the total of the target population and hence, the use of the sampling technique.

### 3.7 Data Collection Instruments

The types of data collection instruments include interviews, questionnaires, observation, and experiments. For this study, questionnaires and personal observation were employed to gather the data.

#### 3.7.1 Questionnaire

Babie (2005) explains that a questionnaire is a document containing a set of questions and other types of items such as statements designed to solicit information on specific issues, themes, problems, or opinions to be investigated. The study adopted both open and closed-ended type of questions to solicit information from the participants. As noted by Agyapong and Adam (2015), questionnaires may contain open or closed-ended questions.

Questionnaires were administered to the workers of Ghana Water Company who manage the Jambusie Water Treatment Plant. The choice of a questionnaire to collect data was informed by the research objectives and the caliber of respondents, and also because, almost all the respondents could read and write, and hence, they could complete the questionnaires without much struggle.

The questionnaire was used to collect quantitative data for the survey.

### 3.7.2 Key informant interviews

An interview can be explained as a face-to-face interaction between the researcher and the respondents, and an informant is someone who possesses knowledge about the social phenomenon the researcher is interested in and is willing to tell the researcher what he or she knows about the phenomenon (Babie, 2005). Specifically, a key informant interview was conducted on the management of the Jambusie Water Treatment System who were deemed to have adequate knowledge of the subject under investigation. Key informant interviews often demand interviewing a select group of individuals who are deemed likely to have rich information, ideas, and insights on a particular subject (Kumar, 1989). In this study, an interview guide was used which covered the topic, and issues on the subject were listed.

### 3.7.3 Documentary analysis

The study collected some documents from JWTP which were included in the analysis process. These included documents on the average annual values for selected climate variables, water quality classification system, water quality index of major rivers in Ghana, and elevation of parameters – Total Suspended Solids (TSS).

As noted by Twumasi (2001) research starts from the known to the unknown. This, therefore, necessitated the reading and consulting of existing documents. Grix (2004:131) asserted that:

> Secondary documentary evidence comes in all shapes and sizes, ranging from official and private documents to personal letters or memos. To some extent, all these engage with specific texts or

documents. The level at which this is done can range from the full-blown and technical discourse analysis to simply reading texts to gain information on a person's or organisation's viewpoint or policy. This type of analysis usually points to specific sources with written documents or texts. You must consider carefully the origins and authors of these documents or texts, the purpose they were originally written for, and the audience they were intended to address.

Document analysis is often used because of the many different ways it supports and strengthens research. This can be used in many different fields of research. It can be used either as a primary method of data collection or as a complement to other methods. Documents can provide supplementary research data, making document analysis a useful and beneficial method for most research. Documents can provide background information and broad coverage of data, and are therefore helpful in contextualizing one's research within its subject or field (Bowen, 2009).

No meaningful study can be undertaken without a prior examination of existing documents germane to the topic under consideration as espoused by Grix (2004).

### 3.7.4 Personal observation

An unclean environment is not difficult to be seen, and so the researcher employed personal observation in the data collection process. Observation means a method of data collection that employs personal experience as its main means of data collection (Sarantakos, 1993). Thus, the researcher visited the plant to have a firsthand look at the environment and plant that is managed at

Jambusie. This was done to help draw a valid conclusion in support of the face-to-face interview.

**3.8 Data Analysis and Presentation**

Data collected in any scientific research will be meaningless if it is not analysed and interpreted to make the results meaningful. In the view of Creswell (2009), data analysis involves collecting open-ended data, based on asking general questions and developing an analysis from the information supplied by participants.

To analyze and present the quantitative information, data was first edited, coded, and categorized to detect errors of incorrect answers as well as missing data. The data was then analysed using the numerical information obtained from the survey. This was effectively achieved using descriptive statistics with the aid of the Statistical Package for Social Sciences (SPSS) version 20.

Also, the qualitative data were analysed by first preparing the data for analysis. The researcher moved deeper and deeper to understand the data, present the data, and make the interpretation of the larger meaning of the data. The data were sorted and analysed based on the various themes, concepts, patterns, and categories as the objectives of the study suggested.

Furthermore, documents obtained from the Company were scrutinized to obtain the needed data. The data were then discussed and presented in support of other data obtained while some pictures that were taken during the observation tour of the JWTP were also presented as a way of emphasizing the rest of the data obtained by the other means.

### 3.9 Reliability and Validity

To achieve this, ten questionnaires were administered to people outside the study population. This was to ensure that the questionnaires were consistent and intended to achieve results when replicated anywhere.

Also, to make the questionnaire relevant, four copies were printed for the researcher's supervisor including three people for their inputs before the final copies were made. This means that the questionnaires were pretested to ensure validity and reliability. This was in line with the views of Kiama (2014) that if the questionnaire can test what it is intended for, it refers to validity, whereas, reliability measures the relevance.

Also, agreeing with the views of Agyapong and Adam (2019) that reliability refers to the "consistency" or "repeatability" of what one measures but validity is the degree to which the measurement process measures the variable it claims to measure in a study.

### 3.10 Ethical Consideration

To win the confidence and trust of respondents, they were made to understand the purpose of the research and the reasons why they are vital to the achievement of the research objectives. Research participants were allowed to voluntarily participate or opt out of the research. They were assured of the confidentiality of any personal information that they may willingly or involuntarily give out. The questionnaire and interview guide were sent to the respondents with a cover letter explaining the aims and objectives of the study. It further assured them of their confidentiality and anonymity (Creswell, 2009 cited in Sanwine, 2020).

The researcher also respected the dignity of the participants by ensuring that their privacy was not invaded during the interview process.

As indicated by Agyapong and Adam (2019), ethics relate to moral choices affecting decisions and standards, and behaviour and as such, it is quite hard to lay down a set of clear rules, which cover all possible moral choices, especially in research, where the practical aspects of the study such as, how and when to meet people for interview, how to deal with some respondents changing their mind about being part of the study and many more.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter presents the data gathered from the field. Only key issues emerging from the results are discussed. The results and discussions are presented under sub-sections based on the objectives of the study. These sections include demographic characteristics of respondents the effects of flooding on infrastructure at the Jambusie water treatment supply facility, effects of flooding on water treatment, cost implications for water treatment, and the facility during the flooding, activities that affect water treatment during the flooding and summary of the chapter.

## 4.2 Demographic Characteristics of Respondents

Table 4.1 shows the demographic characteristics of the respondents. Classification of the participants by sex showed that out of the total number of 45 respondents, the majority, 40 (88.9%) were males and 5 were (11.1%) females. Kanter and Pfeffer (1983) noted that an organization's demographic composition can affect communication because employees tend to communicate with familiar people. Considering the composition of respondents of the Ghana Water Company Limited (GWCL) in Wa, this issue might not be different. The male dominance could be attributed to the Company being more technically oriented and perhaps, females, in general, do not want to venture into technical jobs as the case may be in Ghana.

The results also showed that a good number of the senior staff 18 (40.0%) were within the age group of 31-40 years while those under 30 years were 17 (37.8%).

The results further revealed that 5 (11.1%) were within the age group of 41-50 years. The statistics presented above imply that the future of GWCL in terms of human capital is brighter since the majority of the employees who were captured by this survey still have many years to work. It can also be inferred that the work output will be greater holding all factors constant. The results further showed that only a few of the staff 4 (8.9%) and 1 (2.2%) were within the age group of 51-60 years and 60 and above, i.e., 60+. Table 4.1 shows detailed information on the above submission.



**Table 4.1: Demographic characteristics of respondents**

| Variables | Characteristics | Staff N=45, %(100) | |
|---|---|---|---|
| | | Frequency | Percentage |
| Gender | Male | 40 | 88.9 |
| | Female | 5 | 11.1 |
| Age | Under 30 | 17 | 37.8 |
| | 31-40 | 18 | 40.0 |
| | 41-50 | 5 | 11.1 |
| | 51-60 | 4 | 8.9 |
| | 60+ | 1 | 2.2 |
| Education Level | Technical/Vocational | 3 | 6.7 |
| | Certificate | 16 | 35.6 |
| | Diploma | 4 | 8.9 |
| | Bachelors | 14 | 31.1 |
| | Masters | 8 | 17.8 |
| Years of Engagement | <1year | 4 | 8.9 |
| | 1-5years | 20 | 44.4 |
| | 6-10years | 5 | 11.1 |
| | 10+ years | 16 | 35.6 |

*Source:* Field Survey, 2020

The classification of respondents based on their educational levels revealed that a good number of the Company's staff 16 (35.6%) were Certificate holders while 31.1% were First Degree holders. Also, 8 (17.8%) of the staff were Master's Degree holders with 4 (8.9%) being Diploma holders.

The study also investigated the accumulated level of experience of respondents and the findings showed that only 4 (8.9%) of the respondents had served less than a year in the Company. A sizeable number of them 20 (44.4%) had worked in the Company for the past 1-5years, and 16 (35.6%) had worked for 10 years and above. It can be deduced from the findings that the experience gained by the study participants is enough to propel the growth and development of the Company. Besides, their levels of experience are enough for the respondents to understand the subject under investigation. Thus, every response given by them can be described as meaningful and can adequately answer the research questions.



### 4.3 Effects of Flooding on Water Treatment Infrastructure at Jambusie

#### 4.3.1 Water resources information on Northern Ghana

Secondary analysis revealed that the Water Resource Commission (WRC) has been monitoring the quality of surface waters in Ghana since 2005 and the main objective of the Commission is to collect and analyze water quality data to determine the state of water quality, pollution, and trends. The monitoring programme covers forty-one stations which include thirty-two river stations and nine reservoir/lakes stations and this does not exclude the Jambusie Station.

The breakdown of monitoring of the stations is as follows:

- ❖ South-western System - 19 stations
- ❖ Coastal System - 8 stations
- ❖ Volta System - 14 stations

The report of the Commission on the Jambusie Plant revealed some anthropogenic activities that affect the water quality at the Plant. This includes:

a) *Riverbank crop farming;*

b) *Illegal mining;*

c) *Waste disposal;*

d) *Fishing and sand winning; and*

e) *Deforestation and river bank degradation.*

This finding goes to confirm the primary data collected from the staff of Ghana Water Company Limited and Jambusie Plant on the activities that affect the quality of the raw water at the facility.

Chapman (2006) reveals that water quality is an important part of environmental monitoring because water plays a vital role in many aspects of the ecosystem. The quality of surface water refers to the measure of its chemical, physical, and biological characteristics, relative to the requirements of one or more living species and or to any human need or purpose. Assessments were carried out on the physico-chemical water quality parameters which include; temperature, pH, conductivity, total suspended solids, transparency, nutrients, and major ions.

The water quality index (WQI) is used to assess water quality relative to the standard for domestic use and to provide insight into the degree to which water quality is affected by human activity. The Table below shows average annual values for selection climate variables in northern Ghana.

**Table 4.2: Average annual values for selection climate variables in northern Ghana**

| Station | Navrongo | Wa | Tamale | Yendi | Bole | Kete-Krachi |
|---|---|---|---|---|---|---|
| **Region** | Upper East | Upper West | Northern | Northern | Northern | Volta |
| **Rainfall (mm/y)** | 987 | **1007** | 1083 | 1192 | 1069 | 1346 |
| **Potential evap. (mm/y)** | 1723 | **1770** | 1839 | 1710 | 1541 | 1606 |
| **Avg. temp. (°C)** | 28.9 | **27.9** | 28.3 | 27.9 | 29.1 | 27.8 |
| **Min. tem. (°C)** | 19.3 | **19.5** | 18.7 | 19.2 | 16.6 | 20.7 |
| **Max. temp. (°C)** | 39.3 | **37.4** | 38.2 | 37.7 | 36.6 | 35.8 |
| **Min. relative humidity (%)** | 40.3 | **44.0** | 44.6 | 46.7 | 50.1 | 54.9 |
| **Max. relative humidity (%)** | 68.8 | **71.8** | 75.9 | 78.0 | 83.9 | 88.9 |
| **Sun hours (h)** | 7.8 | **7.6** | 7.3 | 7.2 | 7.0 | 7.0 |
| **Wind speed (m/s)** | 0.91 | **1.25** | 1.57 | 1.26 | 0.84 | 1.10° |

*Source:* Data from MSD, 2006

(Note; since 2020 Bole is now in the Savannah Region whilst Kate Krachi is now in the newly created Northen Volta Region)

**Table 4.3: Water quality classification system**

| Class | Range | Description |
|---|---|---|
| **I** | > 80 | Good – Unpolluted |
| **II** | 50 – 80 | Fairly Good |
| **III** | 25 – 50 | Poor Quality |
| **IV** | < 25 | Grossly Polluted |

*Source:* Data from MSD, 2006

**Table 4.4: Water quality index of major rivers in Ghana from 2010 to 2016**

| Sampling sites/year | 2005 | 2006 | 2007 | 2008 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bamboi - Black Volta** | | | | | 68.5 | 64.4 | 54.8 | 53.2 | 45.2 | 53.71 | 62.41 |
| **Buipe - Black Volta** | | | | | 63.8 | 67.4 | 50.4 | 51.7 | 52.2 | 59.85 | 68.28 |
| **Lawra - Black Volta** | | | | | | | | 45.6 | 44.5 | 58.91 | 52.93 |

*Source:* Data from MSD, 2006

*The coloured boxes depict sampling stations with decreasing WQI in 2016 as compared to that of 2015*

Table 4.4 reveals that there is a notable improvement in water quality within the Basin at Bamboi and Buipe from 2010 to 2016, both downstream of Jambusie. This may be attributed to less anthropogenic activities along with those areas whereas the Lawra part of the Basin which is upstream of Jambusie shows some rate of degradation in water quality.

In 2015 and 2016, the sampling station at Lawra had a water quality index of 58.91% and 52.93% respectively. These are below the previous years which show a deterioration of water quality, generally across that part of the Basin as depicted in Table 4.4 in pink colour; that area mostly responds to the class III (poor quality) as captured in Table 4.3 above. This means that the continued and unregulated activities of small-scale mining popularly known as "*galamsey*" is almost entirely responsible for the apparent deterioration of the Black Volta around that stretch, which is further carried into the JWTP thereby affecting the water quality.

This is evidenced by the elevation of parameters such as Total Suspended Solids (TSS) in River for February and July 2018 as shown in the table below.

**Table 4.5: Elevation of parameters - Total Suspended Solids (TSS) in River for February and July 2018**

| | | | | WRC WQ MONITORING RESULTS - FEBRUARY 2018 | | | | | | | | | | WRC WQ MONITORING RESULTS - FEBRUARY 2018 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Feb. 2018** | **$H_2O$** | | **Cond** | **TSS** | **BOD** | **$NO_2^-$-N** | **$NO_3^-$-N** | **$NH_3^-$-N** | **$PO_4^-$-P** | **DO** | **Turbidity** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$Na^+$** | **$K^+$** | **$Cl^-$** | **$SO_4^{2-}$** | **$SiO_2$** | **$F^-$** | **Hardness** | **Alkalinity** | **$HCO_3$** | **$CO_3$** | **TDS** | **Fe** | **Mn** |
| **Sample** | **Temp °C** | **pH** | **µS/cm** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **NTU** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l $CaCO_3$** | **mg/l $CaCO_3$** | **mg/l $CaCO_3$** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lawra - Black Volta | 29.9 | 7.9 | 169 | 11.0 | 2.60 | 0.079 | 0.083 | 0.422 | 0.267 | 7.80 | 18.0 | 6.41 | 9.71 | 5.20 | 3.50 | 12.9 | 9.20 | 15.0 | <0.005 | 56.0 | 50.4 | 61.5 | 0.00 | 110.0 | 0.287 | 0.016 |
| Bamboi - Black Volta | 27.1 | 7.56 | 76.0 | 1.00 | 2.95 | 0.134 | 0.196 | 0.403 | 0.070 | 8.00 | 2.00 | 5.61 | 2.03 | 4.10 | 3.20 | 2.98 | 2.10 | 11.1 | <0.005 | 22.4 | 26.6 | 32.5 | 0.00 | 49.4 | 0.661 | 0.129 |
| Buipe - Black Volta | 29.6 | 7.47 | 74.0 | 3.00 | 3.98 | 0.001 | 0.085 | 0.436 | 0.008 | 8.13 | 13.0 | 3.21 | 2.52 | 4.10 | 3.30 | 2.00 | 2.82 | 15.1 | <0.005 | 18.4 | 25.6 | 31.2 | 0.00 | 48.1 | 0.348 | 0.032 |
| **July. 2018** | **$H_2O$** | | **Cond** | **TSS** | **BOD** | **$NO_2^-$-N** | **$NO_3^-$-N** | **$NH_3^-$-N** | **$PO_4^-$-P** | **DO** | **Turbidity** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$Na^+$** | **$K^+$** | **$Cl^-$** | **$SO_4^{2-}$** | **$SiO_2$** | **$F^-$** | **Hardness** | **Alkalinity** | **$HCO_3$** | **$CO_3$** | **TDS** | **Fe** | **Mn** |
| **Sample** | **Temp °C** | **pH** | **µS/cm** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **NTU** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l $CaCO_3$** | **mg/l $CaCO_3$** | **mg/l $CaCO_3$** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| Lawra - Black Volta | 32.4 | 6.95 | 54.0 | 656 | 3.80 | 0.128 | 0.224 | 0.267 | 0.556 | 6.92 | 726 | 0.98 | 1.55 | 4.40 | 2.89 | 3.47 | 3.31 | 13.4 | <0.005 | 8.80 | 11.6 | 14.2 | 0.00 | 35.1 | 0.212 | 0.008 |
| Bamboi - Black Volta | 27.4 | 7.42 | 70.2 | 1.00 | 4.60 | 0.086 | 0.142 | 0.366 | 0,081 | 9.10 | 1.00 | 3.21 | 2.52 | 5.00 | 2.90 | 3.97 | 2.61 | 9.9 | <0.005 | 18.4 | 22.0 | 26.8 | 0.00 | 45.6 | 0.438 | 0.006 |
| Buipe - Black Volta | 28.2 | 7.17 | 87.0 | 55.0 | 3.58 | 0.023 | 0.112 | 0.454 | 0.105 | 7.92 | 60.0 | 4.32 | 2.09 | 5.00 | 3.60 | 2.28 | 2.48 | 12.3 | <0.005 | 19.4 | 28.0 | 34.2 | 0.00 | 56.6 | 0.530 | <0.005 |

*Source*: MSD, 2006

#### 4.3.2 Documentary analysis

Also, a review of a report on Ghana Water Company Limited, Jambusie Water Treatment Plant by Joy News (2019) revealed that the shortage of water in the Wa Municipality during the flooding is mostly due to an overflow of water during downpours. Observation made by a team from the Black Volta Basin Office during a visit to the Jambusie Water Treatment Plant on September 9, 2019, revealed that the stretch of the Black Volta River had overflown its banks, causing havoc to its riparian zone including the Jambusie Water Treatment Plant.

The field visit by the Water Resource Commission (WRC) also revealed that the River had overflown its banks and flooded its catchment areas. Consequently, the WRC team met with the Manager of the Jambusie Water Treatment Plant to ascertain the situation. Explaining to the team, the Manager of JWTP indicated that one of the pump stations was flooded because of a heavy downpour which resulted in the inability of the Plant to supply water to the Wa Municipality. On the contrary, the WRC team noticed that the cause of the flooding could not be blamed solely on the overflow from the Black Volta River but also on heavy downpours and the improper design of the Plant's drainage system. This finding confirms a similar concern raised by respondents as an issue that contributes to the flooding of the facility.

The Station Manager further mentioned the low elevation of the pump station as a factor that contributes to flooding of the area. He indicated that heavy downpours usually cause the drainage system near the pump station to get full and overflow into the pump station thereby causing it to be flooded. He said the flood height at the Plant could reach as high as 6.8 feet.

The Station Manager indicated that the damage caused by the flooding of the pump station is always enormous as the pumps and other electrical installations often get submerged. As a stopgap measure, he said the pumps and electrical installations are usually turned off to prevent damage. The Station Manager thus outlined some measures for consideration and implementation to forestall a future reoccurrence of the problem. The measures include:

- diversion of the water channels to the plant catchment area;
- reconstruction of some of the drains within the premises of the plant for easy flow of water during heavy downpours; and
- the building of a concrete wall around the flooded pump station to prevent water from flowing into the pump station.

He, however, indicated that a temporary measure was put in place thus, placing sandbags at strategic locations to prevent water from flowing into the pump station. The Figure below shows water around the catchment area of the Plant. This picture was captured by Joy news during their visit to the Plant on September 5, 2019.

**Plate 4.1: Floodwater around the Plant**
*Source*: Joy News, 2019

### 4.3.3 Effects of the flooding on the treatment plant

The respondents were asked whether rainfall over the years has had some effects on the water treatment plant at Jambusie. This question was posed to put the study into perspective. Consequently, options were given for the respondents which were "Yes", "No", and "Not Sure" as shown in Figure 4.1. The results revealed that out of 25 respondents, the majority of 19 (76%) indicated "Yes", 1 (4%) said "No" whilst 5 (20%) said they were not sure. This means that majority of the respondents agreed that rainfall has had effects on the water treatment plant over the years. The data therefore suggest that rainfall has had negative consequences on the water treatment plant. Some of the effects respondents identified included damage to some components of the plant and sometimes, a complete breakdown of the facility due to the floods. This damage came with their financial implications on the Company.

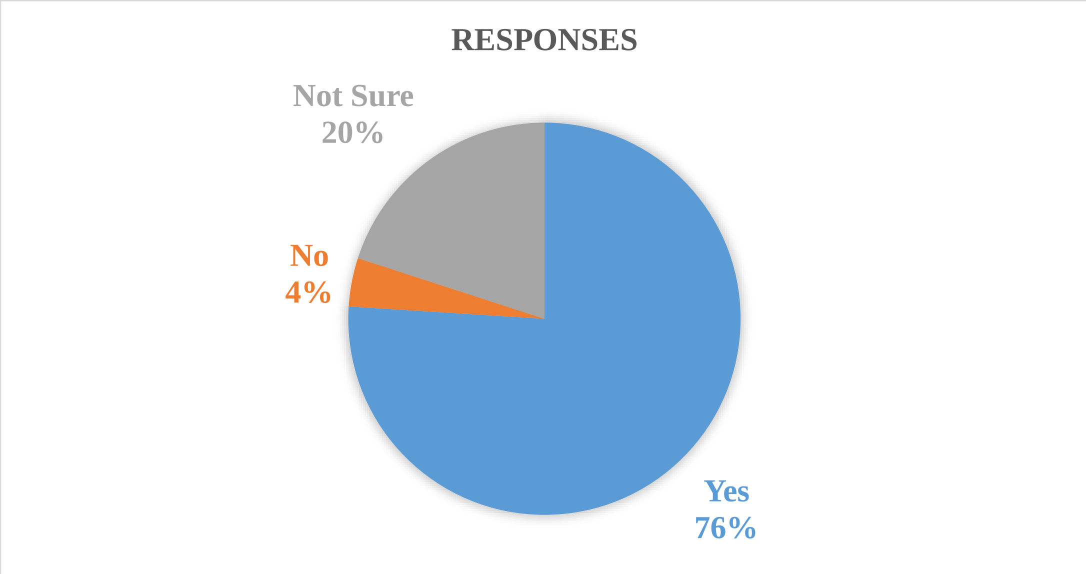



**Figure 4.1: Effects of flooding on the water infrastructure**
*Source*: Field Data, 2020

A key informant had this to say regarding the effect of flooding on the plant:

> *The effects of the rainfall on the water treatment infrastructure at Jambusie are of great concern, especially during the flooding. Some of these concerns range from the breaking down of the water treatment plant to the high cost of energy used in treating the raw water due to poor quality of the water parameters such as high turbidity level, poor colour, low pH value, high alkalinity level and the inaccessibility of the route to the pumping facility as a result of the floods, run-off water, and erosion around the intake facility. These and many other issues have negative consequences on the water treatment plant. This means that it could take consumers days to get wholesome water from the Company as long as the facility is inundated with these challenges*, September 2020.

In another breath, a key informant remarked on the damages caused by the rains to the pumps and other installations:

> *Rainfall sometimes causes damage to the pumps and other installations. This often necessitates a shutdown of the plant for days to fix damaged pumps, thereby, making it impossible for consumers to have access to water from Ghana Water Company Limited. The rainfall also causes accumulation of sediments in the low-lift pumps and water stagnation at the high-lift pump house which sometimes results in damage to the facility.* September 2020.

**Plate 4.2: Rainwater just at the verge of the facility**
*Sources*: Field Survey, 2019

### 4.3.4 Factors affecting the water treatment facility

Table 4.6 shows the ranking of factors affecting the water treatment facility in order of priority. The analysis started with the quantitative data and thereafter, corroborated with the qualitative data. The data was analysed and presented with a 4-point Likert scale-like form e.g. 1st, 2nd, 3rd, and 4th with assigned values of 4, 3, 2, and 1 respectively. The accumulated frequencies were multiplied by the assigned values and added to get the total weight for each of the factors. Comparatively, the findings revealed that flooding recorded a total weight of 165 and was ranked number one while soil erosion has a total weight of 159 and was also ranked the second factor. Also, the third-ranked factor was surface run-off per the total weight accumulation of 113. Finally, inaccessible roads accumulated total weight of 89 and were ranked fourth. Despite the ranking positions of the factors, the data showed that all these factors were challenges affecting the Jambusie Water Treatment Facility and must be given the needed attention.

**Table 4.6: Factors affecting the water treatment facility at Jambusie**

| Factors | 1st | Freq. | 2nd | Freq. | 3rd | Freq. | 4th | Freq. | Total Weighted Point | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| **Flooding** | 112 | 52.8 | 36 | 21.1 | 12 | 12.2 | 5 | 11.1 | 165 | 1 |
| **Soil Erosion** | 60 | 28.3 | 63 | 36.8 | 26 | 26.5 | 10 | 22.2 | 159 | 2 |
| **Surface Run-off Water** | 24 | 11.3 | 45 | 26.3 | 32 | 32.7 | 12 | 26.7 | 113 | 3 |
| **Inaccessible Roads** | 16 | 7.5 | 27 | 15.8 | 28 | 28.6 | 18 | 40 | 89 | 4 |

*Source:* Field Survey, 2020

The qualitative finding from a key informant corroborates with the quantitative data in the table above:

*Agrochemicals from nearby farmers, illegal mining, and faecal matter from human and animal excreta are normally washed into the watercourse, causing the raw water quality to deteriorate, September 2020.*

The plate below shows how the station is normally flooded during a heavy downpour. The plate depicts a typical situation at the work station any time there are heavy downpours and, in some instances, the pumping station is shut down.

**Plate 4.3: Water on some parts of the facility**
*Sources*: Field Survey, 2019

### 4.3.5 The length of time water stays around the treatment plant

The study sought respondents' views on the effects of water that gathers around the facility anytime there is a heavy downpour. Figure 4.2 contains the views of the respondents. From Figure, 7 (11.1%) of the respondents indicated that water can stay for about three 3weeks anytime there is heavy rainfall. The majority 24 (53.3%) of the respondents also indicated that the water can stay at the treatment facility for a week. It can be inferred from the results that even though rainfall is the source of raw water for the treatment at Jambusie, it can have a devastating effect on water treatment especially anytime it renders the area unsafe for the workers to work.

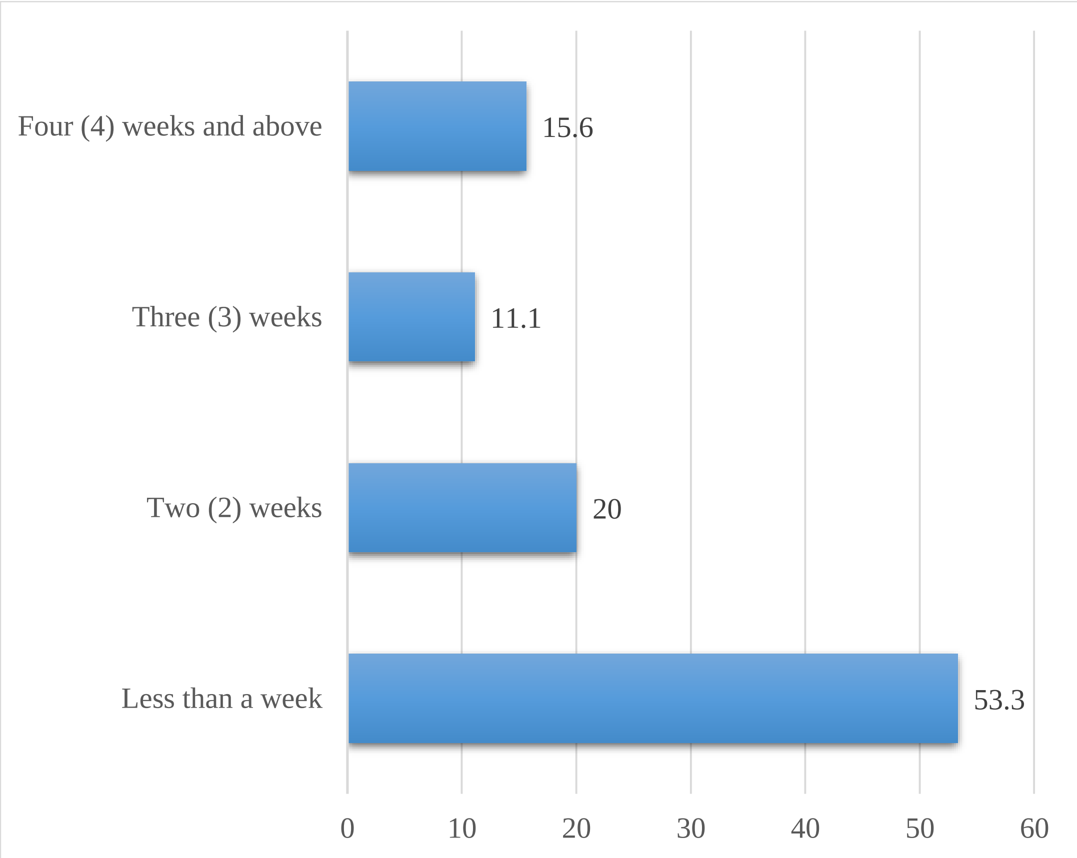



**Figure 4.2: Length of time water can stay around the treatment facility**
*Source:* Field Survey, 2020

### 4.4 Effects of Flooding on Water Treatment

Apart from the water flooding the facility and creating inconvenience to workers and affecting the treatment plant, there are other factors or properties of the flooding which hampers water production as captured below.

#### 4.4.1 Physico-chemical properties of the river water during the flooding

Figure 4.3 shows that many physico-chemical properties are found in the river water at the Jambusie Treatment Plant and these contaminants increase in quantity and extent when the flooding sets in. Hence, the findings revealed that these physico-chemical properties have negative consequences on the water. For instance, the water colour, turbidity level, and pH value among others are adversely affected during the flooding. Some of the views of the respondents are captured in Figure 4.3. From the Figure, 25 (26.9%) of the respondents indicated that the water colour increases as it becomes dirtier as the rainfall increases. 24 (25.8%) of the respondents also indicated that the turbidity of the water increases during the flooding and the nitrate pollution of the water increases because of the waste, which is usually transported by the surface run-off. Further, 21 (22.6%) of the respondents indicated that the alkalinity level of the water increases during the flooding. The results suggest that all the physico-chemical properties present in the water worsen during the flooding. The data also indicate that the concentration level of these properties increases as a result of the floods, erosion, and run-off water caused by rainfall. When this happens, pollution occurs due to the chemicals, substances, and particles that get carried along into the water bodies. This finding is similar to that of Florida LakeWatch (2017) that indicated that the colour of the water may change as the result of the presence of inorganic materials such as clay particles, debris, dead plants, and algae from storm-water, runoff, or shoreline erosion.

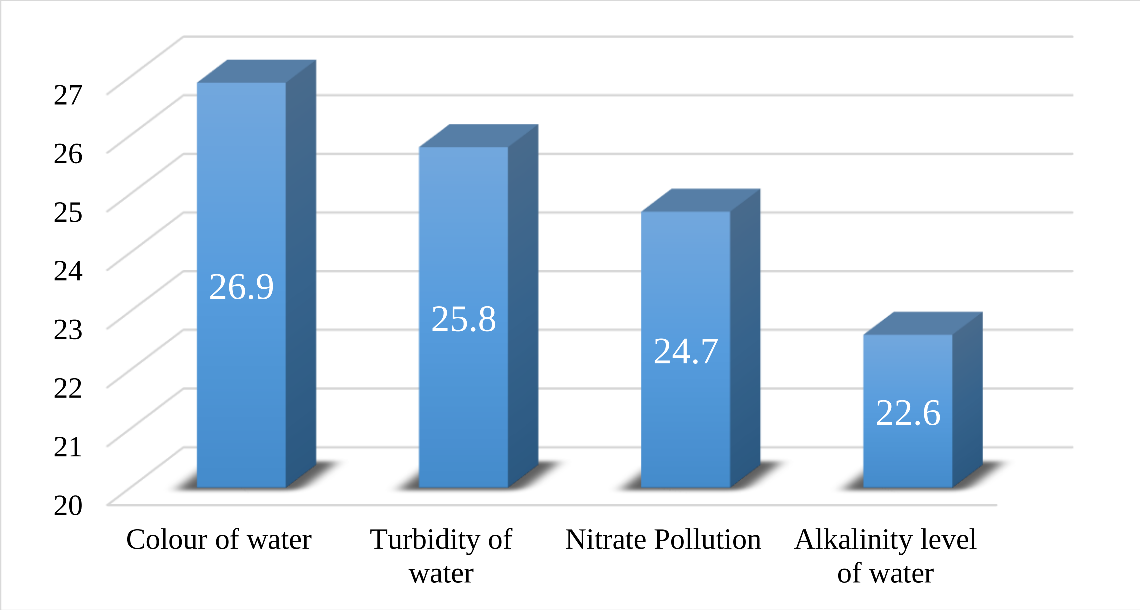



**Figure 4.3: Physico-chemical properties in the river water at the Jambusie Treatment Plant during the flooding**
*Source:* Field Survey, 2020

A key informant recounted that in support of the above findings:

> *Traces or residuals of chemicals used in farming, mining, and fishing are deposited into the water, resulting in deterioration of water quality parameters such as water colour, turbidity, pH value, alkalinity, nitrate pollution, and the presence of some of these substances or particle deposits [usually]lead to algae formation on the water surface* (September 2020).

As indicated above, about 26.6% of the respondents felt that the colour of the water changes due to pollution, and 25.8% said the turbidity of the river water is excessively high because of the deposits in the water, especially during the flooding. This means that more resources are needed to treat the river water before it can be consumed. This will increase the cost of treatment of the water, and the consequences on the plant could be disastrous. Thus, it means regular maintenance of the plant.

### 4.4.2 Physico-chemical properties in the river water at Jambusie Treatment Plant before and during the flooding

In the view of Braun and Smirnov (1993), water has an intrinsic colour, and that this colour has a unique origin. This intrinsic colour is easy to see. Coloured water denotes pollution with the associated adverse effect on human health and the aquatic environment and organisms. Water colour may provide evidence that there is some form of contamination. For example, from Table 4.7 out of the 45 respondents, 5 (13.3%) of them indicated that before the flooding the raw water colour becomes greenish due to the presence of algae. Comparing this to the flooding and out of 45 respondents, 7 (15.6%) of them mentioned that the flooding comes with highly coloured water due to surface run-off whilst 25 (53.3%) of the respondents indicated that the colour becomes brownish during the rainfalls and flooding.

This data suggests that there are variations in the water colour during the dry season and rainy seasons or during floods. This finding corroborates with that of indicates that heavy rain events are known to wash organic substances into the water where they dissolve and act as a dye; seasonal algae blooms resulting in such high concentrations of algae where the water becomes tinted with the coloration of the algal cells; or wind events may stir up fine particles off the bottom, re-suspending them into the water column. This, therefore, affects the physico-chemical properties of the raw water such as the colour.

As can be seen from Table 4.4, 20 respondents, representing 40% indicated that before the rains, the Nephelometric Turbidity Unit can range from 40NTU - 120NTU, whilst 26 (57.8%) of the respondents mentioned that the Nephelometric Turbidity Unit can range from 121NTU - 1000NTU during the flooding. As noted by Pendergrass, Knutti, Lehner (2017), some parts of the world are expected to experience an increase in the frequency and intensity of precipitation and will find it increasingly difficult to limit the impact of storms such as flooding or heavy run-off. Also, Khan, Deere, Leusch, et al (2015) indicate events such as flooding and heavy surface run-off are associated with elevated turbidity and dissolved organic matter in water sources. The table below shows more details.

**Table 4.7: Nature of the Physico-chemical properties of raw water at the Jambusie Treatment Plant before and during the flooding**

| **Variables** | ***Characteristics*** | **Before (%) N=45** | | **During (%) N=45** | |
|---|---|---|---|---|---|
| | | *F* | *%* | *F* | *%* |
| **Colour of raw water** | Greenish | 5 | 13.3 | 7 | 15.6 |
| | Brownish | 14 | 31.1 | 24 | 53.3 |
| | Yellowish | 12 | 26.7 | 6 | 13.3 |
| | Blue-wish | 8 | 17.8 | 3 | 6.7 |
| | I don't know | 6 | 11.1 | 5 | 11.1 |
| **Nephelometric Turbidity Unit** | 40NTU - 120NTU | 20 | 44.4 | 8 | 17.8 |
| | 121NTU - 1000NTU | 6 | 13.3 | 26 | 57.8 |
| | 130NTU - 200NTU | 11 | 24.4 | 6 | 13.3 |
| | I don't know | 8 | 17.8 | 5 | 11.1 |

*Source:* Field Survey, 2020

### 4.4.3 Persistence change of alkalinity level during the flooding

This is what a key informant had to say about the alkalinity level in the Jambusie Water Treatment Plant:

*The persistent change of the alkalinity during the flooding many at times depends on the extent of the flooding. On average, it could last for 4 weeks depending on whether there is runoff, erosion, or flooding*, October 2020.

This means that if the alkalinity in the river water persists, more treatment agents are needed to remove the alkaline to make the water wholesome for use. This can also cause corroding of some components of the treatment plant if it stays in the plant for a longer period. However, this is what the Illinois Department of Public Health (n.d.) has to say about High alkalinity (above 500 mg/l). High alkalinity is usually associated with high pH values, hardness and high dissolved solids and has adverse effects on plumbing systems, especially on hot water systems (water heaters, boilers, heat exchangers, etc.) where excessive scale reduces the transfer of heat to the water, thereby resulting in greater power consumption and increased costs.

A minimum level of alkalinity is therefore desirable because it is considered a “buffer” that prevents large variations in pH. The results revealed that during the flooding, the concentration level of the alkaline increases due to floods carrying toxic substances into the water. The results also indicated that alkalinity in the water could persist for four weeks or more depending on the period of the rainy season.

## 4.5 Cost Implication of Flooding on Water Treatment and the Plant.

### 4.5.1 Cost Variations in Water Treatment

The survey sought the views of the research participants on the cost implications of the flooding on water treatment. From Table 4.8, out of 45 respondents, the majority 35 (77.8%) of them mentioned that the cost of treating water during the floods increases, while 10 (22.2%) of them answered in the negative. Their reason given was that the cost of treating the water could vary depending on the season. The respondents believed that the cost could be high either in the rainy season or dry season. They cited the dry season as an example where the water becomes murkier and would need more chemicals to treat for use. It can however be inferred from the majority view that rainfalls that result in flooding can impact negatively on the cost of treatment.

This stems from the fact that the level of pollution increases, which warrants the use of more chemicals and materials to purify the water for domestic and other uses. The situation also demands the use of more energy in the pumping and processing of raw water. For example, this could account for about 55% – 90% of the total load depending on the details of the hydraulic system and treatment process as noted by Electric Power Research Institute [EPRI] and Water Research Foundation [WRF] (2013).

The finding is similar to that of the Electric Power Research Institute [EPRI] and Water Research Foundation [WRF] (2013), which states that water treatment processes vary, but pumping accounts for most of the electricity used in the water treatment systems.

**Table 4.8: Cost Implication of flooding on Water Treatment and the Facility**

| Increase cost in treating water during the rainy season | Frequency (f) | Percentage (%) |
|---|---|---|
| **Yes** | 35 | 77.8 |
| **No** | 10 | 22.2 |
| **Cost Variations in water treatment** | **Frequency (f)** | **Percentage (%)** |
| **Raw water quality decreases** | 9 | 20.0 |
| **Additional use of chemical** | 7 | 15.6 |
| **High turbidity** | 13 | 28.9 |
| **Pollution of water** | 6 | 13.3 |
| **Surface run-off water into the water** | 5 | 11.1 |
| **Bad farming practices near the facility** | 3 | 6.7 |
| **Colour variation** | 2 | 4.4 |

*Source*: Field Survey, 2020

Table 4.8 shows what accounts for the cost variations in the treatment of water and the facility. The analysis revealed a number of things that accounted for the cost variation in the water treatment plant. 28.9% of the respondents indicated that high turbidity level causes variations, 20.0% of the respondents mentioned flooding, 15.6% noted that pollution from other sources can cause variation and 6.7% indicated that farming practices account for cost variation in water treatment. For instance, the wrong use of agrochemicals could cause the chemicals to be washed into the water by runoff and erosion. This data suggests that more chemicals would be used to treat the raw water to remove the substances, impurities, and particles and make it wholesome for human consumption and other uses.

It also implies that more funds would be needed during the rainy season to treat water as compared to the off-seasons. As noted by Bastaraud, et al. (2020), modeling showed significantly different lags among indicators of bacteria occurrence after cumulative rainfall, which ranges from 4 to 8 weeks. Among the effects of low-income urbanization, a rapid demographic transition and the degradation of urban watersheds have gradually affected the quality of the water supplied and resulted in the more direct effects of rainfall events and the cost.

This is what a key informant had to say regarding the cost variation in the treatment of water:

*The cost of treating water is dependent on the seasons. For example, during the rainy season, a flood normally carries debris and other substances into the water which may warrant the use of more chemicals,* September 2020.

As observed by Jachimowski (2017), seasonal variations in drinking water system performance were potentially due to rapid changes in raw water quality as a result of precipitation (e.g. increased storm water flows and discharges, soil erosion, sporadic high turbidity) and an increased microbial load entering drinking water distribution. This is supported by the findings of Anand, John and Lienhard (2012) which state that water quality is a major reason of variation in treatment costs, and also by the results of Dearmont et al. (1998) which revealed that approximately every 1% increase in turbidity increases the chemical cost by 0.27%.

Also, regarding the cost variation of water treatment, another key informant had this to say:

> *Many a time, the rainy season comes with flooding, erosion, and runoff water that wash chemicals, and carry debris, and other substances into the water, thereby, increasing the parameters of the raw water. This causes the use of more chemicals to treat the raw water and some of these chemicals are imported from other countries. Also, the cost of energy increases due to the rampant or continuous backwashing of the filters and dislodging of excess water of the facility,* September 2020.

**5.2.2 Raw water average parameters and cost of chemical consumption at Jambusie Head works**

This section of the study presents the data in two folds using a table and a line chat. Table 4.9 depicts the general outlook of chemical usage and dosage including cost whilst Figure 4.4 shows the trend of chemical consumption and the associated cost per rainy season for four years.

Table 4.9 shows the average parameters and cost of chemical by the Jambusie Water Treatment Facility for the year ended in 2017. The consumption spans from January to December 2017. The highest consumption levels were recorded for June and July and with the lowest being recorded for December 2017. As evidenced from Table 4.6, the cost of water treatment increased for about five months in 2017, that is, from May to September, which can be considered as the peak period for rains in the Upper West Region where the study was conducted. However, the cost was that high as compared with the 2018, 2019, and 2020 cost of consumption of the chemicals. What could have accounted for this would have been because the facility had just started operations in that year and might not have been in its full operation capacity. Results from this quantitative data corroborated the qualitative responses from the study participants.

**Table 4.9: Raw Water Average Parameters and Cost of Chemical Consumption in 2017**

| DATE/MONTH | pH | COLOUR/HU | TURBIDITY/NTU | DOSAGE PART PER MILLION | | | COST/GHS/1000M$^3$ | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Alum* | *Lime* | *Chlorine* | *Alum* | *Lime* | *Chlorine* | |
| **April** | 6.7 | 380 | 279.3 | 55 | 30 | 2.5 | 96.8 | 48.3 | 24.8 | **169.9** |
| **May** | 6.6 | 860 | 648.2 | 95 | 30 | 2.5 | 167.2 | 48.3 | 24.8 | **240.3** |
| **June** | 6.4 | 904 | 776.4 | 110 | 45 | 5 | 193.6 | 72.5 | 49.6 | **315.7** |
| **July** | 6.4 | 963 | 779 | 110 | 45 | 5 | 193.6 | 72.5 | 49.6 | **315.7** |
| **August** | 6.5 | 790 | 436.2 | 90 | 45 | 5 | 158.4 | 72.5 | 49.6 | **280.5** |
| **September** | 6.7 | 430 | 216 | 55 | 30 | 2.5 | 96.8 | 48.3 | 24.8 | **169.9** |
| **October** | 6.8 | 415 | 189 | 38 | 30 | 2.5 | 66.9 | 48.3 | 24.8 | **140** |
| **November** | 7 | 217 | 72.1 | 25 | 30 | 2.5 | 44 | 48.3 | 24.8 | **117.1** |
| **December** | 7.2 | 127 | 34 | 20 | 30 | 2.5 | 35.2 | 48.3 | 24.8 | **108.3** |

*Source*: Jambusie Water Treatment Headwork, 2020

Figure 4.4 reveals the cost of chemicals used in the treatment of the water at the facility. These chemicals include chlorine, lime, and alum. Even though the chemicals used during the rainy season were more as compared to off-season, the most used chemical was alum. This is an indication that the rainfalls lead to high water pollution which triggers the use of more of this chemical for the treatment of the water. The Figure below shows the months and usage of the chemicals spanning from May to September covering 2017, 2018, 2019, and 2020. This period is normally the peak of the rainy season in the Upper West Region. As indicated in Figure 4.4, the usage of the chemicals in 2018, 2019, and 2020 was much higher than in 2017. The findings revealed that the facility started working in April 2017 and perhaps this could have brought about the low usage of chemicals.

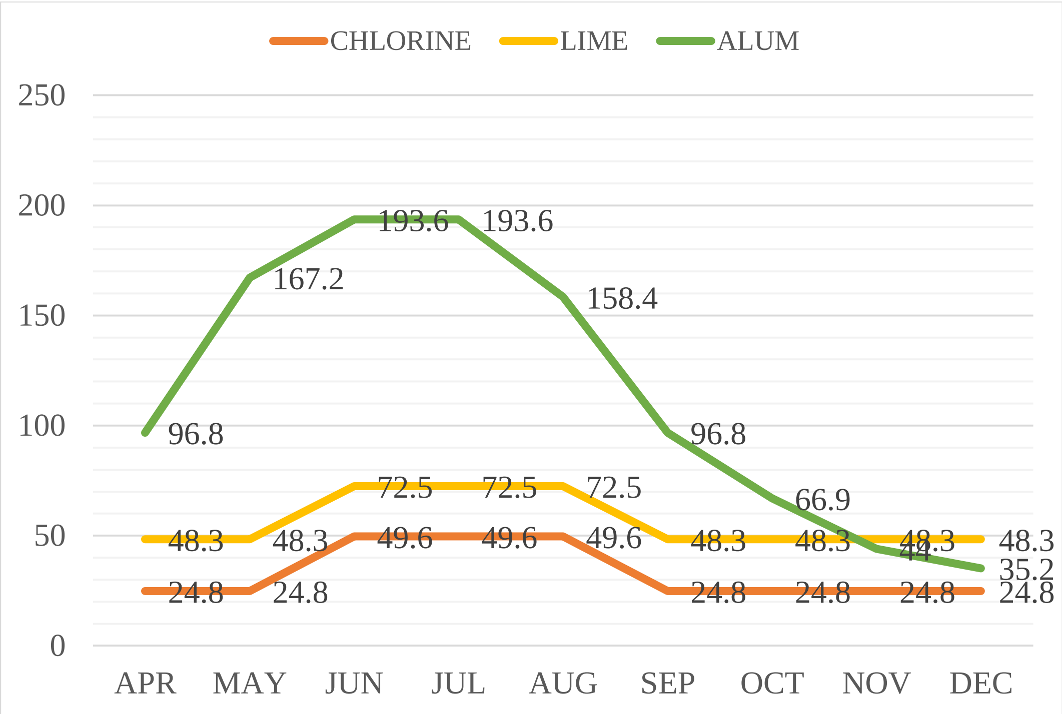



**Figure 4.4: Cost of Chemical Consumption in 2017**
*Source*: Field Data, 2019

Table 4.10 presents the data on the cost of chemical consumption for the year ended, 2018. There are cost variations concerning the various months in the year with July being the peak with a total chemical consumption of 290.4 ppm. It appears from the data presented that the cost of chemical consumption was steady as compared to that of 2017 for the same months. As can be seen from Table 4.10, from May to July 2018, there has not been a sharp increase in the cost of chemical consumption compared with the 2017 period.

**Table 4.10: Raw Water Average Parameters and Cost of Chemical Consumption in 2018**

| DATE/MONTH | pH | COLOUR/HU | TURBIDITY/NTU | DOSAGE PART PER MILLION | | | COS/GHS/1000M³ | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Alum* | *Lime* | *Chlorine* | *Alum* | *Lime* | *Chlorine* | |
| **January** | 7.1 | 75.4 | 35.7 | 25 | 30 | 2.5 | 44 | 48.3 | 24.8 | **117.1** |
| **February** | 7.2 | 216.3 | 125.8 | 32 | 30 | 2.5 | 56.3 | 48.3 | 24.8 | **129.4** |
| **March** | 7.2 | 242.9 | 127.1 | 38.5 | 30 | 2.5 | 67.8 | 48.3 | 24.8 | **140.9** |
| **April** | 6.9 | 368.9 | 182.3 | 52.1 | 30 | 2.5 | 91.7 | 48.3 | 24.8 | **164.8** |
| **May** | 6.7 | 495.3 | 348.9 | 58 | 40 | 5 | 102.1 | 64.4 | 49.6 | **216.1** |
| **June** | 6.6 | 919.6 | 748 | 75 | 45 | 5 | 132 | 72.5 | 49.6 | **254.1** |
| **July** | 6.6 | 1046.5 | 857.8 | 95.6 | 45 | 5 | 168.3 | 72.5 | 49.6 | **290.4** |
| **August** | 6.6 | 541.1 | 324.5 | 53 | 45 | 5 | 92.3 | 72.5 | 49.6 | **214.4** |
| **September** | 6.7 | 317.2 | 142.3 | 40 | 30 | 2.5 | 70.4 | 48.3 | 24.8 | **143.5** |
| **October** | 6.8 | 22.4 | 78.5 | 35 | 30 | 2.5 | 61.6 | 48.3 | 24.8 | **134.7** |
| **November** | 6.9 | 232.7 | 121.5 | 33 | 30 | 2.5 | 58.1 | 48.3 | 24.8 | **131.2** |
| **December** | 7 | 177.9 | 72.9 | 30.5 | 30 | 2.5 | 53.7 | 48.3 | 24.8 | **126.8** |

*Source:* Jambusie Water Treatment Headwork, 2020.

Figure 4.5 presents the data on the cost of chemical consumption for the year ended, 2018. There are cost variations regarding the various months in the year from May to August 2018. The peak period of consumption was in July with a total amount of GHS168.30 spent on alum while GHS72.5 was spent in June, July, and August on lime in that same year. Besides, GHS49.6 was spent from May through to August also still suggesting the peak period of the rainy season. The Figure below shows that the most used chemical during the rainy season was alum, which is an indication that the contamination of the water could have been too much warranting more use of the chemical.

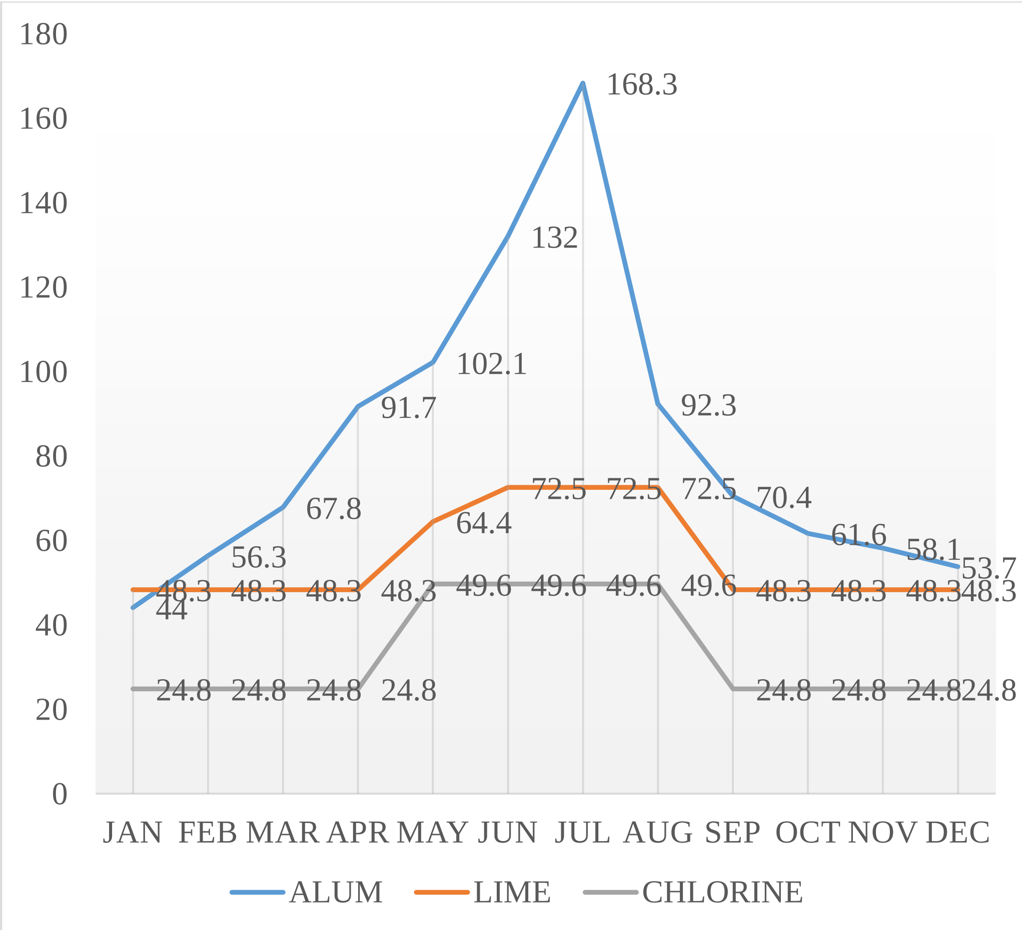



**Figure 4.5: Cost of Chemical Consumption in 2018**
*Source:* Jambusie Water Treatment Head Works, 2020.

Table 4.11 sheds light on the cost of chemical consumption for the year ended, 2019. The highest cost figure, which is GHS333.30, was recorded in June, and thereafter fell for the remaining months of the year. The months that recorded high cost of chemical consumption figures except for July as mentioned above were May, July, and August. The figures as compared to the 2018 cost figures are not very different. It can therefore be inferred that the Management of the Jambusie head works spent relatively almost the same amount for the two years.

**Table 4.11: Raw Water Average Parameters and Cost of Chemical Consumption in 2019**

| DATE/MONTH | pH | COLOUR/HU | TURBIDITY/NTU | DOSAGE PART PER MILLION | | | COS/GHS/1000M$^3$ | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Alum* | *Lime* | *Chlorine* | *Alum* | *Lime* | *Chlorine* | |
| **January** | 7.2 | 102.7 | 54.8 | 31 | 30 | 2.5 | 54.6 | 48.3 | 24.8 | **127.7** |
| **February** | 7.3 | 103 | 56.1 | 34.5 | 30 | 2.5 | 60.7 | 48.3 | 24.8 | **133.8** |
| **March** | 7.3 | 137.2 | 68.7 | 38 | 30 | 2.5 | 60.9 | 48.3 | 24.8 | **134** |
| **April** | 6.9 | 158.1 | 120.5 | 54.2 | 30 | 2.5 | 93.4 | 48.3 | 24.8 | **166.5** |
| **May** | 6.6 | 964.3 | 648.3 | 100.1 | 45 | 5 | 176.2 | 72.5 | 49.6 | **298.3** |
| **June** | 6.4 | 1431.3 | 685.3 | 107.6 | 45 | 5 | 189.4 | 72.5 | 49.6 | **311.5** |
| **July** | 6.4 | 1550 | 926.7 | 120 | 45 | 5 | 211.2 | 72.5 | 49.6 | **333.3** |
| **August** | 6.5 | 1060 | 585.7 | 85 | 45 | 5 | 149.6 | 72.5 | 49.6 | **271.7** |
| **September** | 6.6 | 262.5 | 134.3 | 54 | 30 | 2.5 | 95 | 48.3 | 24.8 | **168.1** |
| **October** | 6.8 | 143.3 | 89.5 | 40 | 30 | 2.5 | 70.5 | 48.3 | 24.8 | **143.6** |
| **November** | 6.8 | 215 | 123 | 37.5 | 30 | 2.5 | 66 | 48.3 | 24.8 | **139.1** |
| **December** | 6.8 | 250 | 138 | 35 | 30 | 2.5 | 61.6 | 48.3 | 24.8 | **134.7** |

*Source***:** Jambusie Water Treatment Head Work, 2020

Figure 4.6 presents the data on the cost of chemical consumption for the year ended, 2018. There are cost variations throughout the year. This started from May to August. The peak period of consumption of more chemicals was in July totaling GHS211.2 which was spent on alum while GHS72.5 was spent in June, July, and August on lime in that same year. Also, GHS49.6 was spent from May through to August. It can be inferred that this is the peak period of the rainy season in that part of the country. The Figure below shows that the peak period of the rainy season also comes with a lot of contaminants warranting the use of more chemicals.

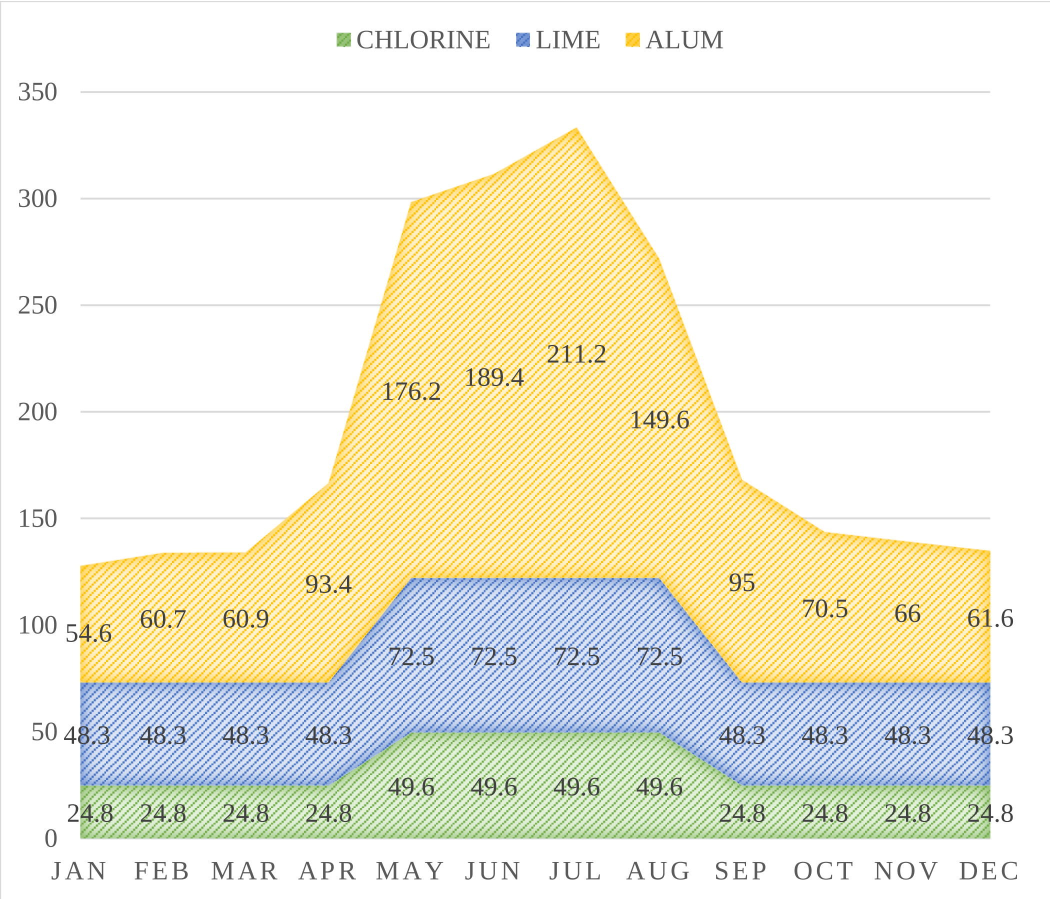



**Figure 4.6: Cost of Chemical Consumption, 2019**
*Source*: Field Data, 2019

The study further considered the cost of chemical consumption for the 2020 financial year. It considered the period from January to July. The remaining periods have not been considered because of the limited time space for this project to be completed. From Table 4.8, the cost of chemical consumption increased from January to July, with the peak period being July.

**Table 4.12: Raw Water Average Parameters and Cost of Chemical Consumption in 2020**

| DATE/MONTH | pH | COLOUR/HU | TURBIDITY/NTU | DOSAGE PART PER MILLION | | | COST/GHS/1000M3 | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Alum* | *Lime* | *Chlorine* | *Alum* | *Lime* | *Chlorine* | |
| **JANUARY** | 7.2 | 96.6 | 58.1 | 37 | 30 | 2.5 | 65.12 | 48.3 | 24.8 | **138.22** |
| **FEBRUARY** | 7.3 | 100.2 | 66 | 38.5 | 30 | 2.5 | 67.76 | 48.3 | 24.8 | **140.86** |
| **MARCH** | 7.3 | 108.7 | 68.4 | 41.7 | 30 | 2.5 | 73.4 | 48.3 | 24.8 | **146.5** |
| **APRIL** | 7.3 | 120.1 | 87.4 | 50.2 | 30 | 2.5 | 88.35 | 48.3 | 24.8 | **161.45** |
| **MAY** | 6.7 | 200.8 | 125.5 | 95.3 | 40 | 2.5 | 167.73 | 64.4 | 24.8 | **256.93** |
| **JUNE** | 6.4 | 490.3 | 348.5 | 101.5 | 45 | 5 | 178.64 | 72.5 | 49.6 | **300.74** |
| **JULY** | 6.5 | 1200 | 667.8 | 110 | 45 | 5 | 193.6 | 72.5 | 49.6 | **315.7** |

*Source:* Jambusie Water Treatment Head Works, 2020

Figure 4.7 reveals the cost of chemical consumption for the year ended in 2020. The data was collected from January to July. It can be inferred from the data that the monthly costs vary as evidenced from May to July. The peak period of consumption of chemicals began in May and reached the highest point in July with the amount of GHS193.6 being spent on alum while GHS72.5 was spent between June and July on lime in that year.

Also, GHS49.6 was spent in June and July. It can be inferred from the findings that the peak period of the rainy season in that part of the country is normally from May to September. The Figure below shows that the period of the rainy season comes with a lot of contaminants warranting the use of more chemicals.

The peak period for rainfall in the Upper West Region spans from June to September each year. This implies that the raw water that is usually treated for consumption gets more contaminated with substances and other impurities. This is often occasioned by surface run-off and other activities. This could account for the increase in the cost of chemical consumption and treatment within those periods.

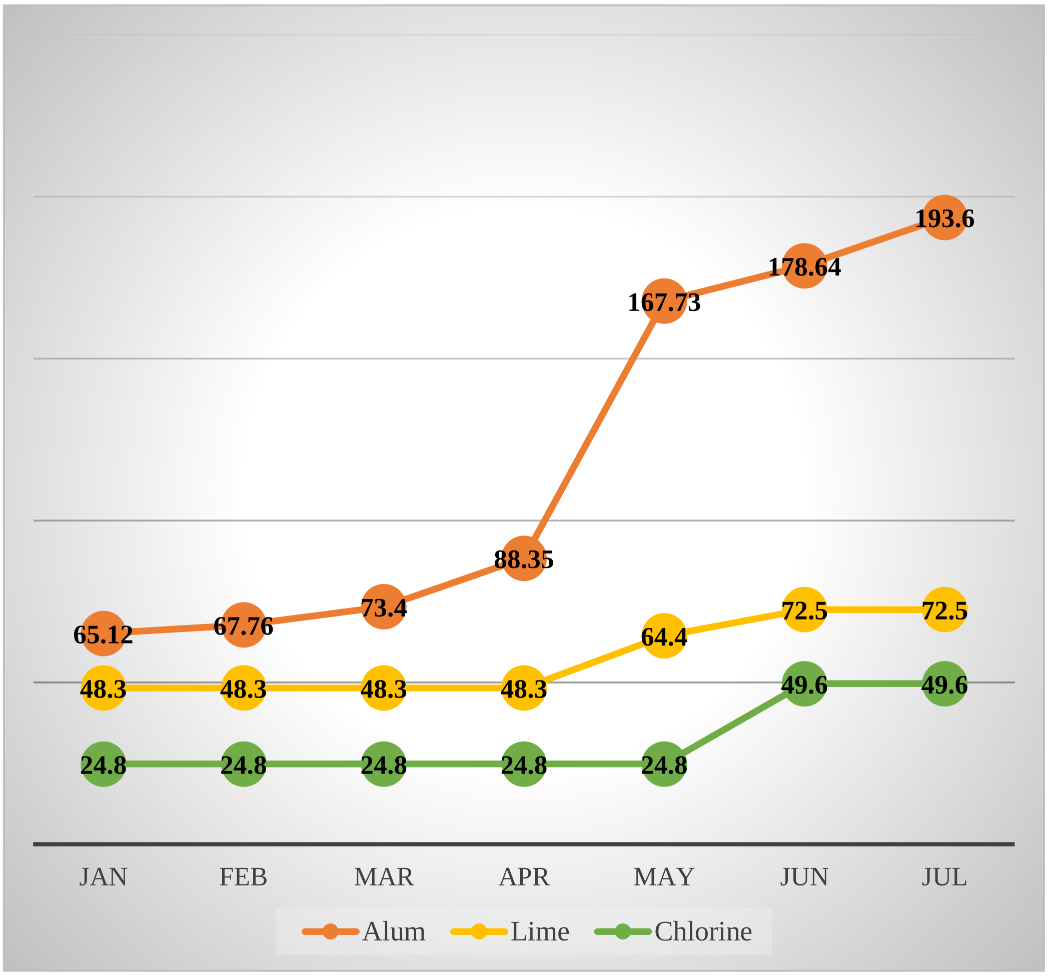



**Figure 4.7: Cost of Chemical Consumption in 2020**
*Source*: Field Data, 2019

### 4.5.3 Operation and Maintenance Cost of treatment infrastructure

When respondents were asked whether the cost of maintaining the water treatment facility changes during the rainy season, the majority 29 (64.4%) of them said the cost of maintenance of the facility increases during the rainy season, while 16 (35.6%) were of the contrary view. They opined that the variation in cost was that significant. They said this was to be expected because the flooding that results from the heavy downpour sets in with its challenges.

**Table 4.13: Cost of maintaining infrastructure**

| Cost of maintaining infrastructure during the rainy season | Freq. | Percentage |
|---|---|---|
| **Yes** | 29 | 64.4 |
| **No** | 16 | 35.6 |
| ***Total*** | ***45*** | ***100*** |
| **What accounts for the increase in maintenance cost** | **Freq.** | **Percentage** |
| **De-silting of dam and waterways** | 13 | 28.9 |
| **Damage of components** | 11 | 24.4 |
| **Replacement of damaged parts of a machine** | 21 | 46.7 |
| ***Total*** | ***45*** | ***100*** |

*Source*: Field Survey, 2020

A good number of the respondents 13 (28.9%) pointed out issues that account for an increase in the cost of maintenance to be de-silting of the dam waterways. This they attributed to flooding, surface run-off, and erosion. Also, 11 (24.4%) of the respondents noted that damage to components of the plant due to the submergence of equipment by floodwater often requires maintenance which comes with a cost. The results further showed that some parts of the equipment must always be replaced due to submergence and the associated damage that requires repairs.

# CHAPTER FIVE

# SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## 5.1 Introduction

This chapter presents a summary of the key research findings, as well as the conclusions and recommendations made based on the findings as presented in the previous chapter.

## 5.2 Summary of Key Findings

The key focus of the study was to examine the effects of flooding on the Jambusie water plant in the Wa West District of the Upper West Region, specifically the effects of flooding on infrastructure at the water supply facility; and also to assess the effects of flooding on water treatment, to determine the cost implications of the rainy season on water treatment and the facility and to identify the activities that affect water treatment during floods.

The findings of the first objective revealed that floods have had effects on the water treatment infrastructure over the years with some of the effects being damage to some components of the plant and sometimes complete breakdown of the facility due to the floods. The damage comes with their financial implications on the Company. Some of the effects of the rainy season on water treatment as the results showed were flooding, erosion, and surface run-off which posed a serious challenge with flooding being the major challenge.

In assessing on water treatment the survey revealed that many physico-chemical properties are carried into the water when the rainy season sets in. For instance, the water colour, turbidity level, pH of the water, among others are affected during the rainy season. These physico-chemical properties have negative consequences on water treatment. The survey revealed that before the rainy season the raw water colour is usually milkier/greenish due to the presence of algae but brownish during the rainy season. This data suggests that there are variations in the water colour for both dry and rainy seasons. The results revealed that during the rainy season the concentration level of the alkaline increases due to floods carrying substances into the water and that alkalinity in the water could persist for four weeks or more depending on the period of the rainy season. The results further revealed that before the rains, the Nephelometric Turbidity Unit can range from 40NTU - 120NTU, and that the Nephelometric Turbidity Unit can range from 121NTU - 1000NTU during the rainy season.

In determining the cost implications of the rainy season on water treatment and the facility the study revealed that a number of factors accounted for the cost variation in the water treatment facility including high turbidity level, flooding, and farming practices accounts for cost variation in water treatment The study also revealed that more chemicals are used to treat the raw water to remove the substances, impurities, and particles to make it wholesome for consumption and other uses during the rainy reason. These chemicals often come with a cost. It was further revealed that the turbidity level increase during flooding and thus, the quality of the raw water gets affected. Besides, the cost of maintenance or repair works increases during floods. The study on the third objective finally reveals that the cost of chemical consumption varies yearly, with the highest figures often recorded between July and September.

The findings on the final objectives revealed that crop farming, illegal mining, open defecation, animal rearing, fishing, and felling of trees are the main activities affecting water treatment at the Jambusie water facility.

The findings revealed that the construction of retention wells to retain excess water, the construction of good drainage systems for the easy flow of water around the facility, re-direction of watercourse/path, de-silting of drains regularly, increasing the depth of the intake embankment, and planting of trees around the treatment facility served as coping mechanisms by the management of the Jambusie Water Treatment Facility to reduce the amount of water entering the facility.

## 5.3 Conclusions

The study concludes that floods have had negative effects on the water treatment plant over the years at Jambusie with some of the effects being damage to some components of the plant and even sometimes, a complete breakdown of the plant due to the floods. The effects include: erosion, and surface runoff water.

The study also concludes that the raw water quality deteriorates during the rainy season, as indicated in the elevation of physico-chemicals of the raw water and this is worse when the rainy season intensifies. These physico-chemicals have negative consequences on water treatment. Also, before the rainy season the raw water colour is usually greenish due to the presence of algae but brownish during the rainy season. It was established that before the rains, the Nephelometric Turbidity Unit can range from 40NTU - 120NTU, whilst 57.9% of the respondents mentioned that the

Nephelometric Turbidity Unit can range from 121NTU - 1000NTU during the rainy season.

The study concludes that more chemicals are used to treat the raw water to make it wholesome for consumption during floods. Besides, the cost of maintenance or repair works increases during the rainy season. The cost of chemical consumption also varies yearly, with the highest figures often recorded between July and September.

The study concludes that Crop farming, illegal mining, open defecation, animal rearing, fishing, and felling of trees are the main activities affecting water treatment at the Jambusie Water Treatment Facility.

## 5.4 Recommendations

The study has thrown light on the effects of flooding on the water treatment facility at Jambusie. The valuable contributions from the research respondents have helped to identify some factors that affect water treatment during the floods. The factors that affect the water treatment facility have been categorised into flooding, erosion, and surface run-off; and high cost of operations and maintenance during the rainy season. Based on the research objectives, the researcher proposes the following policy and practical recommendations.

Ghana Water Company Limited should ensure that a well-engineered drainage system is constructed at the facility. This will enable the free flow of water and also prevent flooding and its devastating effects. This will ultimately ease the effect of the flood on the infrastructure.

Ghana Water Company Limited should ensure that there are no stock-outs in terms of chemicals and parts of the machinery that aid in the treatment of water. This will ensure that water treatment is not disrupted during the periods when the raw water quality is affected by the activities of the rainfall.

Ghana Water Company Limited should collaborate with the relevant stakeholders such as Water Resource Commission, Environmental Protection Agency (EPPA), and the Ghana Police Service to check activities such as illegal mining and farming that could impact the raw water quality negatively.

It is finally recommended that Ghana Water Company Limited should take steps to stone-pitch the access road to the intake facility to prevent it from being washed away by the perennial flooding of the facility and to reduce the recurrent maintenance cost.

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# APPENDICES

## Appendix I: Questionnaire for GWCL Staff

**UNIVERSITY FOR DEVELOPMENT STUDIES**
**DEPARTMENT OF ENVIRONMENT AND RESOURCE STUDIES**
**WA CAMPUS**

I am currently conducting graduate research on the topic: "*Effects of Floods on the Jambusie Water Treatment Plant at the Wa West District of the Upper West Region of Ghana*". There have been great discussions about rainfall and its effects on water treatment plants. My concern here is to gauge the views of participants and the findings will help shape the current discourse on the subject.

I would therefore be grateful if you could take a few minutes of your time to answer the short questions that follow. I guarantee that your responses will be kept confidential.

The questionnaire consists of four sections. Kindly provide answers to the questions in all sections. The answers you provide in this section will help make a statistical comparison; at no point will the researcher try to identify you.

### A. Background Information of Respondents

1. Gender: Male [ ] Female [ ]

2. What age bracket do you fall into:
   Under 30 [ ] 31 to 40 [ ] 41 to 50 [ ] 51 to 60 [ ]
   60 and above [ ]

3. What is your academic qualification?
   Technical/ Vocational [ ] Certificate [ ] Diploma [ ]
   Bachelors [ ] Masters [ ] PhD [ ]
   Others
   specify…………………………………………………………………………

4. How many years have you worked with Ghana Water Company Limited?
   Less than 1 [ ] 1 to 5 [ ] 6 to 10 [ ] More than 10 [ ]

### B. Effects of Rainfall on Infrastructure at the Water Supply Facility

5. Would you say that rainfalls usually affect the water infrastructure at Jambusie? Yes [ ] No [ ] Not Sure [ ]

Rank the following in order of priority as factors that affect the water treatment facility. Use 1, 2, 3, and 4 in the spaces provided under number/ranking.

| **Factors of the rainy season on infrastructure** | **Number/ranking** |
|---|---|
| Flooding | |
| Soil erosion | |
| Run-off leading to siltation | |
| Inaccessible roads | |

6. What are the possible causes of flooding around the water treatment facility?
   …………………………………………………………………………………
   …………………………………………………………………………………
   …………………………………………………………………………………

7. How long does the flood water stay around the treatment facility?
   a. Less than 1 Week [ ]    b. 2 Weeks [ ]    c. 3 Weeks [ ]
   d. 4 Weeks and above [ ]

8. What are the effects of the floods on the water treatment facility?
   ………………………………………………………………………………
   …………………………………………………………………………………

## C. Effects of Rainfall on Water Treatment

9. Tick **(✓)** whether any of the following physicochemical properties in the table below usually can get affected during the rainy season;

| **Physico-chemical Properties** | **Tick (✓)** |
|---|---|
| Colour of the water | |
| Turbidity of the water | |
| Nitrate of the water | |
| The alkalinity of the water | |

10. What is the colour of the raw water ***before*** the rainy season?
    a. Greenish [ ]    b. Brownish [ ]    c. Yellowish [ ]
    d. Blue-wish [ ]    e. Don't know [ ]

11. What is the colour of the raw water ***during*** the rainy season?
    a. Greenish [ ]    b. Brownish [ ]    c. Yellowish [ ]
    d. Blue-wish [ ]    e. Don't know [ ]

12. What is the Nephelometric Turbidity Unit (NTU) of the water ***before*** the rainy season?    a. 40NTU – 120NTU [ ]    b. 121NTU – 1000NTU [ ]
    c. 130NTU – 200NTU [ ]

13. What is the Nephelometric Turbidity Unit (NTU) of the water ***during*** the rainy season? a. 40NTU – 120NTU [ ] b. 121NTU – 1000NTU [ ] c. 130NTU – 200NTU [ ]

14. How long does the alkalinity change persist ***during*** the rainy season? ……………………………………………………………………………………

**D. Cost Implications of the Floods on Water Treatment and the Facility**

15. Does the cost of treating water increase during the rainy season? Yes [ ] No [ ]

16. What accounts for the cost variations in water treatment? ……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

17. Does the cost of maintaining infrastructure increase during the rainy season? Yes [ ] No [ ]

18. What accounts for the cost of maintenance? ……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

**E. Activities that Affect Water Treatment During the Rainy Season**

19. Please choose an option that best describes the activities in the table below by placing a **tick (✓)** in the spaces provided.

| **Activities** | **Strongly Agreed** | **Agreed** | **Neutral** | **Strongly Disagreed** | **Disagreed** |
|---|---|---|---|---|---|
| Crop farming | | | | | |
| Illegal mining | | | | | |
| Open defecation | | | | | |
| Animal rearing | | | | | |
| Fishing | | | | | |

**F. Coping mechanisms/safeguard during the rainy season**

20. Apart from the construction of an embankment around the water plant to prevent excess water from entering the plant ***during*** the rainy season, what other measures are put in place to safeguard the plant from rainwater. Kindly mention them.
……………………………………………………………………………………

**Thank you**

**Appendix II: Interview Guide for Key Informants**

**UNIVERSITY FOR DEVELOPMENT STUDIES**
**DEPARTMENT OF ENVIRONMENT AND RESOURCE STUDIES**
**WA CAMPUS**

I am currently conducting graduate research on the topic: *"Effects of Floods on the Jambusie Water Treatment Plant at the Wa West District of the Upper West Region of Ghana"*. There have been great discussions about rainfall and its effects on water treatment plants. My concern here is to gauge the views of participants and the findings will help shape the current discourse on the subject.

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**A. Background Information of Respondents**

1. Gender: Male [ ] Female [ ]

2. What age bracket do you fall into:
   Under 30 [ ] 31 to 40 [ ] 41 to 50 [ ] 51 to 60 [ ] 60 and above [ ]

3. What is your qualification?
   Technical/ Vocational [ ] Certificate [ ] Diploma [ ]
   Bachelors [ ] Masters [ ] PhD [ ]
   Others specify……………………………………………………………………

4. How many years have you worked with Ghana Water Company Limited?
   Less than 1 [ ] 1 to 5 [ ] 6 to 10 [ ] More than 10 [ ]

**B. Effects of Rainfall on Infrastructure at the Water Supply Facility**

5. Generally, what are the effects of rainfalls on the infrastructure of the Wa Water Supply System at Jambusie?
   ………………...................................……………………………………
   …………………………………………………………………………………….
   ……………………………………………………………………………………

6. In times of flooding, what coping mechanisms are put in place to safeguard the infrastructure?
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………

## C. Effects of the Rainfall on Water Treatment

7. In your opinion, do you think the rains affect water treatment?
   Yes [ ]                    No [ ]

8. What are the effects of the rains on water treatment?
   …………………………………………………………………………………
   …………………………………………………………………………………

9. What coping mechanisms are usually put in during the rainy season?
   …………………………………………………………………………………
   …………………………………………………………………………………

## D. Cost Implications of Rainfall on Water Treatment and the Facility

10. Does the cost of treating water increase during the rainy season?
    Yes [ ]          No [ ]

11. What accounts for the cost variations in water treatment?
    …………………………………………………………………………………
    …………………………………………………………………………………

12. Does the cost of maintaining infrastructure increase during the rainy season?
    Yes [ ]                    No [ ]

13. What accounts for the cost of maintenance?
    …………………………………………………………………………………
    …………………………………………………………………………………

## E. Activities that Affect Water Treatment During the Rainfall

14. In your opinion, what are the activities that have the likelihood of affecting water treatment in the Wa Water Supply System at Jambusie?
    …………………………………………………………………………………
    …………………………………………………………………………………

15. How do these activities affect Water Treatment?
    …………………………………………………………………………………
    …………………………………………………………………………………

**Thank you**