UNIVERSITY OF EDUCATION, WINNEBA

ASSESSMENT OF SEASONAL VARIATIONS IN WATER QUALITY OF RIVER TORDZIE, GHANA

GAMELI KWASI TORDZRO

MASTER OF PHILOSOPHY

2022

UNIVERSITY OF EDUCATION, WINNEBA

ASSESSMENT OF SEASONAL VARIATIONS IN WATER QUALITY OF RIVER TORDZIE, GHANA

GAMELI KWASI TORDZRO
(200024764)

A thesis in the Department of Chemistry Education
Faculty of Science Education, submitted to the School of
Graduate Studies in partial fulfillment
of the requirements for the award of the degree of
Master of Philosophy
(Chemistry Education)
in the University of Education, Winneba

JUNE, 2022

DECLARATION

Candidate's Declaration

I, **Gameli Kwasi Tordzro,** hereby declare that this thesis is the result of my original project work except for quotations and references from published works which have been duly acknowledged and supervised by Professor Victus Bobonkey Samlafo and that no part of it has been published, in part or whole, for another certificate in this University or any other institutions elsewhere without permission from the supervisor.

Signature: …………………...

Date: ………………………...

Supervisor's Declaration

I hereby declare that, the preparation and presentation of this work were supervised per the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

Name: Professor Victus Bobonkey Samlafo

Signature: …………………………...

Date: ………………………….……...

DEDICATION

First and foremost, I dedicate this work to Enam B. Tordzro, Aseye B. Tordzro, Shine Abotsi. I also dedicate this work to my parents Mr. and Mrs. Tordzro for how far they have brought me in my educational career and to all my MPhil year batch in the University of Education, Winneba-Ghana.

ACKNOWLEDGEMENT

My foremost thanks go to Jehovah Almighty for giving me life and strength throughout the period of studying at the University of Education, Winneba without any problem that could have cost my life.

My greatest thanks go to Professor Victus Bobonkey Samlafo, my supervisor for the assistance and attention he gave me, outside of his official schedule as well as his encouragement that has seen the success of this thesis. My thanks also go to my uncle, S.K. Tordzro and to my study mates; Felix N. Akompi, Thomas Dorpe for their support and advice. God bless you.

I also give thanks to my brother; Xorve Agawu for taking his time to drive me throughout my sampling periods. This thesis cannot also see the light of success without the contribution of the laboratory Technician at the University of Cape Coast (UCC); Samuel Nketia Boateng who took his time from the day of laboratory analysis till the end of the write-up and his assistants, Mr. Richard Oduro and Mr. Alex Kiss Boateng. To my former lecturers at UCC; Dr. M. A. Anang, Dr. M. P. Oteng and Dr. K.O. Boadu, who took their time to see the progress of this thesis, I say a very big thank you. Not forgetting Dr. Bansah and the family for their assistance.

My final gratitude goes to Mrs. Gladys Binney-Hayford (the headmistress), Mr. Godfrey Mensah, Mr. Seth Akoto, Mr. Eric Eku, Mr. George Boateng, Anthony Gyimah, Mr. A.N.P Koomson, Sylvester Gyepi-Gabrah, Derrick Amoah and Frederick Ampomah, all at A.M.E Zion Girls' S.H.S, Winneba and to Mr. Ambrose Adza at St. Augustine's College, Cape Coast for their advice and support. May the good Lord bless you all.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

ABSTRACT

River Tordzie is one of the poorly studied rivers in Ghana in terms of its water quality. There is little data on the quality of water from this river. The purpose of the study was to assess the water quality of River Tordzie which runs through some communities in the Volta Region. Samples were taken in March (dry season) and July (wet season) in seven communities along the river in the study area. Sixteen physicochemical parameters and three heavy metals were analysed. Lead and cadmium were determined using Flame Atomic Absorption Spectrophotometer using an air-acetylene oxidizing flame. Total hardness, pH, turbidity, chloride and phosphate were determined by EDTA titration, a PC 700 Eutech multi-parameter bench top meter, a potable metalyser HM 1000 Trace2O, argentometric titration and ascorbic acid spectrophotometric method respectively. From the analysis, it was found that the pH, Total hardness, sulphate, phosphate, electrical conductivity, total dissolved solids, chloride, and nitrate were within the permissible limit of Bureau of Indian surface water quality standard as per IS: 2296. Heavy metals such as cadmium, lead, and iron were also within the standard during the dry season but the concentrations of cadmium and lead were above the standard limits during the wet season. Water quality index (WQI) analysis was conducted and the result for the dry season was found to be 92.19 and for the wet season to be 1227.84. The results showed that, the water from this river cannot be used for domestic purposes without treatment. When Nemerow's Pollution Index (NPI) was conducted, it was found that colour, biochemical oxygen demand (BOD), dissolved oxygen (DO), cadmium, and lead were the main parameters causing the quality of the river to decline. The result from the t-test analysis showed that there was no statistically significant difference between the observed values during the dry season and wet season ($p = 0.815 > 0.05$). The quality of water from river Tordzie was therefore affected by changes in the seasons.

CHAPTER ONE

INTRODUCTION

1.0 Overview

The chapter creates a general context for the study. The chapter presents the background to the study, the problem statement, the purpose of the study, the objectives of the study and the significance of the study.

1.1 Background to the study

Water covers over 70% of the earth's surface and is the only natural entity to exist in all three states of matter on the planet. It is worth noting that freshwater accounts for only 2.5 percent of all water on the planet, and it is dispersed globally, leaving less than one percent of freshwater accessible in lakes, river channels, and underground (Food and Agriculture Organization of the United Nations, 2003). Water is the most crucial resource for the ecosystem's survival and life support. Contaminated water is one of the world's most common causes of sickness (Tauxe *et al.*, 1995; Sugimoto *et al.*, 2014). According to Symons *et al.*, (2000), water (H_2O) is a translucent, odourless, and tasteless compound of hydrogen and oxygen. Pure water freezes at 0° C and boils at 100° C at a pressure of one atmosphere. Rain, oceans, lakes, rivers, and other surface water bodies, as well as groundwater, are all made up of water of varying degrees of purity. It is a natural resource that can be used for a variety of purposes, including recreation, transportation, hydroelectric power, and domestic, industrial, and commercial applications. Water is essential for all kinds of life and has an impact on our health, way of life, and financial well-being (Igwe *et al.*, 2017). Water is abundant on the planet, but fresh potable water is not always available at the right time or in the right place for human or ecosystem use, and it is without a doubt the most valuable natural resource vital to life. Water is spread in nature in various forms and sources, including oceans, seas, rivers, streams, lakes, ponds, wells, boreholes, and springs (Pati & Rout, 2018). The evaluation of the quality of water from some of these alternative sources has become critical since it has a direct impact on people's health (WHO, 2006).

According to Leroy *et al*., (2002), rivers provide a variety of services for human populations, including water for drinking and irrigation, recreational opportunities, and habitat for economically important fisheries. Fresh water is a scarce resource that is necessary for agriculture, industry, and even human survival. Sustainable development will be impossible without sufficient quantities and quality of freshwater (Igwe *et al*., 2017). The growing problem of pollution of river ecosystems has necessitated the monitoring of water quality (Puri *et al.,* 2011). Water quality varies greatly based on location and other environmental conditions. Human health continues to be harmed by poor water quality. In impoverished countries, 80% of ailments are caused by a lack of sufficient quality water (Daud *et al*., 2017). Untreated wastewater discharged from industrial and domestic sources is degrading Africa's water resources (Corcoran, 2010). According to studies, over 780 million people worldwide lack access to safe drinking water, with the majority of these individuals living in poor nations such as Ghana (UNICEF and WHO, 2012).

Water has become a limited commodity in many nations throughout the world, including Ghana, where only a small percentage of the population has access to purified water (Nkansah *et al*., 2010). The importance of clean water to human health cannot be overstated. The scarcity of our most valuable natural resource, clean water, has become an issue as the world's population grows. However, in other regions of the world, its significance is of a completely varied degree and scale (Garrick *et al*., 2008). One of the obstacles to direct potable reuse of wastewater is the need for the rapid assessment of microbial contamination of the treated water. Domestic wastewater contains a wide variety of waterborne pathogens such as viruses, bacteria, and protozoa (Abbaszadegan *et al.*, 1997). Water quality has become a critical social, economic and environmental issue for the majority of people in developing countries. The growing population has put a strain on current surface water sources, prompting analysts to foresee future national and international conflicts (Awuah & Anipa, 2002). Unlike other resources, getting immediate and/or future replacements for most water applications is nearly impossible. Water quality has been harmed by rapid pollution from mining and agricultural activities, making it exceedingly expensive to clean for domestic use (Nsubuga *et al.*, 2014). Most of the world is surrounded by water, but we lack access to it, particularly potable water, which is required for necessities such as food production, health, sanitation, and long-term development (Owusu *et al.*, 2016).

Although Ghana receives enough rain and countless rivers never dry up, millions of the people lack access to safe drinking water. There are substantial limits to achieving the challenges of providing adequate water to all rural populations, similar to the rural water sector in many developing countries. Water shortages and decline in quality are two issues that require more attention and action. Various initiatives are being developed by governmental and non-governmental agencies to ensure that all residents have access to water. However, the gap between demand and supply of water continues to expand due to poor infrastructure and rapid population growth (Doe, 2007). Degradation of surface and groundwater sources has long been an unavoidable result of economic development, with remedial measures to compensate for or mitigate environmental consequences always being of a lower priority (Parr *et al.,* 1992).

The quality of Ghana’s groundwater and surface water resources continues to deteriorate, owing to rising levels of pollution from “galamsey” (illegal mining), waste, leachate from chemical fertilizers and pesticides used in agriculture, chemicals from mining, and chemicals use in fishing, as well as rapid population growth. Existing water management strategies are insufficiently robust to meet the issues. Ghana’s per capita availability of water resources has been dwindling over the past six years. Rapid population growth around the world, particularly in emerging nations, poses a substantial danger to water resources as well as sustainability, necessitating careful management and protection of the resource (United Nations, 2014).

Ghana has abundant water resources, however the amount of water accessible varies significantly from season to season and year to year. In addition, the distribution of water across the country is not consistent, with the south-western region receiving more water than the coastal and northern regions. However, due to rainfall variability (climate change), rapid population growth, increased environmental degradation, river pollution, and wetlands draining, water availability is decreasing. Ghana's rivers all flow south to the Gulf of Guinea. The Volta River, which drains the whole north, center, and east of Ghana, is by far the largest in the country, with a catchment area of about 70% of the country. The remaining rivers, all of which are located in the south and southwest, drain the area (Water Resources Commission, 2003).

Mining activities, urban and industrial pollution problems, and agricultural development have all increased the importance of surface water quality considerations. For efficient management, and thus the future protection and development of surface water resources, reliable data on water quality is critical. The current and future development of urban drainage in several of Ghana's major cities, which requires flood and storm runoff data for good planning and design, is another critical continuing topic that necessitates adequate hydrological data (Water Resources Commission, 2003). Even though Africa is widely regarded as a continent with abundant water, both urban and rural residents on the continent lack access to appropriate and safe drinking water, putting their food security at risk, as well as being exposed to preventable water-related diseases. This scenario is due to a scarcity of water as well as a lack of access to safe drinking water and proper sanitation. Due to significant discrepancies in rights, decision-making authority, tasks, and responsibilities over water for productive and domestic activities, water shortages and inadequate access to water disproportionately affect women and girls, especially in rural areas (African Water Development Report, 2006).

Water is essential for all living beings; without it, life would be impossible. According to popular belief, life began in water, and the protoplasm of a cell is a colloidal solution of complex organic molecules in a watery medium. Because the majority of the body's biological processes take place in a watery medium, water is always present in nature. It is a vital component of both plant and animal body fluids, and it is the most crucial substance for the survival and continuation of life in nature through reproduction and many cyclic processes (Krishnan, 2008). However, the quality of the water determines how well a given water source can meet the needs of a community.

The water quality index (WQI) model is a widely used technique for assessing the quality of surface water. It employs aggregation techniques to reduce large amounts of water quality data to a single value or index. The WQI model has been used around the world to assess water quality (surface and groundwater) using local water quality criteria. It has been a popular tool due to its generalized form and ease of use since its invention in the 1960s. WQI models typically have four stages: (1) selecting water quality parameters, (2) generating sub-indices for each parameter, (3) calculating parameter weighting values, and (4) aggregating sub-indices to compute the overall water quality index. Several researchers have used WQI models to assess the water quality of rivers, lakes, reservoirs, and estuaries in a variety of ways (Uddin *et al.*, 2021). Water Quality Index (WQI) measures water quality in terms of an index number that represents overall water quality for any intended purpose. The quality of water is influenced by contaminants present in the water. Water quality monitoring is an essential tool used by environmental agencies to gauge the quality of surface water and to make management decisions for improving or protecting the intended uses.

A water quality index provides a single number (like a grade) that expresses overall water quality at a certain location and time, based on several water quality parameters. The objective of the index is to turn complex water quality data into information that is understandable and useable by the public (Brown *et al.*, 1970; Tyagi *et al.*, 2013). According to Medhi *et al.*, (2019), the water quality index (WQI) is considered the most effective method of measuring water quality. Several water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of the water for drinking.

The polluting potential of the individual parameters was assessed using Nemerow's pollution index (NPI). Nemerow's pollution index measures the extent of pollution of individual parameters at every sampling location per their standard permissible levels (Duncan *et al.*, 2020). NPI offers data on the degree of pollution for a specific water quality parameter in comparison to its standard value. Principal pollutants of a region can be determined by calculating and analyzing the NPI values of water quality metrics for that region, which is an important information for determining if the area's water quality is deteriorating or improving (Swathi & Umesh, 2015).

1.2 Statement of the Problem

River Tordzie runs through a lot of communities in the Volta Region such as Agortime Kpetoe (simply refers to as Kpetoe), Wute, etc. Inhabitants along the river use the water without any treatment for their domestic activities and irrigation purposes. Inhabitants also farm along the river for their livelihood in which they use fertilizers for their farming activities. These anthropogenic activities may lead to pollution of the river. A review of literature showed that there is little or no study done on the quality of the water from this river probably because of lack of mining activities in the communities along the bank of the river. In 2016, Norbert Akpablie from Citi F.M, a radio station based in Accra, reported that residents of Adaklu, Agortime-Ziope, and Anyako communities in the Volta Region, share the same drinking water with cattle and other livestock. Although there are no obvious or reported health issues among the residents, routine monitoring of rivers is an essential requirement for public health. Hence the need to analyse the water quality of River Tordzie for dry and wet seasons.

1.3 Purpose of the Study

The purpose of this study is to assess the seasonal variation of the quality of River Tordzie in selected communities along its banks in the Volta Region.

1.4 Objectives of the study

The objectives of this study are to:

1. determine the levels of some physicochemical parameters and their seasonal variations in River Tordzie.
2. determine the concentration of some selected heavy metals in the water.
3. use water quality index (WQI) and Nemerow's Pollution index (NPI) to determine the suitability of the river for drinking.

1.5 Significance of the Study

The outcomes of this study were expected to provide environmental specialists, planners, and the government, with a complete picture of the water quality of River Tordzie, as well as ideas to improve it to benefit the people who rely on it for their livelihood.

1.6 List of Abbreviations

WHO	World Health Organization
ATSDR	Agency for Toxic Substance and Disease Registry
APHA	American Public Health Association
DWA	Department of Water Affairs
RNA	Ribonucleic Acid
DNA	Deoxyribonucleic Acid
ADP	Adenosine Diphosphate
ATP	Adenosine triphosphate

DWAF	Department of Water Affairs and Forestry
AWWA	American Water Works Association
UNICEF	United Nations International Children's Emergency Fund
EPA	Environmental Protection Agency
MCL	Maximum Contaminant Level

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter provides an overview of previous research and a review of related literature. It is organized such that it discusses the framework and key concepts that underpin the study to highlight how relevant they are to the analysis and interpretation of data.

2.1 Surface Water

Water that runs across the surface of the ground is referred to as surface water (Khatri & Tyagi, 2015). Surface water is the water found in streams, rivers, lakes, and wetlands. Much of the rain and snow that falls on the ground or melts, into ravines, streams, and creeks. Eventually, these smaller waterways converge and join to become rivers (Prud'Homme, 2012). Since surface water is more easily accessible than groundwater, it is relied on for many human uses. It is an important source of drinking water and is used for the irrigation of farmland. In 2015, almost 80 percent of all water used in the United States came from surface water. Wetlands with surface water are also important habitats for aquatic plants and wildlife (National Geographic Society, 2022).

Surface water continues to be a valuable resource. It is generally contaminated, despite being freely available and abstracted (Barrell, 2000). Streams, lakes, and ponds in some sparsely populated places are vulnerable to considerable faecal pollution as a result of improper sewage disposal (Petts, 1994). When it flows it carries microorganisms, biological compounds and minerals. Surface water is nutrient-rich, making it a great environment for all kinds of microbes to thrive (Khatri & Tyagi, 2015). According to Samuel (2013), good quality surface water is critical for maintaining and ensuring varied uses. The presence of a wide array of colloidal contaminants in surface water causes it to appear turbid and therefore reducing its quality.

2.1.1 Importance of surface water

Surface water is mainly used for domestic water supply, livestock watering, irrigation, industrial and other purposes. For domestic water supply, surface water is normally impounded, pumped through transmission mains to a conventional treatment plant, treated, and stored in water reservoirs before distributing through the distribution networks to various homes and public stands. Livestock watering is done by sending livestock to impounded water points such as streams, dugouts, or small reservoirs or transporting the water home for the livestock. Surface water is used in agriculture for irrigation purposes by impounding it and using pumps and irrigation facilities. Some industries use potable water and others use raw water from streams and rivers (UNEP-GEF Volta Project, 2010).

2.2 Water quality

Environmental authorities employ water quality monitoring to assess the quality of surface water to inform management decisions to improve or protect the intended uses (Abdul-Razak *et al.,* 2010). Water quality refers to the chemical, physical, and biological qualities of water, as well as its ability to support a healthy ecosystem. Water quality, according to Boah *et al*., (2015), is a measure of the state of water that takes into account the needs of one or more biotic species as well as any human need or purpose. The most common way to describe water quality is to compare it to a set of standards against which compliance can be measured. Water quality is an important feature of both rural and urban water supply, and it has the potential to influence community attitudes and water supply system sustainability. Water use is influenced by perceptions of poor water quality, which can lead to the development of unsafe alternative sources, posing a health risk (Hoko, 2008). Water quality can be influenced by natural processes as well as human activities, resulting in contamination of water bodies (Department of Water Affairs, 2011). The main causes of poor water quality are contamination of water by human and other animal wastes, toxic chemicals, heavy metals, and oils. Rain, rivers, lakes, oceans, and underground water are all susceptible to contamination. The three main sources of water contamination are industrial pollutants, household wastes, and agricultural wastes. Rainwater that flows into streams as runoff from farms pollutes the environment by transferring residues of chemical fertilizers and pesticides used by farmers (Schueller, 2000).

Water quality often declines as rivers flow through areas where land and water use are intense and pollution from intensive agriculture, large towns, industry, and recreation areas increases (Yogesh & Pendse, 2001). The most common standards used to assess water quality relate to the health of ecosystems, the safety of human contact, and drinking water. Water quality depends on the local geology and ecosystem, as well as human uses such as the use of water bodies as a sink (Adeniran, 2018). Environmental water quality, also called ambient water quality, relates to water bodies such as lakes, rivers, and oceans. Water quality standards for surface waters vary significantly due to different environmental conditions, ecosystems, and intended human uses. Toxic substances and high populations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating, and industrial uses. These conditions may also affect wildlife, which uses the water for drinking or as a habitat. Modern water quality laws generally specify the protection of fisheries, especially endangered species and recreational use (Roosbroeck & Amlalo, 2006). Water Quality Standards (WQS) have been established to regulate substances that potentially affect human health, the environment, and the aesthetic qualities of water. The World Health Organization (WHO, 2011) guideline for Drinking Water Standards (DWS), European Union Specification for Drinking Water (EUSDW), and United States Specification for Drinking (USSD) are among the recognized water quality standards (Edition, 2011). Polluted water is an important channel through which waterborne diseases spread and about 80% of illnesses and deaths in developing countries are due to the use of poor quality water (Schaefer, 2008). There is a clear link between water quality and variables that are likely to reduce its quality, such as rapid population increase, urbanization, industrialization, and pollution-producing human activities (Nhapi *et al*., 2011). In developing countries, about 1.8 million people mainly children die every year due to water-related diseases (WHO, 2004). Therefore, the need for good quality water has become increasingly urgent around the world, as these anthropogenic activities such as agricultural practices, human domestic activities, and dredging are rapidly degrading most water bodies resulting in pollution of aquatic organisms' natural habitats (Ritter *et al*., 2002).

According to Tavakoly Sany *et al*., (2019), water quality index involves evaluating the physical, chemical, and biological nature in connection to natural quality, human effects, and anticipated applications, especially those that may have an impact on human health and the aquatic system. The most prevalent criteria for evaluating water quality are ecosystem health, human contact safety, and drinking water quality. The geology and ecosystem of the area, as well as human activities such as using water bodies as sinks, all influence water quality.

2.3 Water Contamination and Quality Assessment

In today's world, water contamination is a big issue. It is thought to be the world's largest cause of mortality and disease (Pink, 2006; Swaroop *et al*., 2010). Water is a necessary component for the survival of the earth's biota. Freshwater habitats require a variety of water sources to sustain life. Freshwater habitats have a magical function in supporting the life processes of living beings. However, rising population, urbanization, and industry impose a severe strain on freshwater ecosystems, altering the quality of freshwaters by introducing massive amounts of contaminants. Water contamination not only degrades the quality of freshwater but also puts the entire environment at risk (Mushtaq *et al.*, 2020). Many elements, including atmospheric chemistry, underlying geology, climate change, and anthropogenic activity, influence the water quality of a river (Raymond *et al*., 2008, Hamid *et al*., 2020).

To Mushtaq *et al.*, (2020), the chemical substances in the freshwater ecosystem cannot be neutralized easily due to their complex nature and have great potential to remain intact in any kind of environment. These substances nowadays are continuously added into the freshwater ecosystem on daily basis by way of discharging untreated domestic, industrial, and agricultural wastewater. Most of these substances get accumulated in the bottom sediments and very minute concentrations, in the form of organic and inorganic constituents, remain either in suspended form or solution in the liquid medium of the freshwater ecosystem. According to these researchers, the presence of these kinds of pollutants in the freshwater ecosystem has long-term impacts on aquatic and associated biota. Therefore, the need to monitor the quality of the freshwater ecosystem on regular basis, and the focus should be given to the treatment of effluents before their discharge into the freshwater ecosystem to avoid contamination.

In addition to the acute problems of water pollution or contamination in developing countries, industrialised countries continue to struggle with pollution problems as well (Schueller & Holland, 2000). Recently, water quality monitoring has become a matter of concern in a stream and river systems affected by careless disposal of urban effluents. Run-off, atmospheric deposition, and domestic and industrial effluent discharges are the major sources of aquatic pollution (Lomniczi *et al*., 2007). Freshwater contaminants come from both organic and inorganic sources. Among the inorganic contaminants of river water, heavy metals are of great concern for their non-degradable nature and often accumulate through trophic levels, causing a deleterious biological effect (Kar *et al*., 2008; Zhu *et al*., 2015).

Human activities such as the discharge of industrial and domestic effluents, the use of agricultural chemicals, land use, and cover changes are the major factors that affect surface water quality (Peters & Meybeck, 2000; Hussain *et al*., 2008; Zhang *et al*., 2010; Khatri & Tyagi, 2015). Heavy metals are regarded as serious pollutants in aquatic ecosystems, because of their persistent toxicity, and ability to be incorporated into food chains (Howari & Banat, 2001; Armitage *et al*., 2007). Trace amounts of heavy metals are always present in freshwaters from the weathering of rocks and soils (Anderson, 2003; Idoko *et al*., 2012). Empirical evidence has shown that the anthropogenic activities that influence the water quality in River Tordzie are agriculture, domestic wastewater, and uncontrolled landfill sites.

2.4 Effects of Agriculture on Water Quality

Agricultural activities affect the quality of water if not managed well. Some of the activities of agriculture are; cultivating along river banks, fertilizer application, pesticides application, irrigation, etc. These activities affect the physical, chemical, and biological characteristics of water (Dafter *et al*., 2019). It is well known that agriculture is the single largest user of freshwater resources, using a global average of 70% of all surface water supplies. Except for water lost through evapotranspiration, agricultural water is recycled back to surface water and/or groundwater. However, agriculture is both cause and a victim of water pollution. It is caused through its discharge of pollutants and sediment to the surface and/or groundwater, through net loss of soil by poor agricultural practices, and salinization and waterlogging of irrigated lands. It is a victim through the use of wastewater and polluted surface and groundwater which contaminate crops and transmit disease to consumers and farm workers (Ganjo *et al*., 2006).

According to Elser *et al.,* (2007), pollution from agriculture is considered to be a non-point source that is pollution that is diffuse across a landscape. Non-point sources of pollution are often intermittent and linked to seasonal agricultural activities or irregular events such as heavy precipitation. The non-point sources of pollution often originate from extensive areas of land and are transported overland, underground, and through the atmosphere to water bodies. The non-point sources are therefore difficult to measure and regulate. Cultivation along the river banks also influences the presence of plant organic matter in rivers and lakes which results in a reduced amount of dissolved oxygen (DO) in the water (Weiner & Group, 2007). Tundu *et al*., (2018) opined that the cultivation of crops along river banks should be strongly avoided, not just because it influences the decreased amount of dissolved oxygen and loading of organic matter but because the practice also encourages the siltation of rivers leading to the loss of base flows of many rivers around the world.

Fertilizers, pesticides, herbicides, and animal wastes all pose a potential threat to groundwater and surface water quality. For example, common problems include the spillage of fertilizers and pesticides during handling, runoff from the loading and washing of chemical application equipment and the use of chemicals uphill from or within a few hundred feet of a well. Contamination may also result from the storage of chemicals in uncovered areas, or in locations where groundwater flows from the direction of the chemical storage to a well (Bernhardt *et al*., 2008). These pesticides may find their way into surface water and groundwater through surface water runoff or leaching respectively, depending on the soil properties and the slope, the type of pesticide used, and the timing of the application (Reichenberger *et al*., 2007). The introduction of pesticides in groundwater or surface water results in the contamination of water, which may travel far from the sources. This may result in increased water treatment costs. Besides these, pesticides are toxic and may cause death to aquatic life. The presence of these substances can make water unfit for use by humans and animals and can destroy aquatic habitats (Schweitzer & Noblet, 2018).

Anthropogenic activities like mining, disposal of treated and untreated waste effluents containing toxic metals as well as metal chelates from different industries, e.g. tannery, steel plants, battery industries, thermal power plants, etc., and also the indiscriminate use of heavy metals containing fertilizers and pesticides in agriculture resulted in deterioration of water quality (Ghosh & Vass, 1997; Kamara, 2019). Some of these metals like Cu, Fe, Mn, Ni, and Zn are essential as micronutrients for life processes in plants and micro-organisms, but other metals like Cd, Cr, and Pb have no known physiological activity, but they are proved to be detrimental beyond a certain limit (Bruins *et al*., 2000, Kar *et al*., 2008). One of the other major challenges associated with agricultural-related water quality deterioration is the difficulty associated with its “hard-to-notice” initial impacts, and by the time the impacts are noticed, remedial strategies are difficult to implement (Sharpley, 1999).

A high level of living entails a big demand for water, while simultaneously polluting this crucial resource to an alarming degree. It is critical to verify the quality of a water supply before it is used to avoid probable health risks or the extinction of specific species (van Dam *et al.*, 2011). Environmental difficulties develop as a result of inefficient management and control of residential, municipal, agricultural, and industrial wastes that end up in water bodies, as well as erosion in river catchments caused by clearing for farming, forestry, and firewood extraction, among other things (Water Resources Commission, 2000).

Since ancient times, most rivers in Ghana have served as both water extraction points and trash disposal areas. In Ghana's history, human settlement and land clearing for agriculture have played a significant role in the decline in water quality (Hillel, 1991). Similarly, there are several human activities along the banks of River Tordzie which threatens the quality of the water resources. These activities cut across agriculture, urbanization and domestic activities. Both commercial and subsistence farming is practiced along the banks of the river. Other economic activities include rearing of livestock mainly of dairy cattle, sheep and goats. These farmers use fertilizers and pesticides in their farming activities. The runoff from these finally finds its way into the river leading to the reduction of the water quality. According to Samah (2012), pesticide runoff occurs when pesticides are carried outside of the intended area of application through water or soil erosion thereby reducing the quality of rivers and other water bodies.

2.5. Physicochemical parameters

2.5.1 Alkalinity

It is the total measure of the substances in water that have an "acid-neutralizing" ability. Alkalinity indicates a solution's power to react with acid and neutralize it (Amosa, 2016). It is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known. It is significant in many treatments and uses of natural waters and wastewaters. Alkalinity above alkaline earth metal concentrations, is significant in determining the suitability of water for irrigation. Its measurements are used in the interpretation and control of water and wastewater treatment processes. Raw domestic wastewater has alkalinity less than or only slightly greater than that of water supply for domestic use. Proper operating anaerobic digesters, typically, have supernatant alkalinities in the range of 2000 mg/L to 4000 mg/L calcium carbonate ($CaCO_3$) (APHA, 2003). High alkaline waters are usually unpalatable. Excess alkalinity in water is harmful for irrigation which leads to soil damage and reduces crop yield. Alkalinity measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH (Asiamah, 2013). The main sources of natural alkalinity are rocks that contain carbonate, bicarbonate, and hydroxide compounds that dissolve in water. High alkalinity results in physiological stress on aquatic organisms and may lead to loss of biodiversity (WHO, 2008).

According to Fianko *et al*., (2013), farming practices that expose the soil and underlying rocks through the process of weathering could also have contributed to the alkalinity levels in the water. Alkalinity between 30 mg/L and 500 mg/L is generally acceptable to fish and shrimp (Abowei & George, 2009). Water that is a good buffer contains compounds, such as bicarbonates, carbonates, and hydroxide which combine with hydrogen ions (H^+) from the water hence raising the pH (more basic) of the water. Without the buffering capacity, any acid added to a lake would immediately change its pH drastically. Aquatic organisms benefit from a stable pH value in their optimal range (Addy *et al.,* 2004). The standard for alkalinity in a drinking water sample is 600 mg/L (WHO, 2003) but does not have a specific value regarding surface water quality.

In Assessment of water quality parameters of Kpeshie Lagoon of Ghana Alkalinity was determined by titrimetric method Apau *et al*., (2012). Another study by Duncan *et al*., (2020) also employed titrimetric method to analyse water quality withing Cape Coast metropolis. In the present study, the same method was employed to analyse the water quality of River Tordzie. This method was preferable to the other method because of the greater accuracy, convenience and its more rapid nature.

2.5.2 Total Suspended Solids (TSS)

Total suspended solids are all solid materials retained in a special glass fibre filter of pore size 0.45µm and are the difference between total solids and total dissolved solids. It is responsible for the turbidity of water creating health and aesthetic concerns for the end-users. Total suspended solids (TSS) contain organic and inorganic matter causing the water treatment process to be less effective and overly costly (Kadlec & Wallace, 2009). Total Suspended Solids (TSS) contribute to turbidity levels and play a role in the transport of nutrients, toxic and pollutants. The presence of total suspended solids in the water column may lead to clogging of fish gills, fills spawning and breeding grounds, and smothers benthic communities. Total suspended solids levels in surface water according to Bonareri, (2013) are elevated by soil erosion; urban runoff, wastewater, septic system effluent, and decaying plants and animals.

High total suspended solids levels in surface water absorb heat from sunlight, which increases water temperature and decreases levels of dissolved oxygen (Iqbal *et al*., 2010). Photosynthesis would hence also decrease since less light would be able to penetrate the water. As less oxygen is produced by plants and algae, there is a further drop in dissolved oxygen levels. It can further smother the eggs of fish and aquatic insects and can suffocate newly-hatched insect larvae. It is therefore important to control the level of total suspended solids in lagoons within the guideline since inorganic suspended solids attenuate light, primarily through the process of scattering. This results in the water body losing its ability to support aquatic life (Aglanu & Appiah, 2014). Though total suspended solids do not have a specific guideline value by surface water quality standard, the total suspended solids guideline value in drinking water is 500 mg/L (WHO, 2011).

According to research by Karikari and Ansa-Asare (2006), total dissolved solids was measured by gravimetric method after drying in an oven to a constant weight at 105 ^{o}C. The total suspended solid of the water was measured in the current study by using a Potable HM 1000 Trace2O photometer. This was used because of its availability at the laboratory at the time of conducting the research and its accurate results.

2.5.3 Electrical Conductivity

Electrical conductivity is a function of the total quantity of ionized materials in water. Higher conductivity values indicate the presence of dissolved salts such as sodium, chloride and potassium chloride in water. Electrical conductivity is directly proportional to temperature and it increases at a rate of 2% per 1^{o}C rise in temperature (Kadlec & Wallace; 2009; WHO, 2011). Electrical conductivity is an indicator of dissolved solids and hence dissolved ions in water. The concentration of ionic species is important in determining current conduction in an electrolyte (Odiyo *et al*., 2012). Electrical conductivity value in water is usually an indication of the presence of dissolved ions in water and their presence can alter the taste of water and contribute to its hardness. It also indicates the total dissolved solids present in the water. Water with high electrical conductivity values is not suitable for domestic purposes and irrigation, since it can lead to the salinity of agricultural soils. Electrical conductivity is also a measure of the ability of water to carry an electric current depending on the presence of ions, their total concentration, mobility, valence, and the temperature during measurement and is a rough indicator of mineral content in a water body. It is associated with free ions and water temperature and is a good indicator of the ionic content of salts in water and helps in determining ionic pollutants that are present in any water body (Mwaura, 2005).

The geology of the area through which the water travels has the greatest impact on conductivity in streams and rivers. Because granite is made up of more inert minerals that do not ionize when washed into the water, streams that run through granite bedrock have lower conductivity. Streams that pass-through clay soils, on the other hand, have increased conductivity due to minerals that ionize readily when washed into the water (Selvanayagam & Abril, 2015). Conductivity is affected by human activity as well. If minerals containing these ions are exposed to air and water, acid mine drainage can add iron, sulfate, copper, cadmium, and other ions. Also, due to the presence of nitrate and phosphate in sewage and farm runoff, conductivity might rise. Salts and other compounds that add ions to water can also be carried by roadway runoffs. Electrical conductivity in drinking water can have a negative impact on health at levels as low as 370 µS/cm *(*Saviour, 2012).

According to Fatoki and Muyima (2003), water sources with electrical conductivity levels of more than 1000 µS/cm are generally considered contaminated and not safe for human consumption. Asare-Bediako (2008), reported a mean value of electrical conductivity of 228 µS/cm in a study on the quality of drinking water in River Ofin. Kyekyeku (2011), also did a similar study on the Suraw River in Ghana as a result of the Chirano Gold Mines operations, however, the conductivity levels he observed, ranged from 181 µS/cm to 605 µS/cm. The concentrations of total dissolved solids and major ions are related to conductivity. Most freshwaters have a conductivity of 10 µS/cm to 1000 µS/cm, but some may reach 1500 µS/cm particularly in contaminated waterways or those that receive a lot of runoffs (APHA, 1995).

Electrical conductivity in water can be determined by using several instruments such as conductivity meter. A study by Jindal & Wats (2022) on Lake Sukhna determined the conductivity using E-Merck's conductivity. Another study by Miyittah *et al.*, (2020) on Abby Lagoon determined conductivity by using Water Quality Checker. However, in the current study, PC 700 Eutech Multi-Parameter bench top meter because of its precisions and cost effective.

2.5.4 Phosphates

Phosphorus, like nitrogen, is a critical nutrient required for all life. The most common form of phosphorus used by biological organisms is phosphate (PO_4), which plays major roles in the formation of DNA, cellular energy, and cell membranes (and plant cell walls) (U.S. Environmental Protection Agency, 2022). Phosphorus in natural and wastewaters is usually found in the form of phosphates. It exists in an inorganic form as orthophosphates and condensed phosphates and in an organic form as organically bound phosphates. Phosphorus plays a vital role in plant production. It is a constituent of nucleic acids (RNA and DNA), phospholipids, and coenzymes (Tucker, 1999). It also activates co-enzymes for amino acid synthesis and, like adenosine diphosphate (ADP) and adenosine triphosphate (ATP), plays a key role in energy transfer and storage (Uchinda, 2000). Phosphorus is a macronutrient required by plants that can also be found in soil in various forms as apatite phosphorus (AP), non-apatite inorganic phosphorus (NAIP), organic phosphorus (OP), and dissolved soluble reactive ortho-phosphorus (DSROP or SRP). Phosphorus can be adsorbed by soil particles and transferred to surface water as erosion debris (Lory, 1999). The main cause of anthropogenic eutrophication or nutrient enrichment in surface waterways is phosphorus. Leaching and drainage from agricultural lands, particularly where fertilizers are directly applied to the soil, as well as run-off, are non-point sources of phosphates (Mustapha & Gesto, 2014).

Phosphorus is a common ingredient in commercial fertilizers. High concentrations of phosphorus may result from poor agricultural practices, runoff from urban areas and lawns, leaking septic systems or discharges from sewage treatment plants. Too much phosphorus can cause increased growth of algae and large aquatic plants, which can result in decreased levels of dissolved oxygen– a process called eutrophication. High levels of phosphorus can also lead to algae blooms that produce algal toxins which can be harmful to human and animal health (U.S. Environmental Protection Agency, 2022). High phosphate levels in water are quickly consumed by plants and other microorganisms, reducing available dissolved oxygen and increasing turbidity thereby lowering water quality (Perera *et al*., 2014). Phosphates are not toxic to people or animals but when present at very high levels, can cause digestive problems and eutrophication of water bodies, increased biological oxygen demand, and decreased dissolved oxygen. Overdose of laxatives containing phosphates can cause hypocalcaemia due to low plasma calcium levels (Kumar & Puri, 2012). The guideline value for phosphate in drinking water is 400 mg/ L (WHO, 2008).

There are several methods used in analysing total phosphate. A study conducted by Nyantakyi *et al*., (2020) to determine phosphate in River Tano, used Aquakem 200 discrete analyser methods. A similar work by Abubakari *et al*., (2016) on the effect of industrial effluents on the quality of Onukpawahe Stream at Tema, employed the

Wagtech Potalab Photometer Model 7100 method for the analysis. However, in the present study, the ascorbic acid spectrophotometric method was employed to determine the total phosphate in the water. It provides an accurate, easy, quick and cheap method of analysis. It can be used to measure from low concentrations up to minor constituents.

2.5.5 Ammonia

In natural surface waters, ammonia occurs in two forms: ionized ammonia, NH_4^+, and un-ionized ammonia, NH_3. Ammonia can be produced naturally from the breakdown of organic matter and excreted by fish as a nitrogenous waste product. In fish, ammonia is a by-product of protein metabolism and is primarily excreted across the gill membranes, with a small amount excreted in the urine (Levit, 2010). Agricultural, industrial, and physiological processes are the most common sources of ammonia in the environment. Chloramine disinfection of water can result in the creation of ammonia in water bodies. Cement manufacturing industries can also be a cause of ammonia contamination in water bodies. Animal husbandry is a major source of ammonia in surface water. Ammonia has low toxicity on its own but in the presence of transition metals, it can be toxic as well as when the pH is high in a solution. In natural water, ammonia concentration is about 0.2 mg/L but groundwater can have a concentration up to 3.0 mg/L (WHO, 2011).

According to Metcalf *et al.*, (1991), the presence of a high level of ammonia in surface or groundwater, poses some form of challenge to both humans and other living organisms. Ammonia interferes with disinfection efficiency and causes taste and odour problems in water purification processes. A high concentration of ammonia results in nitrite formation through the nitrification process in which Nitrobacter spp and

Nitrosomonas spp bacteria oxidize it to form nitrite and the nitrite is further oxidized to form nitrate. High level of ammonia, greater than 1.0 mg/L, in water results in low dissolved oxygen content. Ammonia has a toxic effect on healthy humans only if the intake becomes higher than the capacity to detoxify. At a dose of more than 100 mg/kg of body weight per day (33.7 mg of ammonium ion per kg of body weight per day), ammonium chloride influences metabolism by shifting the acid-base equilibrium, disturbing the glucose tolerance, and reducing the tissue sensitivity to insulin (Gupta *et al*., 2015). It has been reported toxic to freshwater organisms at concentrations ranging from 0.53 mg/L to 22.8 mg/L. Toxic levels are both pH and temperature-dependent and the toxicity increases as the pH and temperature increase (Rim-Rukeh, 2016). High level of ammonia may affect hatching and growth rates of fishes. In the structural development of fishes, changes in tissues of the gills, liver, and kidneys may also occur leading to the dying of the fishes. Toxic concentrations of ammonia in the human body may cause loss of equilibrium; convulsions, coma, and death. That is why ammonia concentration level monitoring is an important task in water quality (Bollman & Revsbech, 2005).

Ammonia in water can be determined by several methods such as titrimetric method, ammonia-selective electrode method, a phenate method, automated phenate method and flow injection analysis (APHA, 2017). Mensah (2011) used direct Nesslerization Method was used to determine ammonia in water in Volta region. Another study by Samlafo and Adakwah (2021) also used Nessler method under alkaline condition to determine the concentration of ammonia in River Birim. Ammonia in the River Tordzie in the present study was determined by using phenate method (spectrophotometric method). This method was employed because it is environmentally friendly and less harmful as compared to Nessler method that make use of mercury and is more sensitive to give accurate result.

2.5.6 pH

The pH (power of hydrogen) is a measure of the concentration of hydrogen ions in the water or a measure of how acidic or basic it is on a scale of 0 to 14. A pH of 7 means neutral (Talling, 2010). Naturally occurring fresh waters have a pH range between 6.5 and 8.5. The pH of the water is very essential because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms (Stone *et al*., 2013). The pH of water is changed by detergents put into it and algae blooms. High alkalinity is indicated by pH values of 9.5 and above, while the acidity is indicated by pH values of four (4) and lower. In the aquatic environment, values below four (4) are often not conducive to life. The solubility and biological ability of chemical components such as nutrients and heavy metals, as well as other processes in a water body, are all determined by pH in the water (Ireland Environmental Protection Agency, 2001; Bellingham, 2006).

High pH may result from a high rate of photosynthesis by dense phytoplankton blooms. A pH higher than 7 but lower than 8.5 is ideal for biological productivity, but a pH less than 4 is detrimental to aquatic life (Abowei, 2010). The pH may be affected by total alkalinity and acidity caused by runoff from surrounding rocks, and water discharges. The pH of a water body influences the concentration of many metals by altering their availability and toxicity. Metals such as zinc (Zn) and cadmium (Cd) are most likely to have increased detrimental environmental effects as a result of lowered pH (Department of Water Affairs and Forestry, 1996). Water samples with low pH attributed to the discharge of acidic water into these sources by agricultural and domestic activities

(Meybeck, 1997). The pH value can sensitively indicate variations in water quality and is affected by dissolved substances (WHO, 2006). Irritation of the eyes, skin, and mucous membranes occurs when pH values are too high. pH values greater than 11 have been linked to eye discomfort and the worsening of skin conditions. Gastrointestinal discomfort is also possible in sensitive people. Low pH levels can have comparable consequences (WHO, 1996).

There are several instruments that can be used to measure the pH of water. A study by Kodom *et al*., (2018) on Physicochemical Parameters Assessment and Seasonal Variations of Surface Water Quality of the Volta Lake in Ghana, determined the pH by using Oakton Waterproof PCD 650 Multi-parameter Handheld Meter. In the present study, the pH was determined by using PC 700 Eutech Multi-Parameter bench top meter because of its precisions and cost effective.

2.5.7 Turbidity

Turbidity refers to the quantity of suspended material, which interferes with light penetration in the water column (Tessema *et al*., 2014). The clarity of the water is important in producing products destined for human consumption and in many manufacturing uses. Beverage producers, food processors, and treatment plants drawing on a surface water supply commonly rely on coagulation, settling, and filtration to ensure an acceptable product. The clarity of a natural body of water is a major determinant of the condition and productivity of that system**.** Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample.

Correlation of turbidity with the weight concentration of suspended matter is difficult because the size, shape, and refractive index of the particulates also affect the light-scattering properties of the suspension. Optically black particles, such as those of activated carbon, may absorb light and effectively increase turbidity measurements (APHA, 2017).

Turbidity is an important parameter in that, it can protect microorganisms from disinfection effects. It can encourage bacteria growth and can also create problems during water treatment processes (WHO, 2004). In water bodies, water turbidity can result from planktonic organisms or suspended clay particles. Turbidity limits light penetration, thereby limiting photosynthesis in the bottom layer. Higher turbidity can cause an increase in temperature and dissolved oxygen stratification in water bodies. Planktonic organisms are desirable when it is not excessive, but suspended clay particles are undesirable. It can cause clogging of gills or direct injury to tissues of aquatic organisms (Tessema *et al*., 2014).

Deterioration in drinking water quality in the distribution network is probably due to an increase in microbial numbers, an elevated concentration of iron, or increased turbidity, all of which affect the taste, odour, and colour, of the drinking water. Turbidity can provide shelter for opportunistic microorganisms and pathogens. Hence, waters with high turbidity, from organic sources, also give rise to a substantial chlorine demand for disinfection purposes. This could result in reductions in the free chlorine residual in distribution systems as protection against possible recontamination (Farooq *et al*., 2008; Karikari & Ampofo, 2013). According to the WHO (2011), although turbidity is not a threat to health it is an important indicator of the presence of contaminants that would be of health concern, especially from inadequately treated or unfiltered surface water.

Kodom *et al*., (2018) used the Colorimeter (HACH DR/890) method to measure the turbidity of water in their study on Volta Lake. The turbidity of the water was measured in the current study by using a Potable HM 1000 Trace2O photometer. This was used because of its availability at the laboratory at the time of conducting the research and its accurate results.

2.5.8 Total Dissolved Solids (TDS)

Total dissolved solids are a measurement of the total amount of organic and inorganic compounds in a liquid (Anantnarayan *et al.*, 2018). This includes anything present in water other than the pure water molecules. These solids are primarily minerals, salts, and organic matter that can be a general indicator of water quality (Suseela *et al*., 2020). Total dissolved solids levels beyond a certain threshold indicate hard water, which can lead to scale buildup in pipes and appliances. Scale building lowers system performance and raises maintenance expenses (Catli, 2009).

Natural sources, sewage, urban runoff, industrial wastewater, chemicals used in the water treatment process, and the nature of the pipe or hardware used to transfer the water, all contribute to the total dissolved solids in drinking water. There is no primary drinking water standard for total dissolved solid but the secondary standard for total dissolved solids is 500 mg/L (U.S. Environmental Protection Agency, 1991). In drinking water, the palatability of water with a total dissolved solids concentration of less than 600 mg/L is generally considered to be good; drinking water becomes significantly and increasingly unpalatable at total dissolved solid levels greater than about 1000 mg/L (WHO, 2006). When total dissolved solid levels exceed 1,000 ppm (parts per million), it is deemed unfit for human consumption. A high level of total dissolved solids is an indicator of potential concerns and should be investigated before drinking. Even the best water purification systems on the market require monitoring for total dissolved solids to ensure the filters and/or membranes are effectively removing unwanted particles from the water. Total dissolved solids are formed due to the ability of water to dissolve salts and minerals and these minerals produce unwanted taste in water (Mohsin *et al*., 2013). High total dissolved solids levels are undesirable because they promote scaling in water pipes, heaters, boilers, and other household appliances. (Gupta *et al*., 2009).

Total dissolved solid changes in natural water are frequently caused by industrial effluent or salt-water intrusion. Total dissolved solids can also suggest high quantities of ions like aluminum, arsenic, copper, lead, nitrate, and others which can be harmful to health. Consumers may find water with exceptionally low total dissolved solids concentrations unpalatable due to its flat, insipid taste; it is also corrosive to water supply systems (Anhwange *et al*., 2012). The United States Environmental Protection Agency recommends treatment when total dissolved solids concentrations exceed 500 mg/L or 500 parts per million (Farooq *et al*., 2008; Karikari & Ampofo, 2013). The permissible limit by WHO ranges from 250 mg/L to 500 mg/L. The surface water quality standard for total dissolved solids is 500 mg/L for category A surface waters according to Indian standards.

In research conducted by Attua *et al*., (2014), on water quality analysis of rivers in Akyem-Abuakwa area, total dissolved solid (TDS) was determined by weighing after evaporating a known volume of samples. According to research by Karikari and Ansa-Asare (2006), total dissolved solids was measured by gravimetric method after drying in an oven to a constant weight at 105 ºC. Total dissolved solids in the present study, was determined by using PC 700 Eutech Multi-Parameter bench top meter because of its precisions and cost effective.

2.5.9 Total hardness

The number of divalent cations present in water and the capacity of their salts to precipitate soap are measured by water hardness (Lutz *et al*., 1997). Hardness is generally defined as the sum of the polyvalent cations present in the water and expressed as an equivalent quantity of calcium carbonate ($CaCO_3$) (U. S. Environmental Protection Agency, 1976). The most common of such cations are calcium and magnesium (American Water Works Association, 1990). According to Roxas and Salgados (2014), total hardness is the sum of the hardness of calcium and magnesium and is expressed in mg/L of calcium carbonate because calcium and carbonate are the most dominant ions in water. Water hardness is based on the amount of calcium per litre. Dissolved polyvalent metallic ions from sedimentary rocks are natural sources of water hardness. Both calcium and magnesium are present in many sedimentary rocks such as limestone and chalk (WHO, 2011).

Excessive water hardness causes the formation of scale on heater surfaces such as kettles and hot water pipes. There is also the formation of scum on surfaces through the formation of insoluble salts of long-chain fatty acids requiring increased soap use to produce a lather when cleaning or bathing. Excessively soft water can interfere with the buffering capacities of copper plumbing materials, causing copper to be discharged into the water causing the concentrations to rise. The hardness of the water can be remedied by adding lime and then using an ion exchange process for mineralization to re-carbonate it (Department of Water Affairs and Forestry, 1996). Water with a hardness of more than 300 mg/L is regarded hard, water with a hardness of more than 150 mg/L is considered noticeable by most people, and water with a softness of less than 75 mg/L is considered soft. Hardness up to 500 mg/L is considered harmless from a health standpoint, but anything higher may have a laxative impact (APHA, 2003).

Total hardness in a study conducted by Saana *et al*., (2016) was determined by Aquachek® Total Hardness (Hach, USA) in groundwater. Another research by Karikari & Ansa-Asare, (2006) on Densu River also determined the total hardness by complexometric titration using ethylenediaminetetraacetic acid (EDTA). In the present study, EDTA titration was used to determine the total hardness. The determination of concentrations was completed using argentometric titration. This method was preferable to the other method because of the greater accuracy, convenience and its more rapid nature.

2.5.10 Chloride

Natural sources of chloride in drinking water include sewage and industrial effluents, de-icing salt in urban runoff, and saline intrusion. The addition of salt to food is the most common form of human exposure to chloride, and the amount consumed from this source is usually much higher than that obtained through drinking water (Soni & Bhatia, 2014). There are no biological mechanisms that can eliminate chlorides after they have entered a water body. Because of the prohibitively high expense, they are rarely removed at water treatment plants. Natural spikes in chloride concentration can occur during summer "low flow" periods when evaporation exceeds precipitation. However, recent increases in chloride concentrations nationwide are thought to be due to anthropogenic, or human-caused, factors such as road salt, sewage contamination, and water softeners (Pal & Chakraborty, 2017). Depending on the alkalinity of the water, excessive chloride concentrations accelerate metal corrosion in the distribution system. This may result in higher metal concentrations in the supply (Soni & Bhatia, 2014).

Excessive intake of chloride in drinking water tends to increase the asthmatic pressure of the extracellular fluid, this is closely related to the sensation of thirst, thus the regulation of the body fluids and electrolytes is achieved by the kidney and it is harmful to the kidneys. One of the principal inorganic ions in water is chloride in the form of chloride ions (Soni & Bhatia, 2014). Chloride in excess imparts a salty taste to water and beverages (WHO, 2011). The chloride concentration can be used as an important parameter for the detection of contamination by sewage, before other tests like BOD and COD (Verma *et al.*, 2013). However, chloride concentrations above about 250 mg/litre can give rise to a detectable taste in water (WHO, 2008).

Research by Catherine *et al.*, (2021) to determine the surface water quality of Onuiyieke River in Nigeria determined the concentration of chloride by mercuric nitrate titration. The present study employed Argentometric titration method. This method was used because of the availability of chemicals and its cheap price in the market, less hazardous as compared to mercuric nitrate titration and precise result.

2.5.11 Sulphates

Sulphates are widely distributed in nature and may be present in natural water in substantial concentrations. Sulphates occur naturally in numerous minerals, including barite, epsomite, and gypsum (APHA, 2003). Sulphates are found in low amounts in natural waters. However, if in abundance, sulphate may form sulphuric acid which is detrimental to aquatic ecosystems. Sulphuric acid is a strong acid that drastically lowers the pH of water bodies, resulting in a salty or bitter taste in the water. Sulphate ions are converted to hydrogen sulphide in the absence of oxygen, which is likewise hazardous to live creatures. It has the potential to disrupt cellular and enzyme functions (Dallas & Day, 2004). Sulphates are discharged into water bodies from mines, smelters, kraft pulp and paper mills, textile mills, and tanneries. Sodium, potassium, and magnesium sulphates are all highly soluble in water, whereas calcium and barium sulphates and many heavy metal sulphates are less soluble. According to Delisle and Schmidt (1977), atmospheric sulphur dioxide produced by fossil fuel combustion and metallurgical roasting processes may add to the sulphate concentration of surface waters.

Sulphate may also contribute to the corrosion of pipelines in the public distribution system (Mariraj & Vanalakshmi, 2013). When the concentration of sulphates rises above 100 mg/L the coagulation processes in drinking water treatment plants may be adversely affected. Sulphates and sulphide products lead to an increase in suspended solids and dissolved solids which lead to salination and decrease the dissolved oxygen content of the water system (Ashton *et al*., 2001). Even though there is no health-based sulphate guideline, high sulphate intake has gastrointestinal effects. This could lead to health problems like osteoporosis and renal damage. It is suggested that sources of drinking water with sulphate concentrations greater than 500 mg/L be reported to health authorities. The presence of sulphate in drinking water may also cause a noticeable taste and may contribute to the corrosion of distribution systems (WHO, 2008).

Sulphate in water can be determined in several ways such as turbidimetry method, gravimetric method with drying of residue, gravimetric method with ignition of residue, methylthylmol blue flow injection analysis (APHA, 2017). Sulphate ion in water was determined by the turbidimetric method in water (Magna, *et al.,* 2018). The present study saw the use of spectrophotometric method. This method was chosen because it provides an accuracycy, easy, quick and cheap method of analysis. It can be used to measure from low concentrations up to minor constituents.

2.5.12 Nitrates

Nitrates are naturally occurring forms of nitrogen present in the environment providing plants and living organisms with essential nutrients for growth (Burt, 1993). Anthropogenic sources of nitrates in the form of synthetic nitrogen fertilizers and animal manure application in agriculture are regarded as the main diffuse sources contributing to excess nitrates in soil and water aside from those from the atmospheric deposition processes (Bogardi & Kulzelka, 1991; Mclay *et al*., 2001). Local point sources of nitrate leaching include sewage effluents, septic tanks, latrines, buried domestic waste, livestock holding areas, and manure storage facilities (Bogardi & Kuzelka, 1991; Kross *et al*., 1992).

Several studies addressed nitrate contamination of groundwater from agricultural land in the African continent (Antrade & Stiger, 2009; Sall & Vanclooster, 2009). Eutrophication of surface waters represents an additional global environmental risk caused by the release of excess nutrients from agricultural land surface runoff and sewage effluents (Galloway *et al*., 2003). It has been established that high concentrations of nitrates result in the apparition of toxic algal blooms and hypoxic conditions in rivers, lakes, and coastal waters (Nyenje *et al.,* 2010). High levels of nitrate are toxic, especially to infants and it causes methemoglobinemia or blue baby disease, and eutrophication of rivers (Bellingham, 2006). When ingested into the human system, both nitrate and nitrite oxidize blood hemoglobin to methemoglobin with nitrite being approximately ten times as potent as nitrate. Methemoglobin cannot transport oxygen, and the oxygen-deficient blood causes the development of blue colour in tissues (cyanosis). The abnormal colour is usually first noticed in the lips, followed by the fingers and toes, the face, and then the whole body, and infants below 6-12 months of age are particularly susceptible (UNICEF & WHO, 2008).

Abdul-Razak *et al*., (2009) conducted a study on Oti River in Ghana to determine the level of nitrate used Dionex-80 ion analyzer method. In related study by Miyittah *et al.*, (2020) on water quality status of Aby Lagoon analysed nitrate by means of distillation method. In the present study, the ascorbic acid spectrophotometric method was employed to determine the nitrate in the water. It provides an accurate, easy, quick and cheap method of analysis. It can be used to measure from low concentrations up to minor constituents.

2.5.13 Chemical oxygen demand (COD)

The chemical oxygen demand is the measurement of the amount of oxygen in water consumed for the chemical oxidation of pollutants (Boyles, 1997). According to Talib and Amat (2012), chemical oxygen demand is the ability of water to absorb oxygen during the breakdown of organic substances and the oxidation of inorganic compounds such as ammonia and nitrite. The chemical oxygen demand determines the quantity of oxygen required to oxidize the organic matter in water samples, under specific conditions of an oxidizing agent, temperature, and time (Boyles, 1997).

The chemical oxygen demand is used to indirectly measure the number of organic compounds in water. Most applications of chemical oxygen demand determine the number of organic pollutants found in surface water, making chemical oxygen demand a useful measure of water quality (Harrafi *et al.*, 2012). It is expressed in mg/L, which indicates the mass of oxygen consumed per litre of solution. The chemical oxygen demand measurements are commonly made on samples of the waste-water treatment facility or of natural water contaminated by domestic or industrial waste (Alam, 2015). Its reliability is important to protect the environment and guarantee the economical sustainability of the treatment facility (Guoqing *et al.,* 2011). The chemical oxygen demand concentrations observed in surface water resources typically range from 20 mg/L or less in unpolluted waters to greater than 200 mg/L in waters receiving effluents. Industrial waste waters may have COD ranging from 100 mg/L to 60,000 mg/L (Chapman, 1992; Yilma *et al*., 2019).

There are several methods for COD determination. But the most common ones are open reflux and closed reflux. Open reflux method is suitable for a wide range of wastes where large volume of sample is required (for samples with COD = 50 mg O_2/L). In the second method: closed reflux methods, small quantities of metallic salt reagents are required and small quantities of hazardous waste is produced (for samples with COD = 5 to 50 mg O_2/L) (APHA, 2017). A study conducted to assess the water quality parameters of Kpeshi lagoon of Ghana by Apau *et al*., (2012) deployed closed reflux method to determine the COD. In the present study, closed reflux method (5220 C) was used because it is economical in the use of metallic salt reagents and is more efficient in the oxidation of volatile organic compounds than is the opened reflux method. Again, the method less contaminating and allows for the simultaneous digestion of a great number of samples.

2.5.14 Biological oxygen demand (BOD)

Biological oxygen demand (BOD) is the amount of oxygen required by aerobic microorganisms to stabilize the organic material of wastewater, wastewater treatment plant effluent, polluted water, or industrial waste (Sen *et al*., 2013). Biological oxygen demand is a measure of the dissolved oxygen consumed by microorganisms during the oxidation of reduced substances in waters and wastes. Natural sources of biological oxygen demand in surface waters include organic material from decaying plants and animal wastes. Human sources of BOD include faeces, urine, detergents, fats, oils, and grease (Penn *et al.*, 2009). The increasing oxygen consumed in the decomposition process robs other aquatic organisms of the oxygen they need to live. Therefore, organisms that are more tolerant of lower dissolved oxygen levels may replace a diversity of natural water systems containing bacteria, which need oxygen (aerobic) to survive. These organisms are part of the decomposition cycle and they feed on dead algae and other dead organisms (Anhwange *et al.*, 2012).

According to Eljaiek-Urzola *et al.*, (2019), biological oxygen demand is widely used to indicate the organic strength of the water. It indicates the concentration of biodegradable organic matter in the water. Usually, biological oxygen demand is measured for wastewaters and heavily polluted watercourses, because these types of water usually contain high concentrations of organic matter. Unpolluted waters typically have biological oxygen demand values of 2.0 mg/L or less, whereas water bodies receiving wastewater may have biological oxygen demand values up to 10.0 mg/L or more. The biological oxygen demand is usually proportional to the amount of organic matter present and, therefore, is a measure of the strength of the waste (Tikariha & Sahu, 2014). Increased oxygen consumption poses a potential danger to a variety of aquatic organisms, including fish. The presence of high BOD in water may indicate feacal contamination or an increase in particulate and dissolved organic carbon from non-human and animal sources that can restrict water use and development, necessitate expensive treatment, and impair ecosystem health (APHA,1998). The consequences of high biological oxygen demand are similar to those for low dissolved oxygen; aquatic organisms become stressed, suffocate and die. The discharge of wastewater with high levels of biological oxygen demand into waterbodies can cause serious dissolved oxygen depletion and death of aquatic animals in the receiving water bodies (Aniyikaiye *et al.*, 2019).

Research conducted by Anhwange *et al.*, (2012) on River Benue indicated biological oxygen demand value of 66.40 mg/L during the rainy season and 57.00 mg/L in the dry season. They concluded that the variation in biological oxygen demand observed was similar to that of Dissolved Oxygen (DO) and the general high BOD values observed during the wet season may be due to increasing Urban runoff which carries pet wastes from streets and sidewalks; nutrients from lawn fertilizers; leaves, grass clippings, and paper from residential areas into the river. Oxygen consumed in the decomposition process robs other aquatic organisms of the oxygen needed to live. Rivers with low BOD have low nutrient levels and this implies a high concentration of dissolved oxygen. Unpolluted, natural waters are expected to have BOD values of 5.0 mg/L or less (Agbaire & Oyibo, 2009).

In a study by Obiri *et al*., (2021) modified Winkler's method was used to determine the dissolved oxygen and Biochemical oxygen demand in water sample. Ibrahim *et al*., (2009) conducted research on the assessment of the physico-chemical parameters of Kontagora Reservoir, Niger State, used the Winkler Azide method to determine the dissolved oxygen in water. In the presence study, Winkler Azide method as prescribe in APHA, (2017) was used to determine dissolved oxygen and Biochemical oxygen demand. This method was chosen because of its accuracy, less cost and simplicity as compared other methods such as membrane-electrode method and the optical-probe method.

2.5.15 Colour

Drinking water should ideally have no visible colour. Colour in drinking water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. It may also result from the contamination of the water source with industrial effluents and may be the first indication of a hazardous situation. The source of colour in a drinking-water supply should be investigated, particularly if a substantial change has taken place. Suspended and dissolved particles in water influence colour. Suspended material in water bodies may be a result of natural causes and/or human activity (WHO, 2011).

Highly coloured water has significant effects on aquatic plants and algal growth. Light is very critical for the growth of aquatic plants and coloured water can limit the penetration of light. Thus, a highly coloured body of water could not sustain aquatic life which could lead to the long-term impairment of the ecosystem. Very high algal growth that stays suspended in a water body can prevent light penetration as well as use up the dissolved oxygen in the water body, causing a eutrophic condition that can drastically reduce all life in the water body. At home, coloured water may stain textiles and fixtures and can cause permanent damage, as the picture of the sink shows (Team, 2009).

In research conducted by Attua *et al*., (2014), on water quality analysis of rivers in Akyem-Abuakwa area, colour in water was determined by a portable data logging spectrophotometer (HACH DR/2010). In related research conducted by Anim-Gyampo *et al*., (2014), a multipurpose electronic DR/890 Colorimeter was used to measure turbidity. In the present study, a potable metalyser HM1000 Trace2O photometer was used to determine the turbidity. This was used because of its availability at the laboratory at the time of conducting the research and its accurate results. Also, the method is not hazardous to health as compared to other methods.

2.5.16 Dissolved Oxygen (DO)

Dissolved oxygen levels in natural and wastewater depend on the physical, chemical, and biochemical activities in the water. Dissolved oxygen is the main source of life for all organisms that lived in water and on land (Kanth *et al*., 2018). Dissolved oxygen is the measure of the degree of pollution by organic matter, the destruction of organic substances, and the self-purification process of the water body (Chiras, 1998). Dissolved oxygen is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution (APHA, 2003). The higher the concentration of dissolved oxygen, the better the water quality. Oxygen is slightly soluble in water and very sensitive to temperature. For example, the saturated concentration at 20° C is 9.0 mg/L and at 0° C is 14.6 mg/L (Omer, 2019).

The actual amount of dissolved oxygen varies depending on the pressure, temperature, and salinity of the water. Dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people (APHA, 2003). To Cleveland, (1998), dissolved oxygen can range from 0-18 parts per million (ppm), but most natural water systems require 5-6 parts per million to support a diverse population. A decrease in the dissolved oxygen levels is usually an indication of an influx of some type of organic pollutant. This low level of dissolved oxygen, usually called hypoxic levels indicates a high level of pollution or some type of human-caused (change) to the lagoon.

According to Nduka, *et al*., (2008), dissolved oxygen in the water body gives information on bacterial activity, photosynthesis, and availability of nutrients and is an indicator of good water quality. The dissolved oxygen changes with temperature, the lower the temperature the higher the dissolved oxygen, and vice versa. In the water body, dissolved oxygen gives information on bacterial activity, photosynthesis, and the availability of nutrients.

2.5.17 Iron

Iron is a dietary requirement for most organisms, and plays an important role in natural processes in binary and tertiary forms (Kamble *et al.*, 2013). Iron (Fe) is the first element in Group VIII of the periodic table. It has an atomic number of 26, an atomic weight of 55.85, and common valences of 2 and 3 (and occasionally valences of 1, 4, and 6). The average abundance of Fe in the earth's crust is 6.22%; in soils, Fe ranges from 0.5 to 4.3%; in streams, it averages about 0.7 mg/L; and in groundwater, it is 0.1 to 10 mg/L. Iron occurs in the minerals hematite, magnetite, taconite, and pyrite. It is widely used in steel and other alloys. Iron is the second most abundant metal in the earth's crust, of which it accounts for about 5% (APHA, 2017).

Iron exists naturally in rivers, lakes, and underground water. It may also be released into water from natural deposits, industrial wastes, refining of iron ores, and corrosion of iron-containing metals (Sankar & Rao, 2014). The combination of naturally occurring organic material and iron can be found in shallow wells and surface water. This water is usually yellow or brown but may be colorless (Colter & Mahler, 2006). Elemental iron is rarely found in nature, as the Fe^{2+} and Fe^{3+} readily combine with oxygen and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides. Iron is most commonly found in nature in the form of its oxides (Reddy Annem, *et al.*, 2017).

In drinking-water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as rust-coloured silt. Anaerobic ground waters may contain iron (II) at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well, although turbidity and colour may develop in piped systems at iron levels above 0.05 mg/litre – 0.1 mg/litre. Staining of laundry and plumbing may occur at concentrations above 0.3 mg/litre. Iron also promotes undesirable bacterial growth ("iron bacteria") within a waterworks and distribution system, resulting in the deposition of a slimy coating on the piping (Mensah, 2011). Aeration of iron-containing layers in the soil can affect the quality of both groundwater and surface water if the groundwater table is lowered or nitrate leaching takes place. Dissolution of iron can occur as a result of oxidation and a decrease in pH (Ferrante *et al.*, 2013).

Iron is a central component of haemoglobin. It binds oxygen and transports it from the lungs to other body parts. It then transports CO_2 back to the lungs, where it can be breathed out. Oxygen storage also requires iron. Iron is a part of several essential enzymes, and is involved in DNA synthesis. Normal brain functions are iron-dependent (Gupta, 2014). In the body, iron is strongly bound to transferrin, which enables the exchange of the metal between cells. The compound is a strong antibiotic, and it prevents bacteria from growing on the vital element. When one is infected by bacteria, the body produces high amounts of transferrin. When iron exceeds the required amount, it is stored in the liver. The bone marrow contains high amounts of iron because it produces haemoglobin (Marx, 2002).

Iron deficits lead to anemia, causing tiredness, headaches, and loss of concentration. The immune system is also affected. In young children, this negatively affects mental development, leads to irritability, and causes concentration disorder. Young children, pregnant women, and women in their period are often treated with iron (II) salts upon iron deficits (Tech, 2013). When high concentrations of iron are absorbed, for example by hemochromatosis patients, iron is stored in the pancreas, the liver, the spleen, and the heart. This may damage these vital organs. Healthy people are generally not affected by an iron overdose, which is also generally rare. It may occur when one drinks water with iron concentrations over 200 ppm (Kontoghiorghe & Kontoghiorghes, 2016). Iron compounds may have a more serious effect on health than the relatively harmless element itself. Water-soluble binary iron compounds such as $FeCl_2$ and $FeSO_4$ may cause toxic effects at concentrations exceeding 200 mg, and are lethal for adults upon doses of 10-50 g. Several iron chelates may be toxic, and the nerve toxin iron pentacarbonyl is known for its strong toxic mechanism. Iron dust may cause lung disease. The ingestion of large quantities of iron can damage blood vessels, cause bloody vomitus or stool, damage the liver and kidneys, and even cause death (Shivdas, 2014).

The present of iron in water can be determined by several methods such as such inductively coupled plasma method and phenanthroline calorimetric method (APHA, 2017). Varian Fast Sequential Atomic Absorption Spectrophotometer (AAS) was used to determine iron in River Birim (Samlafo & Adankwah, 2021). A similar study by Asiamah, (2013), also used Atomic Absorption Spectrophotometer (VARIAN AA 240FS) to determine iron in Owere River. The present study used calorimetric method to determine the level of iron in the river under study. This method was used because of its low cost and simple instrumentation procedure.

2.5.18 Lead

Lead is the fifth element in group IVA on the periodic table, it has an atomic number of 82, an atomic weight of 207.19, and valences of 2 and 4. The average abundance of lead in the earth's crust is 13ppm, in the soils it ranges from 2.6 to 25ppm; in streams, it is 3 µg/L and in-ground waters it is generally < 0.1 mg/L (APHA, 2017*)*. Lead occurs naturally in the environment. However, most of the high levels found in the environment come from human activities. Environmental levels of lead have increased more than 1,000-fold over the past three centuries as a result of human activity. The greatest increase occurred between the years 1950 and 2000 and reflected the increasing worldwide use of leaded gasoline. Sources of lead in surface water or sediment include deposits of lead-containing dust from the atmosphere, wastewater from industries that handle lead (primarily iron and steel industries and lead producers), urban runoff, and mining piles (ATSDR, 2007). Many studies have reported that environmental lead emissions have resulted in significant health effects on the central nervous system, haem-synthesis, reproductive system, as well as psychological and neurobehavioral functions, which may even increase the risk of cancer (Bellinger, 2005).

Lead is known to have its sources from Automobile emissions, lead smelters, burning of coal and oil, lead arsenate pesticides, smoking, mining, and plumbing. Other sources include domestic waste and discharges, storm runoffs, and sanitary landfills (Schweitzer & Noblet, 2018). Lead is a cumulative general poison, with infants, children up to 6 years of age, the fetus, and pregnant women being the most susceptible to adverse health effects. Its effects on the central nervous system can be particularly serious. Lead exposure is shown to be associated with a wide range of effects including neurological and behavioral defects, mortality (mainly due to cardiovascular disease), impaired renal function, hypertension, impaired fertility, adverse pregnancy outcomes, delay sexual maturation, and impaired dental health (WHO, 2011).

Lead is toxic to the blood and the nervous, urinary, gastric, and genital systems. Furthermore, it is also implicated in causing carcinogenesis, mutagenesis, and teratogenesis in experimental animals (Baht & Moy, 1997). Accumulation of lead in the organism produces damaging effects in the hematopoietic, hepatic, renal, and gastrointestinal systems (Correia *et al.*, 2000). According to Abou-Arab *et al.,* (2016), lead in the case of males, may get accumulated in testes, epididymis, vas deferens, and seminal vesicle. It deteriorates spermatogenesis and steroidogenesis activity by detaching the germinal cell layer from the basal membrane and also causes atrophy of Leydig cells. It reduces the density of seminal plasma with a significant decline in certain constituents like fructose and succinic dehydrogenase (Baht & Moy, 1997). The toxic level of lead in the human body is 500 ppm beyond which it causes anemia, brain damage, and vomiting (Patil & Ahmad, 2011).

Lead poisoning also causes inhibition of the synthesis of haemoglobin; dysfunctions in the kidneys, joints, reproductive system, cardiovascular system, and acute and chronic damage to the central nervous system (CNS) and Peripheral nervous system (PNS). Other effects include damage to the gastrointestinal tract and urinary tract resulting in bloody urine, and neurological disorders and can cause severe and permanent brain damage. Lead affects children by leading to the poor development of the grey matter of the brain, thereby resulting in a poor intelligent quotient (IQ). Its absorption in the body is enhanced by calcium and zinc deficiencies (Duruibe *et al*., 2007). Lead has been classified as an animal carcinogen, but the data on human carcinogenesis are considered inadequate. Some recent studies of cancer rates in lead trade workers (e.g., smelters, painters, body and fender repairmen) have shown an increase in standard mortality rates, but others have not (Landrigan *et al.*, 2000).

The most common analytical methods for the lead trace determination are the flame atomic absorption spectrometry (FAAS), the electrothermal atomic absorption spectrometry (ET AAS) and the inductivity coupled plasma emission spectrometry (ICP) (Anthemidis *et al.*, 2002; Silva *et al.*, 2009). Of the three aforementioned methods, ET AAS is the most sensitive technique with a detection limit in the sub-picogram range for most metals. More recently, the inductively coupled plasma-mass spectrometry (ICP-MS) has produced a detection limit in the same range with (ET AAS) (Becker, 2002). Nevertheless, the detection of metal trace elements in aqueous samples is difficult due to various factors, particularly their low concentration and the matrix effects (Farajzadeh & Fallahi, 2006). A study conducted by Emoyan *et al.,* (2006) to determine the concentrations of heavy metals in River Ijana in Nigeria employed a Pye-Unicam Atomic Absorption Spectrometry method to analyse lead in the water. In the present study flame atomic absorption spectrophotometer was used because the method is simpler and allows the determination of smaller lead concentrations as compared to the above method.

2.5.19 Cadmium

Cadmium (Cd) is the second element in Group IIB of the periodic table. It has an atomic number of 48, an atomic weight of 112.41, and a valence of 2. The average abundance of cadmium in the earth's crust is 0.16 ppm; in soils, it is 0.1 to 0.5 ppm; in streams, it is 1 µg/L, and in-ground waters it is from 1 to 10 µg/L. Cadmium occurs in sulfide minerals that also contain zinc, lead, or copper. The metal is used in electroplating, batteries, paint pigments, and alloys with various other metals. Cadmium is usually associated with zinc at a ratio of about 1-part cadmium to 500 parts zinc in most rocks and soils. The solubility of cadmium is controlled in natural waters by carbonate equilibria. Guidelines for maximum cadmium concentrations in natural water are linked to the hardness or alkalinity of the water (i.e., the softer the water, the lower the permitted level of cadmium). It is nonessential for plants and animals. Cadmium is extremely toxic and accumulates in the kidneys and liver, with prolonged intake at low levels sometimes leading to dysfunction of the kidneys. The United Nations Food and Agriculture Organization recommended maximum level for cadmium in irrigation waters is 10 µg/L. The U.S. EPA primary drinking water standard MCL is 10 µg/L (APHA, 2017).

Cadmium is one of the most toxic pollutants as a result of its teratogenic, carcinogenic, and mutagenic effects (Eisler, 1985; Bhattacharya *et al*., 2014). It is used in the steel, batteries, and plastics manufacturing industries and introduced into surface waters through wastewater discharges and local air pollution. It is also known to interfere with bone repair mechanisms and cause renal failure as it concentrates in the liver, kidneys, pancreas, and thyroid organs of the body. The surface water quality guideline for cadmium is 0.01 mg/L and the WHO has a guideline value of 3 µg/L in drinking water (WHO, 2011). Cadmium is also present as an impurity in several products, including phosphate fertilizers, detergents, and refined petroleum products. Enrichment of agricultural soils with phosphate fertilizers is the most documented source of cadmium contamination (Nziguheba & Smolders, 2008). Plants can accumulate cadmium to the levels that may not be toxic to the plants themselves but toxic to their consumers. Animals accumulate cadmium in the kidney, liver, and reproductive organs. Cadmium toxicity affects humans more than animals, because of their longevity and the accumulation of cadmium in their organs by eating cadmium-contaminated food

(Tudoreanu & Phillips, 2004). Elevated levels of cadmium in humans can cause kidney damage. Because of this reason, cadmium is listed as one of the metals under scrutiny by the U.S. Environmental Protection Agency (Yeung & Hsu, 2005).

The cadmium can be determined in water by several methods such as electrothermal atomic absorption spectrometric method, the flame absorption method and inductive coupled plasma method (APHA, 2017). Analysis of cadmium in the water samples was determined by using Atomic Absorption Spectrophotometer (VARIAN AA 240FS) instrument (Asiamah, 2013). In the present study flame atomic absorption spectrometry (FAAS) was deployed in the present study to determine cadmium and lead in the water because of its more frequently used technique due to its simplicity and lower cost.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.0 Overview

This chapter presents the study area, the materials, and the methodology of the determination of the physicochemical parameters and some selected heavy metals in the study as well as the water quality index and Nemerow's pollution index used to ascertain the quality of River Tordzie for both domestic and industrial purposes.

3.1 Study Area

The study was focused on the River Tordzie. It is located on latitude 5° 59ˡ north and longitude 0° 43ˡ east. River Tordzie is located in Ghana and forms part of the border to southwest Togo. River Tordzie has its source in the Togo Mountains and it enters Ghana around Honuta in Volta Region and flows through Kpedze. It drains a lot of districts in the region and enters the Avu lagoon at Xavi just northwest of the Keta Lagoon. The estimated terrain elevation above sea level is 5 metres. The length of the river is about 267km and drains a total area of approximately 2,228km^2. The area covered in Ghana is about 1865 km^2 which constitutes 83.7% and the remaining area in Togo is about 363 km^2 which is 16.3%. The discharge average of the River Tordzie is 11m^3/s (Water Resources Commission, 2010, Nyatuame & Agodzo, 2017). Agricultural activities such as maize, cassava, sugar cane, and vegetable cultivation are the main livelihood for the people leaving along the river for their daily food supply, source of income and employment. However, only seven communities leaving along the river in the Volta region were selected for the study because of the distance from the researcher to other towns up north.

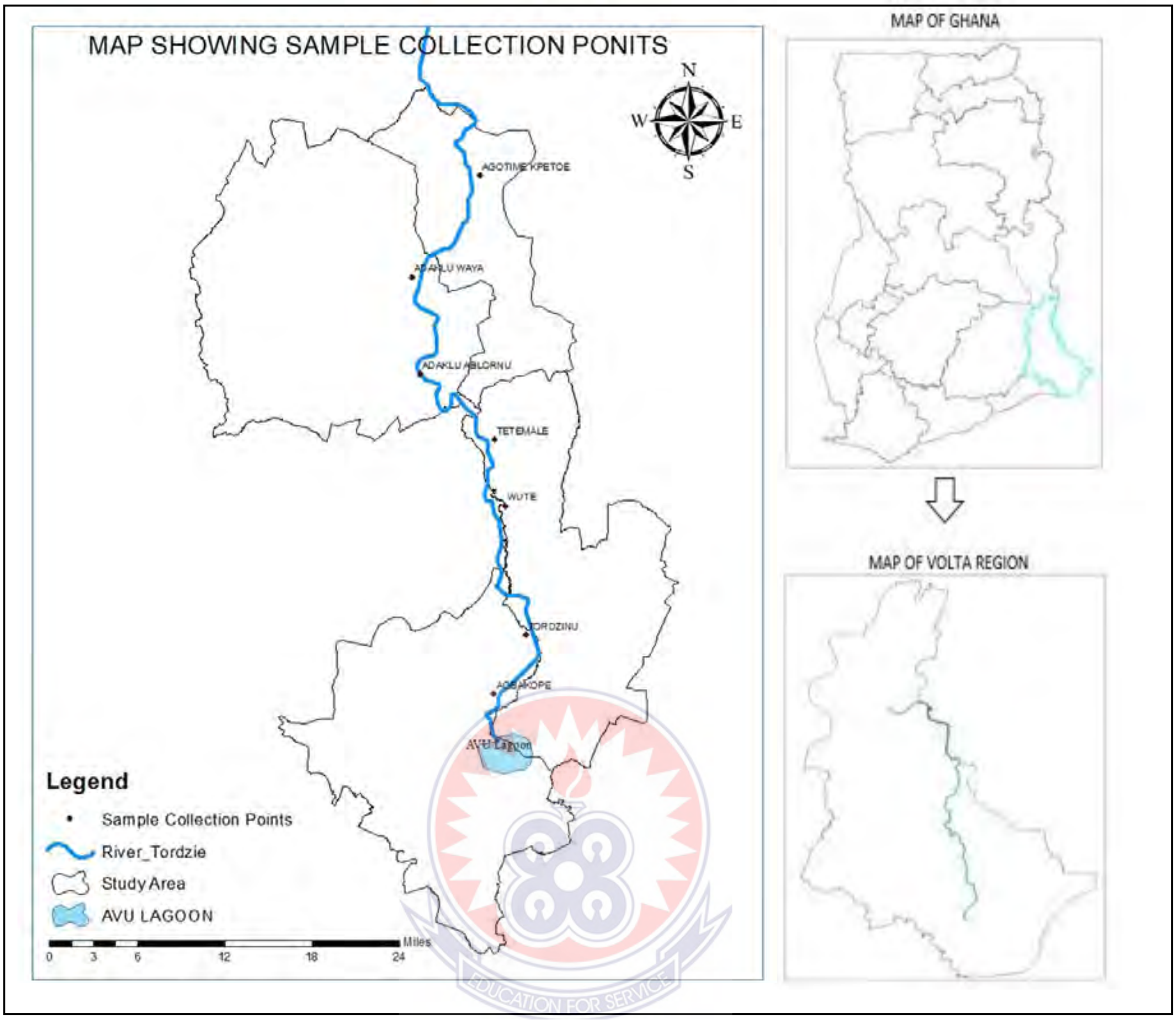

Figure 1: Map of Ghana showing the study area and sample collection points.

3.2 Sampling

Water samples were collected from some selected sampling points from the river. The water samples were collected in March before the main raining season and during the rainy season in July 2021. A total of forty-two samples of water were collected in triplicates at seven sampling points. To prepare the sampling bottles for collecting water samples, many processes were followed. These include using detergent, washing them with plenty of running tap water, rinsing them with deionized water, and finally air-drying them. Before the sampling, the washed 500 mL polyethylene bottles were rinsed with the water sample from the river at each sampling site. A simple grab method was used for the sampling. Water samples for physicochemical analysis were collected and stored in 500 mL sterilized polyethylene bottles. Water samples for metal analysis were acidified with 1.0 mL concentrated trioxonitrate (V) acid. Acidification of samples was done to keep metal ions from precipitating and to minimize the adsorption of dissolved species onto the sample containers. Three samples were taken at each sampling point for physicochemical and heavy metal analysis. Each sample bottle was well labeled and relevant details recorded at the sampling sites. All the samples were stored in an ice-chest containing ice cubes and transported to the University of Cape Coast (UCC) Water and Sanitation laboratory in the Central Region of Ghana for analysis. Water sampled for the physicochemical parameters was analyzed within a week.

3.3 Determination of physicochemical parameters

3.3.1 Determination of pH, Total dissolved Solid, and Electrical Conductivity

These parameters were determined on the site. A PC 700 Eutech Multi-parameter bench top meter was used to determine these parameters. The instrument was calibrated using a pH of 4 and 9 respectively to ensure accuracy and increase precision. Beakers were washed, cleaned, and dried before pouring the samples to be analyzed in them. The pH probe was inserted into the sample and the instrument was allowed to stabilize before the readings were recorded. Similarly, the conductivity probe was calibrated using potassium chloride, KCl solution. The instrument was allowed to stabilize anytime the conductivity reading was taken. Total dissolved solids were measured similarly. All samples were measured in triplicates and the average values were determined.

3.3.2 Determination of Turbidity, Colour, and Total Suspended Solids

A potable metalyser HM1000 Trace2O photometer was used to measure these parameters. The instrument was calibrated with de-ionized water; any time these parameters were to be measured. A 10 mL of the measured samples were transferred into the cleaned washed vial and the surfaces of the vial were wiped with soft tissue, the vial and its content were then placed in the sample chamber of the photometer and the parameter of interest was selected. The read button was then pressed for the concentrations of the samples to be determined, samples that were over range were diluted and later multiplied by the dilution factor to determine the actual concentration. All samples were measured in triplicates and the average values were determined.

3.3.3 Total Hardness

EDTA titrimetric method was used based on APHA (1998) standard. EDTA is Ethylene diamine tetra acetic acid. It dissolves in water with great difficulty, but its disodium salt dissolves in water quickly and completely. It is a hexadentate ligand. It binds the metal ions in water to give a stable chelate complex. Hence it is called the complexometric titration method.

Preparation of the reagents

Indicator: Eriochrome Black T solution. This was prepared by dissolving 0.5g Eriochrome Black T sodium salt in 100 mL triethanolamine.

- Buffer solution: The buffer solution was prepared by dissolving 16.9g NH_4Cl in 143 mL concentrated NH_4OH. A 1.25g of magnesium salt of ethylene diamine tetraacetate (EDTA) was weighed and added and the solution was diluted to 250 mL with distilled water in a volumetric flask.

- Standard EDTA titrant: 0.01M solution was prepared by weighing 3.723g di-sodium salt of EDTA dihydrate, dissolved in distilled water and diluted to 1000 mL, and was stored in a polyethylene bottle.
- Standard calcium solution was prepared by weighing 1.0 g of anhydrous $CaCO_3$ in a 500 mL flask. A small volume (about $3cm^3$) of HCl was added through a small funnel till all $CaCO_3$ was dissolved and 200 mL of distilled water was added and boiled for a few minutes to expel CO_2. It was cooled and a few drops of methyl red indicator was added. It was adjusted to intermediate orange colour by adding 3M NH_4OH. The solution was transferred into a 1000 mL volumetric flask and diluted to the mark with distilled water.

Procedure for determining total hardness

Using a graduated measuring cylinder, 50 mL of the water sample was measured and transferred into a cleaned conical flask and 1.0 mL of the buffer was added to give a pH of 10.0 to 10.1. About 2.0 mL of the indicator solution was added and after 5 minutes, the content was titrated with EDTA titrant which changed in colour from reddish tinge to blue. The titration process was repeated two times to obtain consistent values. The average titre value was calculated.

Total hardness was calculated as:

$$\text{Total Hardness (EDTA), mg CaCO /L} = \frac{A \times B \times 1000}{\text{mL of sample}}$$

Where: A = mL EDTA titrated for sample

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant.

3.3.4 Determination of Chloride

The amount of chloride in the water samples was determined by the Argentometric titration method. Standard methods as prescribed in American Public Health

Association (APHA, 1998) was followed to determine the concentration of chloride in the water.

Preparation of the reagents

- The silver nitrate titrant solution of 0.0141M was prepared by dissolving 2.395g $AgNO_3$ in distilled water and diluted to 1000 mL using a volumetric flask.
- The potassium dichromate (K_2CrO_4) indicator solution was prepared by dissolving 50.0g of K_2CrO_4 in a small volume of distilled water in a beaker. A 1.0 M silver trioxonitrate (V), $AgNO_3$ solution was added until a definite precipitate occurred. The solution was made to stand for twelve hours, after which it was filtered and diluted to 1000 mL.
- Aluminium hydroxide suspension was prepared by dissolving 125.0g aluminium potassium sulphate, $AlK(SO_4)_2.12H_2O$ in 1L distilled water. It was warmed to 60°C and 55 mL concentrated ammonium hydroxide solution was added slowly with stirring. The solution was left to stand for about 1 hour and was transferred to a large bottle. The precipitate was washed two times for it to be free of chloride, by successive addition of distilled water, settling, and decanting.

Procedure for determining chloride

Using a measuring cylinder, 50.0 mL of water sample was transferred into a clean conical flask and 3.0 mL of $Al(OH)_3$ suspension was added, mixed, allowed to settle, and filtered. Then 1.0 mL of 5% Potassium chromate (K_2CrO_4) indicator was added. It was then titrated against 0.0141M $AgNO_3$ solution, with gentle swirling until the colour changed to pinkish yellow. The titre was read and recorded in millimeters. The procedure was repeated two other times and the average titre was calculated. The titration was repeated with distilled water as a blank.

The concentration of chloride was calculated as:

$$Cl^{-}\ (mg/L) = \frac{(A-B) \times N \times 35450}{mL\ sample}$$

where: A = mL titration for sample

B = mL titration for blank

N = normality of $AgNO_3$

3.3.5 Determination of Phosphate

Ascorbic acid spectrophotometric method (Orthophosphate-Phosphorus) method was used to determine the phosphate in water samples after it had been standardized using a 6705 UV / visible spectrophotometer following standard laboratory protocols described by APHA (2017).

Preparation of the reagents

- Sulphuric acid, H_2SO_4 of 5.0M was prepared by diluting 70.0 mL concentrated H_2SO_4 in a 500.0 mL volumetric flask with distilled water.
- Potassium antimonyl tartrate solution was prepared by dissolving and weighing 1.3715g $K(SbO)C_4H_4O_6.1/2\ H_2O$ into 400 mL distilled water and diluted to 500.0 mL volumetric flask. It was stored in a glass stoppered bottle.
- Ammonium molybdate solution. This was prepared after weighing 20.0g of $(NH_4)_6\ Mo_7O_{24}.4H_2O$ and dissolving into a 500.0 mL volumetric flask with distilled water and was stored in a glass stoppered bottle.
- Ascorbic acid of 0.1M was prepared by dissolving 1.76g of ascorbic acid in 100.0 mL distilled water and kept at 4°C.
- Combined reagents: This was prepared by mixing 50.0 mL of 5M, H_2SO_4, 5.0 mL potassium antimonyl tartrate, 15.0 mL ammonium molybdate solution, and 30.0 mL ascorbic acid solution, in the order given and at room temperature. It was allowed to stand for 4 hours.

- Stock phosphate solution was prepared by dissolving 219.5 mg anhydrous KH_2PO_4 in distilled water and diluted to 1 L.
- Standard phosphate solution: this was prepared by diluting 50.0 mL of the stock solution to 1L with distilled water.

Procedure for determining phosphate

50 mL sample of the water was measured into a 125.0 mL conical flask, and 1 drop of phenolphthalein indicator was added. Any red colour that was developed was discharged by adding 5.0M H_2SO_4. About 8.0 mL of the combined reagent was added and mixed thoroughly. It was allowed to stand for about 10 minutes to 20 minutes and the absorbance for each sample was read at 880nm using a Palintest photometer. A reagent blank as a reference was used.

Correction for turbid or coloured samples. A sample blank was prepared by adding all reagents except ascorbic acid and potassium antimonyl tartrate to the sample. The blank absorbance was subtracted from the sample absorbance reading. The same procedure was repeated for the standard solution of different concentrations of distilled water. The concentration was determined with the help of a calibration curve obtained by plotting standard values against absorbance.

Preparation of calibration curve: A calibration curve was prepared from a series of standards between 0.15-1.30 mg per litre range (for a 1.0 cm light path cuvets). Distilled water was used as a blank with the combined reagent. A graph of absorbance versus phosphate concentration was plotted to give a straight line.

3.3.6 Total Alkalinity

The titrimetric method was used to determine total alkalinity in water that is titrimetric to pH = 8.3 (phenolphthalein). This was determined by following standard laboratory protocols described by APHA (2017).

Preparation of the reagents

- Standard sodium carbonate, approximately 0.05M was prepared by dissolving a weighed mass of 2.5g of sodium carbonate in a 1L volumetric flask.
- Standard H_2SO_4 approximately 0.1M was prepared by diluting 2.8 mL concentrated sulphuric acid to 1L. It was Standardized against 40.00 mL 0.05M Na_2CO_3 with about 60 mL distilled water in a beaker by titrating potentiometrically to a pH of 5. The electrode was lifted out, rinsed into the same beaker, and boiled gently for 3 to 5 minutes under a watch glass cover. It was cooled to room temperature and was titrated to a pH of 4.3. The normality of sulphuric acid was calculated as:

  Normality, $N = \frac{A \times B}{53.0 \times C}$

  Where: A = grams of Na_2CO_3 weighed

  B = mL Na_2CO_3 solution taken for standardization titration

  C = mL acid used in standardization titration
- Standard sulfuric acid or hydrochloric acid, 0.1M: 200.00 mL 0.10M standard acid was measured and diluted to 1000 mL with distilled or deionized water.
- Bromcresol green indicator solution, pH 4.5 indicator: 100 mg bromcresol green, sodium salt, was dissolved in 100 mL distilled water.

Procedure for determining Total Alkalinity

The burette was filled to the top with H_2SO_4 and all air bubbles were removed from the tip and the burette was set to 0.00. The initial reading from the burette was taken. Using a graduated measuring cylinder, 50.0 mL of water sample was measured into a clean conical flask. A cleaned magnetic stir bar was added and was placed on stir plate and two drops of indicator, bromcresol green solution were added. The sample turned blue and was titrated against 0.02M H_2SO_4, whiles stirring gently until the blue colour just turned yellow. The titre value was read and recorded.

Total alkalinity, mg $CaCO_3$ /L = $\frac{\mathrm{B \times N \times 50000}}{\mathrm{mL\ sample}}$

Where:

B = total mL of titrant used to bromcresol green endpoint

N = normality of titrant

3.3.7 Determination of Ammonia

Ammonia was determined by using phenate method using spectrophotometer. This was done following standard laboratory protocols as described in APHA (2017). An intensely blue compound, indophenol, is formed by the reaction of ammonia, hypochlorite, and phenol catalyzed by sodium nitroprusside.

Preparation of the reagents

- Alkaline citrate: 200.0g trisodium citrate and 10.0g sodium hydroxide were dissolved in de-ionized water and diluted to 1L.
- A phenol solution: 11.1 ml liquefied phenol was mixed with 95 % ethanol in a 100ml volumetric flask and made up to the mark.
- Oxidizing solution: 100 mL alkaline citrate solution was taken and mixed with 25 mL sodium hypochlorite.

- Stock ammonium solution: 3.8g anhydrous, NH_4Cl, was weighed after being dried at 100°C and cooled in a desiccator, in ammonia-free water, and diluted to 1L.
- Sodium nitroprusside solution: 0.5 g of Sodium nitroprusside was dissolved in 100 ml deionized water in a volumetric flask.
- Standard ammonium solutions: These dilutions were prepared from the stock ammonium solution, in a range appropriate for the concentration of the samples; to prepare a calibration curve. A series of standard solutions was prepared covering concentrations of 0.1, 0.5, 1.0, 1.5, and 2.0 ppm NH_4-N/L by making appropriate dilutions with deionized water. The standards were prepared in 100 ml volumetric flask. A blank was prepared the same way.

Procedure for determining ammonia

A 25 mL volume of the sample was taken into a 50 mL conical flask and was added with mixing to 1 mL phenol solution, 1 mL sodium nitroprusside solution, and 2.5 mL oxidizing solution. Light exposure was avoided by suitably covering the flasks at room temperature. The samples were covered with plastic wrap or paraffin wrapper film. The absorbance was measured after 1 hour at 640nm.

Calculation

A calibration curve was prepared by plotting absorbance readings against ammonia concentration standards. The sample concentrations were computed from the standard curve.

3.3.8 Determination of Sulphate

Sulphate was determined by following standard laboratory protocols described by APHA (2017) by using spectrophotometric method.

Preparation of the reagents

- Buffer solution: A 30.0g magnesium chloride, $MgCl_2.6H_2O$, 5.0g sodium acetate, $CH_3COONa.3H_2O$, 1.0g potassium nitrate, KNO_3, and 20.0 mL acetic acid, CH_3COOH (99%) were dissolved in 500 mL distilled water and made up to 1000 mL.
- Barium chloride, $BaCl_2$ crystals.
- Standard sulphate solution: 10.4 mL standard 0.02M H_2SO_4 was diluted to 100.0 mL in a volumetric flask.
- Standard sodium carbonate solution of approximately 0.05M. 5.0g of sodium carbonate, Na_2CO_3, was dried at 250°C for 4 hours and cooled in a desiccator. A 2.50g was accurately weighed, dissolved in a small volume of distilled water, and made up to the mark in a 1L volumetric flask.
- Standard H_2SO_4 solution of approximately 0.1M was prepared by diluting 2.8 mL concentrated sulphuric acid to 1L. The prepared H_2SO_4 was standardized against 40.00 mL 0.05M of sodium carbonate (Na_2CO_3) in a volumetric flask and boiled gently on a hot plate for 3 to 5 min under a watch glass cover. It was cooled to room temperature; the cover glass was rinsed into the beaker and the titration was completed by titrating it to a pH of 4.3. The normality of sulphuric acid was calculated as:

  Normality, $N = \frac{A \times B}{53.0 \times C}$

  Where: A = grams of Na_2CO_3 weighed

  B = mL Na_2CO_3 solution taken for standardization titration

  C = mL acid used in standardization titration.

Procedure for determining sulphate

A 100 ml volume of water sample was measured into a 250 ml Erlenmeyer flask. Exactly 5 ml conditioning reagent was added and mixed thoroughly by stirring. A 0.3 g (about spoonful) of barium chloride crystals was added while still stirring. It was allowed to stand for 60 seconds. After stirring, the absorbance was measured at 420 nm using UV-Visible spectrophotometer. A blank without $BaCl_2$ was prepared and run at the same wavelength.

3.3.9 Determination of Total Iron

Iron content in the water samples was determined by the colorimetric method as prescribed in APHA (2017) protocol for standard methods for examination of water and waste water.

Preparation of the reagents

- Hydrochloric acid, HCl concentration with less than 0.00005% iron.
- Hydroxylamine solution: 10.0g $NH_2OH.HCl$ was dissolved in 100.0 mL distilled water.
- Ammonium acetate buffer solution: This was prepared by dissolving 250.0g of $NH_4C_2H_3O_2$ in 150 mL distilled water and 700 mL glacial acetic acid was added.
- Sodium acetate solution: This was prepared by dissolving 200 g $NaC_2H_3O_2.3H_2O$ in 800 mL distilled water.
- Phenanthroline solution: 100mg 1,10-Phenanthroline monohydrate, $C_{12}H_8N_2.H_2O$, was dissolved in 100 mL distilled water by stirring and heating to 80°C without boiling.

- Stock iron solution: 20.0 mL concentrated H_2SO_4 was slowly added to 50.0 mL distilled water and 1.404g ferrous ammonium sulphate, $Fe(NH_4)_2(SO_4)_2.6H_2O$ was dissolved in it and 0.1M $KMnO_4$ added dropwise until a faint pink colour persists and was diluted to 1 L with distilled water and mixed.
- Standard solutions were prepared for the following concentrations: 2.0,4.0, 6.0, and 8.0 ppm. Using a pipette 2.0,4.0, 6.0, and 8.0 mL of the 100 ppm stock solution were transferred into five separate 100 mL volumetric flasks. To each of the flasks, 5 mL of a 0.25% ortho-phenanthroline solution were measured and added to each flask. They were diluted to the 100 mL mark by adding deionized water.

Procedure for determining Total Iron

In this method, 50 mL of the sample was taken into a conical flask. A 2.0 mL of concentrated HCl and 1.0 mL of hydroxylamine hydrochloride ($NH_2OH.HCl$) solution were added. Some glass beads were put into the flask and boiled till the volume was reduced to about 15.0 – 20.0 mL. It was cooled and transferred to a 100.0mL volumetric flask. A 10.0 mL volume of acetate buffer solution ($NH_4C_2H_3O_2$) and 2.0 mL of Phenanthroline solution were added, then orange-red colour appeared. Distilled water was added to make the volume up to 100.0 mL in a volumetric flask. It was mixed thoroughly and allowed to stand for 10 minutes for the colour to develop. The absorbance was measured by using a spectrophotometer at 510 nm using distilled water blank with the same amount of chemical. The same procedure was repeated for standard solutions of different concentrations. A graph of the absorbance versus iron concentration for the standards was plotted. The concentration of the iron was determined with the help of the standard curve.

3.3.10 Determination of Nitrate

The nitrate was determined by using UV spectrophotometric method as prescribed in standard methods for examination of water and waste water, APHA 2017 protocol.

Preparation of the reagents

- Stock Nitrate solution: 0.7218g of KNO_3 was dissolved in distilled water and diluted to 1L. It was preserved with 2.0 mL of $CHCl_3$/L.
- Standard Nitrate Solution: 100.0 mL of stock solution was diluted to 1000.0 mL with distilled water, and was preserved with 2.0 mL $CHCl_3$/L.
- The hydrochloric acid solution, HCl, 1M: A volume of 83.0 mL concentrated HCl was added to about 850 mL of distilled water while mixing, cooled, and diluted to 1L.
- Calibration standards of NO_3^- were prepared in the range of 1 to 7 mg NO_3^- N/L by diluting various volumes of stock solution to 50.0 mL. The following volumes of stock nitrate solution were used: 0.2, 0.4, 0.8, 1.4, 2.0, 3.0 4.0, 5.0, 6.0 mL in preparing the calibration standards.

Procedure for determining the nitrate

A 50.0 cm^3 of the water samples were pipetted into conical flasks. A volume of 1.0 mL HCl was added and mixed thoroughly. The mixtures were allowed to stand for 15 to 20 minutes. The nitrate concentrations were determined at a wavelength of 410nm of absorbance. A blank analysis was performed with all the reagents without a sample as a control. This procedure was repeated on the other samples including the standard solutions for making a standard calibration curve.

A straight-line graph of absorbance at 410nm versus concentration passing through the origin was obtained for the prepared standard solutions and the concentration of the nitrate was determined.

3.3.11 Determination of Chemical Oxygen Demand (COD)

The chemical oxygen demand was determined by using the closed reflux titrimetric method as prescribed in APHA, 2017 protocols for determination of COD in water.

Preparation of reagents

- Standard potassium dichromate solution, (0.25 M): 12.30 g of $K_2Cr_2O_7$ was dissolved in a small volume of distilled water and was diluted to 1000 mL.
- Sulphuric acid reagent: Conc. H_2SO_4 containing 23.5 g silver sulphate, Ag_2SO_4.
- Standard ferrous ammonium sulfate (FAS) titrant of approximately 0.250 M: 98.0 g of $Fe(NH_4)_2(SO_4)_2$ $6H_2O$ was dissolved in distilled water. 20 mL of concentrated H_2SO_4, was added, cooled, and diluted to 1 liter.
- Standardization: A 25.0 mL of standard potassium dichromate solution was diluted to about 250 mL with distilled water. 20 mL conc. sulphuric acid was added, Cooled, and titrated with ferrous ammonium sulphate titrant, using 10 drops of ferroin indicator.
- Normality of FAS solution = [(mL $K_2Cr_2O_7$) (0.25)] / [mL $Fe(NH_4)_2(SO_4)_2$]
- Mercuric sulfate: Powdered $HgSO_4$.
- Phenanthroline ferrous sulfate (ferroin) indicator solution: This was prepared by dissolving 1.48 g of 1-10-(ortho) phenanthroline monohydrate, together with 0.70 g of $FeSO_4 .7H_2O$ in 100 mL of water.

Procedure for Determining Chemical Oxygen Demand

A 2.5 mL aliquot of the sample was pipetted into a 10 mL conical flask and 3.5 mL of H_2SO_4 was added and mixed thoroughly. The digestion solution of potassium dichromate was added to the mixture. It was placed in a block digester and preheated to 150°C and refluxed for 2 hours behind a protective shield. Glass beads were added to the refluxing mixture to prevent bumping. The wall of the flask was washed with distilled water and the mixture was allowed to cool. It was titrated with standard ferrous ammonium sulfate using 1 or 2 drops of ferroin indicator. The colour change was from bluish-green to reddish-brown and this was taken as the endpoint. A blank was run, using 2.5 mL of distilled water in place of the sample together with all reagents and subsequent treatment.

The COD was calculated using the formula:

COD as mg O_2/L = $\frac{(B-A)\times M\times 1000}{\text{mL sample}}$

Where:

A = mL FAS used for blank

B = mL FAS used for sample

M = molarity of FAS and

8000 = milliequivalent weight of oxygen × 1000mL/L

3.3.12 Determination of Dissolved Oxygen (DO)

The dissolved oxygen was determined using the Winkler Azide method.

Preparation of the reagents

- Manganous sulphate solution: A 480.0 g $MnSO_4 .4H_2O$ was weighed and dissolved in distilled water, filtered, and diluted to 1 litre.
- Alkali-iodide-azide reagent: This was prepared by dissolving 500.0 g NaOH in distilled water and diluting it to 1 litre. A 10.0 g of sodium azide (NaN_3) dissolved in 40 mL distilled water was added.
- Concentrated sulphuric acid
- Starch indicator: This was prepared by dissolving 2.0 g laboratory-grade soluble starch in approximately 800 mL boiling water with stirring. It was diluted to 1

litre, and allowed to boil for a few minutes. It was allowed to settle overnight. A 0.2 g salicylic acid as a preservative, in 100 mL hot distilled water was used.

- Standard sodium thiosulphate titrant, 0.025M was prepared by dissolving 6.205g $Na_2S_2O_3.5H_2O$ in distilled water. A 0.4 g solid NaOH was added and diluted to 1000 mL and was standardized with a bi-iodate solution.
- Standard potassium bi-iodate solution, 0.0021M: This was prepared by dissolving 812.4 mg $KH(IO_3)_2$ in distilled water and diluted to 1000 mL.

Procedure for determining the dissolved oxygen

The dissolved oxygen was measured by using APHA, (1998) method. The sample was collected in a 300 mL bottle and 1.0 mL of manganese sulphate ($MnSO_4$) solution was added followed by an alkali-iodide- azide reagent. It was carefully stoppered to avoid any kind of bubbling and trapping of air bubbles in the bottle and the bottle was well shaken. The bottle was kept for some time for the precipitate to settle down. A 2.0 mL volume of concentrated H_2SO_4 was added to it and shaken well to dissolve all the precipitate. Then 50.0 mL of sample was taken into a conical flask and titrated against sodium thiosulphate ($Na_2S_2O_3$) of 0.025M using starch as an indicator. At the endpoint, the initial blue colour changed to colourless.

Calculation

The calculated amount of sodium thiosulphate in the volume of solution used to attain the endpoint that is the disappearance of the blue colour was taken as the amount of DO in the sample in mg/L.

Mg DO/L $= \frac{V \times M}{0.025}$

where: V = mL thiosulphate solution used

M = molarity of thiosulphate titrant.

3.3.13 Determination of biological oxygen demand (BOD)

Procedure for determining BOD

After the determination of Dissolved oxygen, the samples were kept/preserved in an air-tight Winchester bottle in the incubator for 5 days as per the procedure of the study. The final DO values were recorded for each sample after 5 days. The BOD value was then calculated as follows:

$$\text{BOD} = \frac{\text{DO}_1 - \text{DO}_5}{\text{P}}$$

$$\text{Where P} = \frac{\text{volume of a sample taken}}{\text{total volume of the bottle}}$$

DO_1 = initial dissolved oxygen

DO_5 = final dissolved oxygen

3.4 Digestion of samples for heavy metals determination

An aliquot of 5.0 mL of concentrated nitric acid was added to 50.0 mL of the sample of water in a 100 mL beaker. This mixture was heated on a hotplate to boil until the colour of the solution became pale and clear. The solution was heated on a hot plate to boil until its volume got to about 20.0 mL. Another 5.0 mL of concentrated nitric acid was added and the beaker was covered with a watch glass and the heating continued for about 10 more minutes. A final 5mL acid was used to rinse the sides of the beaker. The solution was poured into a 50 mL volumetric flask and topped with distilled water to the mark. A blank solution was similarly prepared. The absorbance of the blank was taken before all the analysis.

Calibration curves for each of the selected metals (lead and cadmium) were prepared using standard solutions. From a stock solution of 100 ppm, working standards solution of Cadmium and Lead were prepared. Standards were prepared in 25 mL volumetric flask.

0.05 ppm Cadmium in 25 mL of volumetric flask was prepared by adding 12.5 µL of the 100 ppm Cadmium standard using a micro-pipette in 10 mL of distilled water in the volumetric flask and topped up to 25 mL. The same procedure with the same appropriate dilution was done for the other working standards for various concentrations.

Volumes of cadmium standard for preparing working standards.

Concentration (Cadmium)	Volume
0.05	12.5 µL
0.1	25 µL
0.5	125 µL
1.0	250 µL
2.0	500 µL
5.0	1250 µL

For calibration standard for lead, 0.1 ppm lead in 25 mL of volumetric flask was prepared by adding 25 µL of the 100 ppm lead standard using a micro-pipette in 10 mL of distilled water in the volumetric flask and topped up to 25 mL. The same procedure with the same appropriate dilution was done for the other working standards for various concentrations.

Volumes of lead standard for preparing working standards.

Concentration (Lead)	Volume
0.1	25 µL
0.5	125 µL
1.0	250 µL
2.0	500 µL
5.0	1250 µL
10.0	2500 µL

Calibration curves were drawn for cadmium and lead by plotting absorbance versus metal ion standard concentrations.

3.4.1 Determination of heavy metals by AAS

The Atomic Absorption Spectrophotometer (SHIMADZU AA-7000, Japan) was used for the determination of the concentrations of the metal ions present in the samples by reading their absorbances and comparing to the respective standard calibration curves. The light was generated from a hollow cathode lamp at a wavelength characteristic to each analyte. Each analyte was atomized using an atomizer to create free atoms from the samples. Air-acetylene gas was used as the source of energy for the production of free atoms for the elements lead (Pb) and cadmium (Cd). The sample was introduced as an aerosol into the flame and the burner aligned in the optical path to allow the light beam to pass through the flame where the light was absorbed. The light was then directed into a monochromator which then isolates the specific analytical wavelength of the light emitted by the hollow cathode lamp. The sensitive light detector then measures the light and translates the response into the analytical signals. Three replicate determinations were carried out on each sample and the same analytical procedure was employed for the determination of elements in digested blank solutions and the spiked samples.

3.5. Weighted Arithmetic Water Quality Index (WAWQI)

The Water Quality Index (WQI) is a dependable, practical, and effective instrument for analyzing and briefly disseminating information regarding water quality. Although different forms of the index such as the National Sanitation Foundation (NSF) in additive water quality index (AWQI), the Canadian Council Ministers of Environment (CCME) WQI, the Oregon water quality index (OWQI), multiplicative Oregon water quality index (MWQI), etc. exist, however, in this study, the Weighted Arithmetic Water Quality Index (WAWQI) method was employed because of its convenient calculations and analysis. The WAWQI uses a rating scale ranging from 0 to 100 with each range of value having quality implications (Table 8).

3.5.1 Water quality index calculation procedure

The WQI is calculated by the relation:

$$WQI = \frac{\sum q_n W_n}{\sum W_n}$$

The sub-index q_n is calculated by the expression:

$$qn = 100 \times \frac{V_n - V_i}{S_n - V_i}$$

where: qn = Quality rating for the nth water quality parameter; Vn = The estimated parameter for the nth water quality parameter; Sn = Standard value for the nth parameter; Vi = ideal value of selected parameters tested (in pure water Vi is 0) for all parameters tested. For pH the ideal value = 7.

$$W_n = \frac{K}{S_n}$$

where W_n is the unit weight of each parameter

n = is the number of sub-indices aggregated

Sn = the standard permissible value for the nth parameter
K = proportionality constant and is given by the equation;

$$K = \frac{1}{\sum_{n}^{i} \frac{1}{S_n}}$$

3. 6 Nemerow's Pollution Index

Nemerow's Pollution Index (NPI) is mathematically expressed as NPI = $\frac{C_i}{L_i}$.

Where C_i is the observed concentration of the i^{th} parameter; L_i is the permissible limit of the i^{th} parameter. The individual value of the NPI calculated represents the relative pollution contribution by every parameter. In this water quality assessment, NPI values less than or equal to 1 indicates the absence of pollution and any value above 1 indicates pollution. This means that the higher the measured value, the greater the pollution effect of the water by those parameters.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Overview

This section presents the results of the study and discussed the physicochemical and heavy metal analysis of River Tordzie along the seven different towns, namely Agortime Kpetoe, Adaklu Waya, Adaklu Ablornu, Tetemale, Wute, Tordzinu, and Agbakope and the effects of human activities on the quality of the river during the dry and wet seasons.

4.1 Quality control and Assurance

The chemicals used in the analysis were analytical grades procured from a Benburto chemical company in Accra. Recoveries from the prepared standards were between 95% to 98%. Triplicate analysis was used to assess the reproducibility and precision of the analytical techniques. The mean of the triplicate results did not differ by more than 5% of the mean.

In the study, two major indices were applied to analyse the quality of water from River Tordzie. They were the Weighted Arithmetic Water Quality Index (WAWQI) and Nemerow's Pollution Index (NPI). Permissible levels of the parameters involved in the study were used as a reference point for assessment. Microsoft excel was also employed to analyze the data. The Statistical Package for the Social Sciences (SPSS 16.0 package) was used to determine the t-test of the parameters.

Table 1: Relevant Indian Standards for Surface Water Quality Standards (as per IS: 2296).

Parameters	**A**	**B**	**C**	**D**	**E**
pH (unit)	8.5	8.5	8.5	8.5	8.5
Colour (Hz)	10	300	300	-	-
DO (mg/L)	6	5	4	4	-
BOD (mg/L)	2	3	3	-	-
COD (mg/L)	-	-	-	-	-
Total Hardness (mg/L)	300	-	-	-	-
Chloride (mg/L)	250	-	600	-	600
Sulphate (mg/L)	400	-	400	-	1000
Nitrate (mg/L)	20	-	50	-	-
Phosphate (mg/L)	-	-	-	-	-
Ammonia as N (mg/L)	-	-	-	1.2	
Turbidity (NTU)	-	-	-	-	-
TDS (mg/L)	500	-	1500	-	2100
TSS (mg/L)	-	-	-	-	-
EC (µS/cm)	-	-	-	1000	2250
Alkalinity (mg/L)	-	-	-	-	-
Iron (mg/L)	0.3	-	50	-	-
Lead (mg/L)	0.1	-	0.1	-	-
Cadmium (mg/L)	0.01	-	0.01	-	-
Zinc (mg/L)	15	-	15	-	-

Class A – Drinking water without conventional treatment but after disinfection.

Class B – Water for outdoor bathing.

Class C – Drinking water with conventional treatment followed by disinfection.

Class D – Water for fish culture and wildlife propagation.

Class E – Water for irrigation, industrial cooling, and controlled waste disposal.

The relevant Bureau of Indian standard (BIS) for surface water quality was used for this study because it contains both treated and untreated water specifications as compared to other water quality standard such as World Health Organization (WHO), which does not contain specifications for raw water as used in this work.

Table 2: The mean values of physicochemical parameters during the dry season

Towns	pH unit	Turbidity (NTU)	Colour (Hz)	TDS (mg/L)	EC (µS/cm)	Alkalinity (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	PO_3^- (mg/L)	NH (mg/L)	NO_3^- (mg/L)	Total Hardness (mg/L)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)
Kpetoe	7.11	12.67	133.67	90.17	180.20	16.23	6.84	7.27	3.62	0.74	3.13	175.09	315.33	45.46	9.00	6.88
Adaklu Waya	7.13	16.00	133.67	81.07	162.10	14.27	6.16	12.74	4.07	0.77	4.13	150.09	179.67	73.62	8.33	5.07
Adaklu Ablornu	7.15	42.33	359.33	66.77	162.00	14.90	8.62	15.10	4.67	0.62	4.32	169.13	324.33	36.35	23.27	7.33
Tetemale	7.19	42.67	321.67	87.27	174.83	12.70	7.75	6.55	4.53	0.57	4.33	161.08	281.67	50.03	26.00	5.87
Wute	7.18	36.00	334.67	88.40	176.40	15.67	6.24	6.94	4.50	0.58	4.53	169.15	319.33	40.17	21.00	7.27
Tordzinu	7.1	45.33	372.00	86.37	172.67	13.10	7.69	6.20	4.46	0.77	4.74	186.18	271.67	41.82	30.00	6.23
Agbakope	6.83	50.67	353.00	87.27	171.40	12.30	6.68	11.29	4.12	0.83	4.31	172.15	360.00	56.35	28.43	8.20
Mean	7.10	35.10	286.86	83.90	171.37	14.17	7.14	9.44	4.28	0.70	4.21	168.98	293.14	49.11	20.86	6.69
Min	6.83	12.67	133.67	66.77	162.00	12.30	6.16	6.20	3.62	0.57	3.13	150.09	179.67	36.35	8.33	5.07
Max	7.19	50.67	372.00	90.17	180.20	16.23	8.62	15.10	4.67	0.83	4.74	186.18	360.00	73.62	30.00	8.20
SD	0.12	14.86	105.92	8.06	6.96	1.52	0.91	3.56	0.37	0.10	0.52	11.27	57.87	12.67	8.86	1.05

* **SD: Standard deviation**

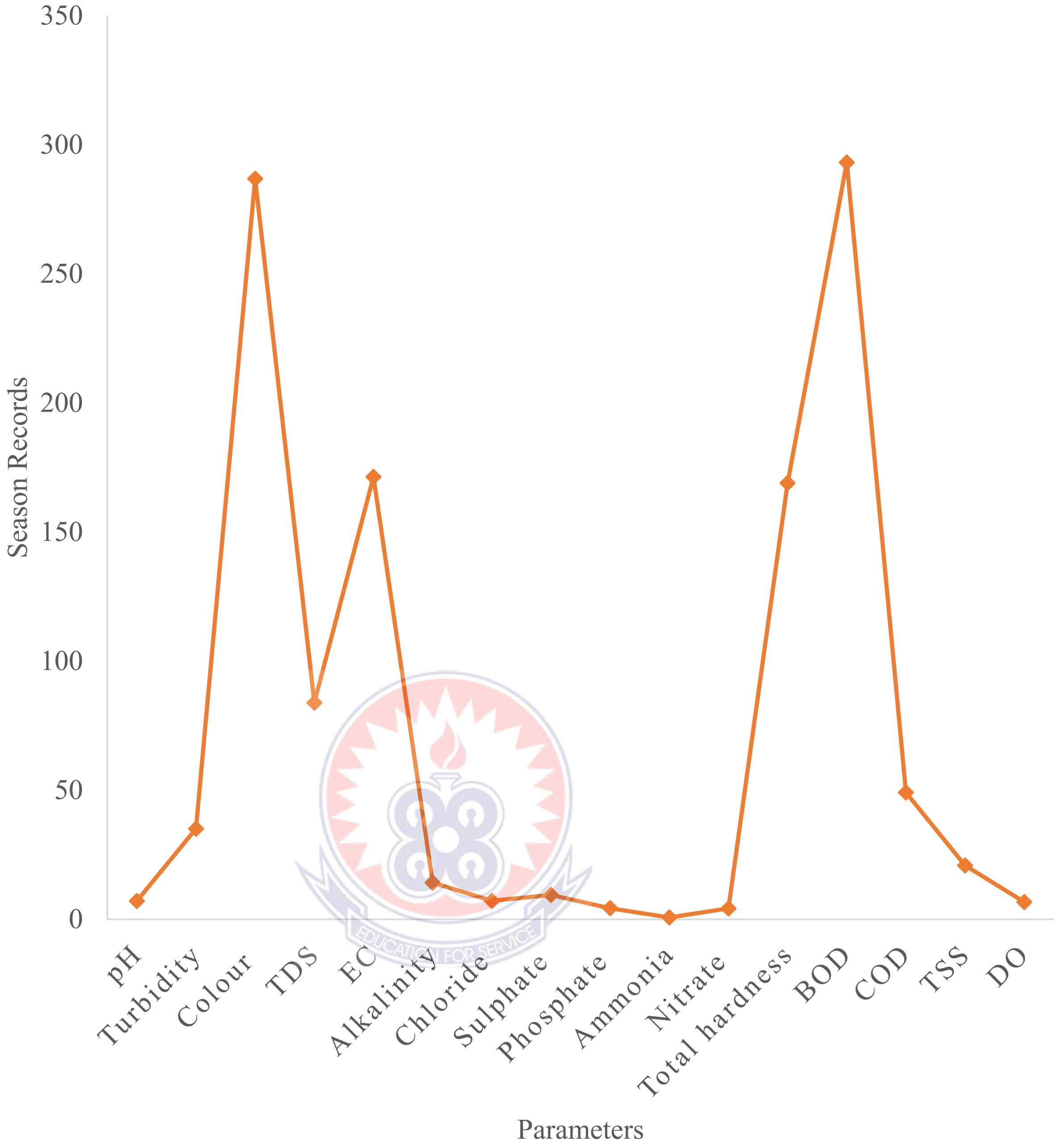

Figure 2: Graphical representation of the mean values of the physicochemical parameters during the dry season.

Table 3: The mean values of physicochemical parameters during the wet season

Towns	**pH unit**	**Turbidity (NTU)**	**Colour (Hz)**	**TDS (mg/L)**	**EC (µS/cm)**	**Alkalinity (mg/L)**	Cl^- **(mg/L)**	SO_4^{2-} **(mg/L)**	PO_3^- **(mg/L)**	NH (mg/L)	NO_3^- **(mg/L)**	**Total Hardness (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**TSS (mg/L)**	**DO (mg/L)**
Kpetoe	6.66	39.67	680.67	81.50	163.63	12.60	27.22	18.56	1.05	5.66	2.53	118.07	165.00	18.16	18.00	6.47
Adaklu Waya	7.08	59.67	635.00	74.97	149.13	11.00	17.45	19.62	1.64	8.66	4.83	79.08	265.00	36.34	35.00	5.67
Adaklu Ablornu	5.06	109.67	698.00	36.70	72.57	5.80	21.07	3.64	2.70	1.26	6.8	44.31	188.33	90.87	75.33	4.33
Tetemale	5.71	49.67	608.33	31.70	62.20	5.60	1.50	7.65	1.57	1.4	2.42	33.17	230.33	145.44	38.83	6.47
Wute	5.76	108.00	699.67	52.47	105.70	10.20	19.21	4.01	2.88	2.54	4.61	77.93	115.00	54.53	78.00	4.30
Tordzinu	5.67	53.33	677.33	31.17	61.30	6.73	18.35	8.37	1.57	3.67	3.93	38.20	225.00	72.67	41.93	6.37
Agbakope	5.48	120.67	700.67	46.50	92.80	7.00	16.57	21.47	0.22	4.84	5.03	46.05	195.00	72.7	101.83	4.13
Mean	5.92	77.24	671.38	50.71	101.05	8.42	17.34	11.90	1.66	4.00	4.31	62.40	197.67	70.10	55.56	5.39
Min	5.06	39.67	608.33	31.17	61.30	5.60	1.50	3.64	0.22	1.26	2.42	33.17	115.00	18.16	18.00	4.13
Max	7.08	120.67	700.67	81.50	163.63	12.60	27.22	21.47	2.88	8.66	6.80	118.07	265.00	145.44	101.83	6.47
SD	0.70	34.00	36.02	20.40	41.27	2.80	7.82	7.71	0.92	2.64	1.53	30.70	48.89	41.23	29.82	1.10

*** SD: Standard deviation**

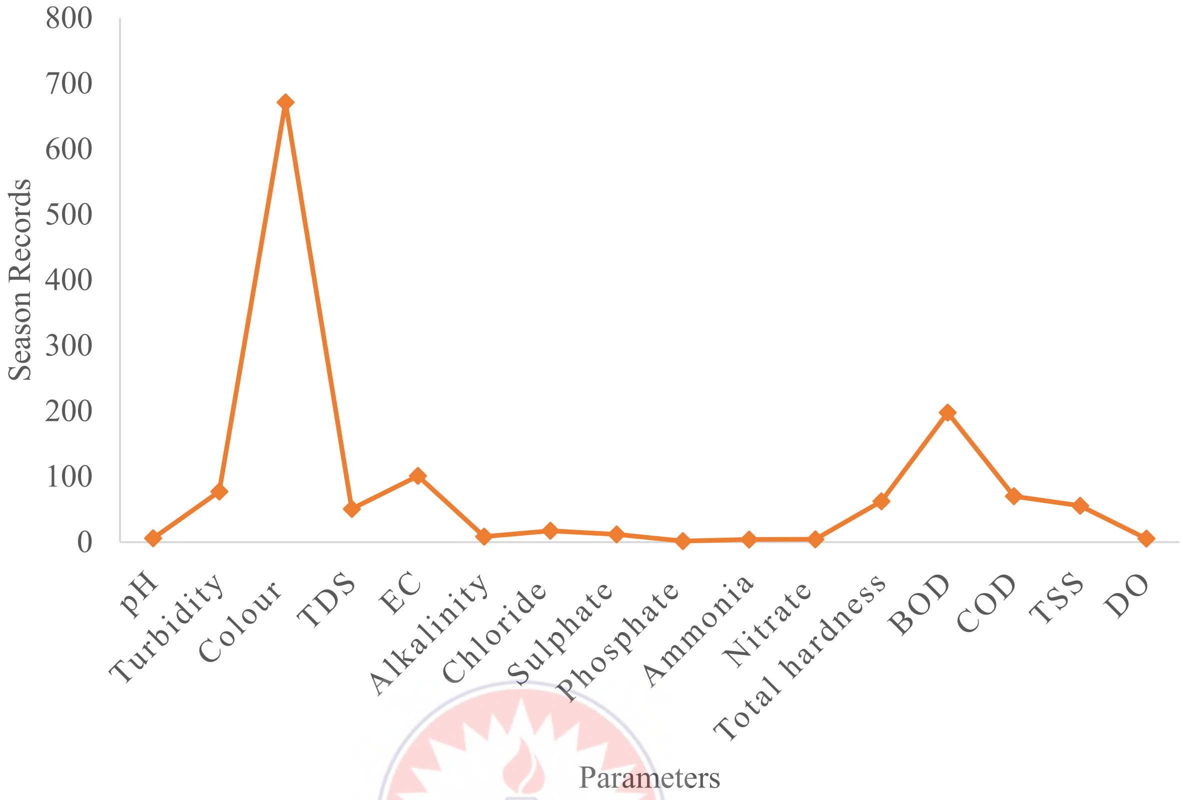

Figure 3: Graphical representation of the mean values of the physicochemical parameters during the wet season.

4.2 Physicochemical parameters

4.2.1 pH

The pH determined for various sample sites ranged from 6.83 units to 7.19 units with a mean value of 7.10 units and a standard deviation of 0.12 in the dry season (Table 2), while the wet season saw the pH ranging from 5.06 units to 7.08 units. The mean value was 5.92 and the standard deviation was 0.70 (Table 3). The pH of the sampling sites during the dry season fell within the Indian surface water quality limit of 8.5 (Table 1), whereas during the wet season, Agortime Kpetoe and Adaklu Waya sites were within the acceptable limit (Table 3). The rest of the sites showed pH values less than the minimum of 6.5 and thus were outside the standard. The low pH values for the wet season means the water is acidic. This might be due to the washing of chemicals from farmlands into the water by runoff. There was statistically a significant difference ($p = 0.00089 < 0.05$) between the pH values for the dry and wet seasons as seen in Appendix 1. A similar study reported a mean pH value of 7.5 units during the wet season and attributed the high pH to dilution of alkaline substances and dissolution of atmospheric CO_2 (Worako, 2015). The present study contradicted the earlier study and recorded a rather low pH during the wet season. A related study reported a minimum pH of 5.96 units and 5.08 units during the wet and dry seasons in Aby lagoon in the Western region of Ghana (Miyittah *et al*., 2020). The pH values in the study for both seasons were a little below the Bureau of Indian Standards (BIS) for surface water quality standard (Table 1).

Acidic water can cause corrosion to a pipe made of metal, and also can result in a bitter taste of water. The pH of water is a useful indicator of water quality because it reveals the various types of geochemical equilibrium that can exist in water (Mitharwal *et al*., 2009). The discharge into water bodies through agriculture and domestic activities could be blamed for low pH of water samples. Biological processes are directly affected by pH. Low levels of pollution could be linked to farming activities and car washing near or in the river (Njue *et al*., 2016). Extreme water pH values can have a negative impact on the aquatic organism, taste, corrosion, hazardous metal solubility, and death (Irenosen *et al*., 2012).

4.2.2 Turbidity

Turbidity is an important parameter because it protects microorganisms from disinfection effects, can stimulate bacteria growth and indicates problems with the treatment process. It does not adversely affect human health (WHO 2004). The recorded turbidity values ranged from 12.67 NTU to 50.67 NTU. The mean value was 35.10 with a standard deviation of 14.86 in the dry season (Table 2), whereas in the wet season, the turbidity ranged from 39.67 NTU to 120.67 NTU with a mean value of 77.24 NTU and a standard deviation of 34.00 (Table 3). All the mean values were above the Bureau of Indian Standard (BIS), 2012 standard value of 5.0 NTU. There was statistically significant difference ($p = 0.01096 < 0.05$) between results of the dry and wet seasons. Agbakope recorded the highest value for both seasons. The high turbidity at the sampling sites could be due to anthropogenic activities from both point and non-point sources in the areas. A similar study correlated with the present study and reported 6.21 NTU and 5.89 NTU turbidity during the wet and dry seasons in Volta Lake with higher peaks during the wet season (Abbas & Hassan, 2018). Another study conducted by Abdul-Razak *et al.,* (2010) on Oti River in Ghana, reported a mean turbidity value of 17.54 NTU upstream and 17.60 NTU downstream. This clearly showed that the observed values for the present study were relatively high.

Turbidity can have a negative impact on consumer acceptability of water as a result of visible cloudiness. Consumption of turbid water does not have any direct health effects. High turbidity implies a high concentration of suspended particles in the water and affects its suitability for domestic uses such as washing, and drinking and may interfere with the effectiveness of disinfection during treatment (Ireland Environmental Protection Agency, 2001).

4.2.3 Colour

The water colour detected during the dry season ranged from 133.67 Hz to 372.00 Hz with a mean of 286.86 Hz and a standard deviation of 105.92 (Table 2). The highest colour value was recorded at the Tordzinu sampling site. In the wet season, colour ranged from 608.33 Hz to 700.67 Hz. The mean observed was 671.38Hz with a standard deviation of 36.02. The lowest colour value was detected at Tetemale sampling site with the highest value recorded at Agbakope sampling site (Table 3). All the values recorded for both seasons were above the surface water quality standard for all classes A, B, and C (Table 1). There was a statistically significant difference ($p = 9.8956 \times 10^{-7} < 0.05$) between the dry and the wet seasons. The higher level of colour in the wet season could be due to soil runoffs and dissolved organic matter during runoff into the river during the wet season.

Colour in drinking water is purely for aesthetical and not really for health reasons, but the presence of colour in water may be a source of contamination (Shittu *et al*., 2008). The colour of the water is often caused by organic material or iron in the water. The colour itself in water is not a threat to health but can create awful water and unpleasant to various consumers. The colour could be the first warning sign if the water has been contaminated (WHO, 2011). Comparing the values recorded in the present study to the similar research conducted by Karikari & Ansa-Asare (2006), on the Physico-Chemical and Microbial Water Quality Assessment of Densu River of Ghana, colour varied between 78.9 Hz and 107 Hz. The colours recorded from River Tordzie were much higher for both seasons.

4.2.4 Total Dissolved Solid (TDS)

The Total dissolved solid (TDS) values ranged from 66.77 mg/L to 90.17 mg/L for the dry season with a mean of 83.90 mg/L and a standard deviation of 8.06 (Table 2), whereas in the wet season the values ranged from 31.20 mg/L to 81.50 mg/L. The mean value was 50.71 mg/L with a standard deviation of 20.40 (Table 3). In the dry season, the minimum value was recorded at Adaklu Ablornu sampling site (66.77 mg/L) and the maximum value was recorded at Kpetoe site with a concentration of 90.17 mg/L (Table 2). The wet season saw the highest value observed at Kpetoe sampling site and the smallest value at the Tordzinu sampling site (Table 3). The TDS for the wet season showed a significant reduction during the dry season. This could be the result of a high volume of water during the wet season due to the over-dilution of some of the dissolved solid which caused the concentration to decrease. These values were below the guideline value for surface water for class A (Table 1). When the results of the present study were compared to the study conducted by Samah (2012), on the Asukawkaw River in the Volta Region, the measured TDS levels varied from 32.90 mg/L to 111.88 mg/L, which was significantly higher than the values recorded in the present study. Statistically significant difference $(p = 0.000175 < 0.05)$ were observed for the two seasons with the dry season taking the lead in total dissolved solid.

High TDS interfere with the taste of foods and beverages and makes them less desirable to consumers. All the values obtained in the present study suggest that using such waters to prepare beverages, food, and others could be palatable to consumers because the recorded total dissolved solid levels were far below the standards for surface water quality. Some organic matter dissolved in water, sewage, runoff, and industrial effluents also affect the TDS in water (Ahmed *et al*., 2016).

4.2.5 Electrical Conductivity

The electrical conductivity (EC) values at different sites for the dry season ranged from 162.0 µS/cm to 180.2 µS/cm with a mean of 171.37 µS/cm and a standard deviation of 6.96 (Table 2). The highest value of Electrical Conductivity was recorded at Kpetoe. During the wet season, electrical conductivity ranged from 61.30 µS/cm to 163.63 µS/cm. The mean value of electrical conductivity was 101.05 µS/cm with a standard deviation of 41.27 (Table 3). The decline in the values during the wet season might be due to the over dilution of the water. The dry season recorded higher levels of electrical conductivity due to the concentration of the dissolved substances and the small volume of water during the dry season. This indicated that seasonal changes affect the electrical conductivity content of the river under the study. There was statistically significant difference ($p = 0.000799 < 0.05$) between the dry and wet seasons. A related study obtained a mean of 98.43 µS/cm and 96.08 µS/cm respectively during wet and dry seasons in Volta Lake (Kodom *et al*., 2018). The present study correlated with the earlier study by recording a higher EC during the wet season. Electrical conductivity in surface waters is influenced by dissolved ions from natural and anthropogenic origins. According to the surface water quality standard, Electrical Conductivity must be below 1000 µS/cm or 2250 µS/cm for a specific purpose as shown in Table 1. Therefore, the electrical conductivity values detected in River Tordzie during both seasons were within the guideline values. According to Fatoki and Awofolu (2003), high electrical conductivity might be due to the high level of soluble salts such as salts comprising anions such as carbonates, chlorides, sulphates, and nitrates and cations such as potassium, magnesium, calcium, and sodium in the sediment and soil of these sources.

4.2.6 Alkalinity

The concentrations of total Alkalinity observed in the dry season ranged from 12.30 mg/L to 16.23 mg/L. The mean alkalinity was 14.17 mg/L with a standard deviation of 1.52. The minimum concentration was observed at Agbakope site and the maximum observed at Kpetoe site (Table 2). During the wet season, the alkalinity value observed ranged from 5.60 mg/L to 12.60 mg/L with a standard deviation of 2.80 and a mean of 8.42 mg/L. The minimum alkalinity was observed at Tetemale sampling site and the maximum at Kpetoe site (Table 3). Statistically significant difference was observed for the two seasons (see appendix 1). A related study conducted by Samlafo and Adakwah, (2021) on River Birim reported a total alkalinity value of 30.19 mg/L. Another study on River Kplikpa in the Volta Region's Ketu District, reported total alkalinity of 72 mg/L (Mensah, 2011). The presented study recorded values lower than the earlier studies during both seasons.

The high alkalinity recorded during the dry season as compared to the wet season could be the result of decomposition of organic materials in the water and over dilution of the water during the wet season leading to the decrease in the value during the wet season. Boyd (2020), opined that the high alkalinity is attributed to the increased rate of organic decomposition during which, the carbon dioxide is released and then reacted with water to form bicarbonates, thereby, increasing the total alkalinity of the aquatic body. High alkalinity indicates that the water body can neutralize acid pollution from rains or basic wastewater inputs and water with too much alkalinity is bad for irrigation, causing soil damage and lowering crop yields (Addy *et al*., 2004). The ability of water to neutralize acid is measured by alkalinity. Carbonates, bicarbonates, and hydroxides linked to calcium and magnesium are the main ions responsible for this (Ramachandra & Solanki, 2007). There are no guideline values for Total alkalinity as indicated in Table 1.

4.2.7 Chloride

The chloride level detected during the dry season ranged from 6.16 mg/L to 8.62 mg/L with a mean of 7.14 mg/L and a standard deviation of 0.19 (Table 2). The minimum chloride concentration was observed at Adaklu Waya site and the maximum concentration was observed at Adaklu Ablornu site. During the wet season, the chloride concentration ranged from 1.50 mg/L to 27.22 mg/L with a mean of 17.34 mg/L and a standard deviation of 7.82 (Table 3). Tetemale site recorded the least value of 1.50 mg/L during the wet season while Agortime Kpetoe recorded the highest value of 27.22 mg/L. There was a statistically significant difference ($p = 0.00503 < 0.05$) between the dry and wet seasons. The increase in the chloride concentration during the wet season might be due to the washing of chemicals from farmlands along the river bank and domestic effluents into the river. The results of the present study were similar to a study by Abdul-Razak *et al*., (2010), who reported chloride concentrations ranging from 3.0 mg/L to 10.0 mg/L in the River Oti, which was substantially lower than the current study during the wet season. According to Mohanta and Potra (2000), sewage waste discharge results in a high chloride level in fresh water. Chlorides in water can come from sodium, potassium, and calcium salts.

4.2.8 Sulphate

The sulphate concentration observed in the water during the dry season ranged from 6.20 mg/L to 15.10 mg/L with the mean and standard deviation of 9.44 mg/L and 3.56 mg/L respectively. Tordzinu sampling site recorded the lowest value of 6.20 and Adaklu Ablornu sampling site recorded the highest value of 15.10 mg/L (Table 2). Whereas the wet season showed sulphate concentrations ranging from 3.64 mg/L to 21.47 mg/L. The mean sulphate concentration for the wet season was 11.90 mg/L and a standard deviation of 7.71. Adaklu Ablornu sampling site recorded the lowest concentration whiles Agbakope sampling site had the highest sulphate concentration (Table 3). There was no statistically significant difference ($p = 0.45798 > 0.05$) between two seasons. The high sulphate values recorded at Kpetoe, Adaklu Waya and Agbakope during the wet season might be the result of heavy use of fertilizers for farming activities in these areas which find their way into the river as a result of runoffs from agricultural land and domestic wastewater.

In a comparable study on River Oti in Ghana, Abdul-Razak *et al.,* (2010) found sulphate concentrations of 8.933 mg/L upstream and 8.533 mg/L downstream of the river. A related study on River Birim by Samlafo and Adakwah (2021), also reported a mean sulphate concentrations of 1.91 mg/L. These values were much lower than the values obtained in the present study during both seasons. Drinking water with sulphate concentrations greater than 250 mg/L has a bad taste and corrodes distribution systems (Issa *et al*., 2013). If the concentration of sulphate surpasses the maximum permissible limit, it is likely to react with human organs and has a laxative effect on the human system due to the excess magnesium (Logeshkumaran *et al*., 2015).

4.2.9 Phosphate

The concentration of phosphate detected during the dry season ranged from 3.62 mg/L at Agortime Kpetoe to 4.67 mg/L at Adaklu Ablornu. The mean concentration and standard deviations were 4.28 mg/L and 0.37 respectively (Table 2). During the wet season, the mean concentration of phosphate was 1.66 mg/L, and a standard deviation of 0.92 with the observed concentration ranging from 0.22 mg/L to 2.88 mg/L (Table 3). The lowest concentration of phosphate was observed at Agbakope and the highest concentration was observed at Wute sampling site. The high phosphate concentration observed during the dry season could be the result of the overconcentration of the water since the volume of water was reduced during this season. During the wet season, the phosphate concentration was reduced. This might be the result of over dilution of the water since the river has overflown its banks during this season though there might be runoff from farmlands close to the river and inflow of domestic wastewater. Statistically significant difference was observed ($p = 1.3746 \times 10^{-5} < 0.05$) for the dry and wet seasons.

An analogous study conducted by Karikari & Ansa-Asare (2006), on Densu River reported concentrations ranging from 0.001 mg/L to 0.921 mg/L. These values were much smaller than the observed values in the present study. Surface water is known for high phosphate concentrations and this assertion resonates with Kronvang *et al*., (2005); Surface water sources exhibited relatively high phosphate concentrations, which might be attributable to stormwater runoff, agricultural runoff, erosion, and sedimentation, or direct input by animals or wildlife. There is no specific surface water quality guideline for phosphate (Table 1).

4.2.10 Ammonia

Ammonia concentration detected in River Tordzie ranged from 0.57 mg/L at Tetemale to 0.83 mg/L at Agbakope in the dry season with a mean of 0.70 mg/L and standard deviation of 0.10 (Table 2). During the wet season, the observed values ranged from 1.26 mg/L to 8.66 mg/L. The mean value was 4.00 mg/L and a standard deviation of 2.64. The minimum ammonia concentration was detected in the wet season at Adaklu Ablornu sampling site and the maximum at Adaklu Waya sampling site (Table 3). The WHO recommended value for ammonia in drinking water is 1.5 mg/L. The high value of ammonia detected during the wet season could be attributed to anthropogenic sources such as sewage entry, agricultural runoff due to the application of ammonia fertilizers by farmers, nitrogen fixation, and the excretion of nitrogenous wastes from animals that entered the aquatic ecosystem. There is no guideline value for ammonia under category A of the Indian surface water quality standard (Table 1).

When the NH_3-N level exceeds 2 mg/L, the problem of taste and odor may occur. Under proper anaerobic circumstances, substantial volumes of NO_3-N can be generated from NH_3-N at concentrations of more than 10 mg/L (WHO, 1993; Kempster *et al.,* 1997). Statistically significant difference ($p = 0.006144 < 0.05$) between the two seasons were observed. Diffusion of ammonia from the sediments also enters the rivers or lakes.

4.2.11 Nitrate

The measured concentration of nitrogen at all the sampling sites ranged from 3.13 mg/L to 4.75 mg/L during the dry season with a mean of 4.21 mg/L and a standard deviation of 0.52. The minimum value was observed at Agortime Kpetoe and the maximum at Tordzinu (Table 2). These values increased from 2.42 mg/L to 6.80 mg/L during the wet season. The mean nitrate concentration observed was 4.31 and a standard deviation of 1.53 with the highest nitrate concentration recorded at Adaklu Ablornu (Table 3). All the sampling sites had their nitrate concentrations for both seasons below the guideline values for surface water quality under all the classes as shown in (Table 1). No statistically significant difference was observed ($p = 0.45798 > 0.05$) between the dry and wet seasons.

An analogue study conducted by Samuel (2013), reported the mean concentration of the River Asuotia in the Dormaa East District of Brong Ahafo Region of Ghana to be between 0.05 mg/L and 0.12 mg/L at various locations along the river, which were lower than the values observed in the current study. In the present study, because the study locations are located near farming and residential areas, the rise in nitrate concentration during the wet season could be the consequence of runoff from anthropogenic sources and some domestic wastewater. According to Tjandraatmadja & Diaper (2006), nitrate is a chemical compound found in drinking water that comes from anthropogenic sources. The most common sources of nitrate in surface water are household and municipal wastes, as well as agricultural effluents.

4.2.12 The Total Hardness

The hardness concentrations observed during the dry season ranged from 150.09 mg/L at Adaklu Waya site to 186.18 mg/L at Tordzinu site with a recorded mean of 168.98 mg/L and a standard deviation of 11.27 (Table 2). The wet season saw the minimum value observed at Tetemale (33.17 mg/L) and the maximum value observed at Kpetoe (118.07 mg/L). The mean concentration of total hardness for the wet season was 62.40 mg/L with a standard deviation of 30.70 (Table 3). Statistically significant differences ($p = 1.7299 \times 10^{-6} < 0.05$) were observed between the dry and wet seasons. The observed total hardness concentrations for both seasons were below the Bureau of Indian surface water quality standard of 300 mg/L. The hardness of water is caused by the presence of magnesium and calcium ions in the water. The low values of hardness detected in River Tordzie at some of the sampling sites are an indication of the presence of a little amount of dissolved calcium and magnesium ions. The higher levels of total hardness in the dry season could be due to increased evaporation leading to the concentration of substances and small volume of water as well as total dissolved solid during the dry season whiles the low concentrations of total hardness observed during the wet season could probably be due to high dilution but the increase in hardness readings found in Tordzinu and Kpetoe sampling sites may be related to larger quantities of dissolved calcium and magnesium ions in these areas. Hard water requires more soap and synthetic detergents for home laundry and washing and contributes to scaling in boilers and industrial equipment.

4.2.13 Biological Oxygen Demand (BOD)

The biological oxygen demand levels detected in River Tordzie at the various sites during the dry season ranged from 179.67 mg/L at Adaklu Waya to 360.0 mg/L at Agbakope with a mean of 293.14 mg/L and a standard deviation of 57.87 (Table 2). However, during the wet season, the biological oxygen demand observed in the River Tordzie ranged from 115 mg/L to 265 mg/L with the minimum biological oxygen demand recorded at Wute sampling site and the maximum biological oxygen demand was recorded at Adaklu Waya sampling site (Table 3). The mean concentration observed during the wet season was 197.67 mg/L with a standard deviation of 48.89. From the research, it could be seen that all the sampling sites in both seasons showed extremely high concentrations of BOD_5 as compared to the 2.0 mg/L for the Indian surface water quality standard (Table 1).

The wide savannah grassland, which is suitable for irrigated mechanized farming and cattle raising, could explain the high observed biological oxygen demand values. These animals create a lot of organic dung, which could have ended up in the river as a result of runoff. This could also be attributable to solid organic waste (excess food, discharge of excreta from residences washout septic tanks, as well as grey water and inorganic waste from the landfill). Organic matter from decaying plants and animal wastes are natural sources of biological oxygen demand in surface waterways. Feces, urine, detergents, fats, oils, and grease are all human sources of biological oxygen demand (Penn *et al*., 2009). A similar work by Abdul-Razak *et al.,* (2010) reported biological oxygen demand of 0.3 mg/L to 2.2 mg/L in the Densu River which was lower than the observed biological oxygen demand values in the present study. Again, a reported biological oxygen demand by Nyantakyi *et al*., (2020) in River Tano was 78 mg/L which was below the observed BOD values in the present study but above the guideline for Indian surface water standard. There was a statistically significant difference ($p = 0.005948 < 0.05$) between the dry and wet seasons.

4.2.14 Chemical Oxygen Demand (COD)

The chemical oxygen demand values detected in the water during the dry season ranged from 36.35 mg/L to 73.62 mg/L. The minimum chemical oxygen demand was observed at Adaklu Ablornu and the maximum value was observed at Adaklu Waya. The mean concentration was 49.11 mg/L and a standard deviation of 12.67 (Table 2). In the wet season, the chemical oxygen demand value observed ranged from 18.16 mg/L to 145.44 mg/L with a mean value of 70.10 mg/L and a standard deviation of 41.23. The maximum value of chemical oxygen demand was detected in the water sample collected from

Tetemale sampling site and the minimum chemical oxygen demand was observed at Kpetoe sampling site during the rainy season (Table 3). There is no standard guideline for chemical oxygen demand according to the Indian surface water quality standard as shown in (Table 1). There was no statistically significant difference ($p = 0.22277 > 0.05$) between the two seasons.

Chemical oxygen demand is the oxygen required for the chemical oxidation of organic matter with the help of a strong chemical oxidant. The elevated chemical oxygen demand measured during the wet season compared to the dry season demonstrated that the water under study was mostly polluted by biodegradable organic matter as a result of anthropogenic runoff and wastewater from communities along the river's bank. Farming along the river banks could also be a contributing factor. A related study conducted by Nyantakyi *et al*., (2020) on the River Tano, reported chemical oxygen demand levels to be 32.7 mg/L during the dry season and 67.7 mg/L during the wet season. These values were relatively lower the COD values recorded in the present study. To Tahershamsi *et al*., (2009), chemical oxygen demand is an indicator of organic pollution, which is caused by the inflow of domestic, livestock, and industrial waste that contains elevated levels of organic pollutants.

4.2.15 Total Suspended Solid

The Total Suspended Solids concentrations in the water samples ranged from 8.33 mg/L at Adaklu Waya sampling site to 30.00 mg/L at Tordzinu sampling site during the dry season with a total mean of 20.86 mg/L and a standard deviation of 8.86 (Table 2). In the wet season, the total suspended solid values varied from 18.16 mg/L to 101.83 mg/L with a mean of 55.56 mg/L and a standard deviation of 29.82. Statistically significant differences (p = 0.01211 < 0.05) were observed for the two seasons. The maximum value of total suspended solid recorded during the wet season was observed at the Agbakope sampling site and the minimum value at the Kpetoe sampling site (Table 3). The variations in total suspended solid concentrations observed during the study could be linked to the various land use activities reported for the sampling sites, such as agricultural run-off, soil erosion, and in-stream activities like car washing. According to Anhwange *et al*., (2012), the elevated TSS content recorded in any surface water could be explained by the presence of increased solid materials (both dissolved and suspended) produced by multiple anthropogenic activities taking place in the catchment area. The total suspended solid concentration in the Birim River was 149.9 mg/L in research conducted by Samlafo and Adakwah (2021), which was higher than the observed values in the present study.

4.2.16 Dissolved Oxygen (DO)

The concentrations of dissolved oxygen (DO) recorded during the dry season ranged from 5.07 mg/L to 8.20 mg/L. The mean value was 6.69 mg/L and the standard deviation was 1.05. The minimum dissolved oxygen was observed at Adaklu Waya and the maximum at Agbakope. All the sites had the dissolved oxygen value above the guideline value for Indian surface water quality of 6 mg/L except the Tetemale sampling site (Table 2). The dissolved oxygen values observed during the wet season ranged from 4.13 mg/L at Agbakope to 6.47 mg/L at Kpetoe and Tetemale sampling sites with a mean concentration of 5.39 mg/L and standard deviation of 1.10. The dissolved oxygen values recorded during the wet season at Kpetoe, Tetemale, and Tordzinu (Table 3) were slightly above the standard for Indian surface water quality as indicated in Table 1. During the dry season, higher dissolved oxygen observed at some sampling sites could be associated with lesser runoff, which carries nutrients and pollutants into water bodies. Increased industrial effluents, which could contain a high concentration of oxygen-demanding compounds from neighboring farmlands, could be blamed for the low dissolved oxygen levels at several of the sampling sites. Also, the low dissolved oxygen could be attributed to the increased growth of aerobic bacteria in the presence of large organic matter, due to anaerobic activities. This could be attributed to the impact of municipal wastes dumped in the river directly or through runoffs. There was a statistically significant difference ($p = 0.0425 < 0.05$) between the dry and wet seasons. Another study reported 6.35 ± 0.7 mg/L and 6.37 ±1.1 mg/L respectively in the dry and wet seasons with $p = 0.956 > 0.05$ in the River Tano basin (Nyantakyi *et al*., 2020). There was no statistically significant difference between the two seasons in the River Tano basin. However, statistically, significant differences were observed in this study, due to the wet season.

According to the Ireland Environmental Protection Agency (2001), the higher dissolved oxygen recorded during the dry season may be attributed to the lower amounts of runoff which usually carry nutrients and wastes into water bodies. It can also be the results of high temperature which influences the dissolution of gases in water. To Alabaster and Lloyd (2013), large-scale industrial development, heavy use of fertilizers, and dumping of human waste can pollute water quickly and lead to oxygen starvation. Low dissolved oxygen has been found to contribute to suffocation and death of fishes and destruction of other aquatic life as a result of active utilization of oxygen in water by bacteria, plants, and animals.

4.3 Heavy metals

Table 4: The mean concentration of heavy metals during the dry season

Towns	Cadmium (mg/L)	Iron (mg/L)	Lead (mg/L)
Kpetoe	0.002	0.030	0.093
Adaklu Waya	0.002	0.010	0.067
Adaklu Ablornu	0.002	0.020	0.107
Tetemale	0.002	0.020	0.093
Wute	0.002	0.030	0.088
Tordzinu	0.004	0.030	0.091
Agbakope	0.002	0.020	0.083
Mean	0.002	0.023	0.089
Min	0.002	0.010	0.067
Max	0.004	0.030	0.107
SD	0.001	0.008	0.012

*** SD = standard deviation**

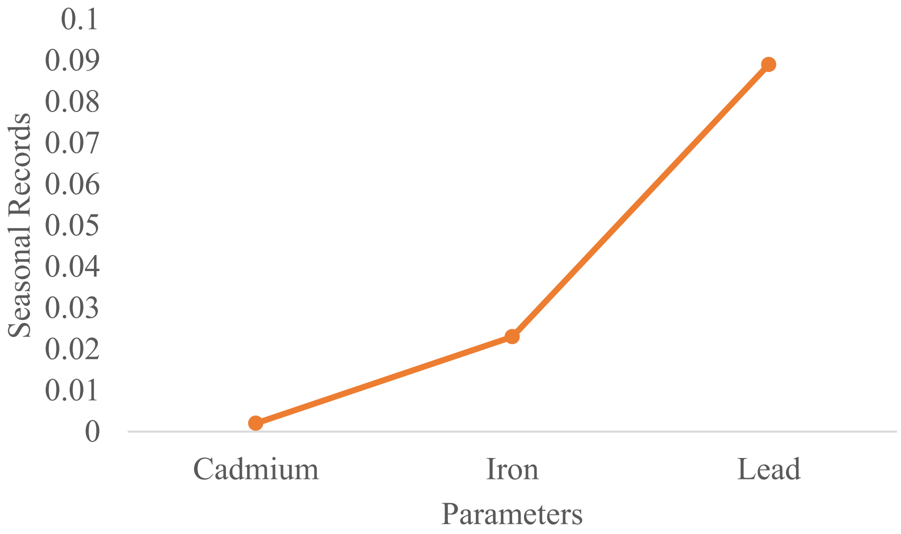

Figure 4: Graphical representation of the mean concentrations of the heavy metals during the dry season.

Table 5: The mean concentration of heavy metals during the wet season

Towns	Cadmium (mg/L)	Iron (mg/L)	Lead (mg/L)
Kpetoe	0.082	0.040	4.330
Adaklu Waya	0.092	0.060	4.503
Adaklu Ablornu	0.091	0.070	4.733
Tetemale	0.089	0.030	4.387
Wute	0.083	0.080	4.224
Tordzinu	0.095	0.040	4.219
Agbakope	0.107	0.080	4.215
Mean	0.091	0.057	4.373
Min	0.082	0.030	4.215
Max	0.107	0.080	4.733
SD	0.008	0.021	0.191

*** SD = standard deviation**

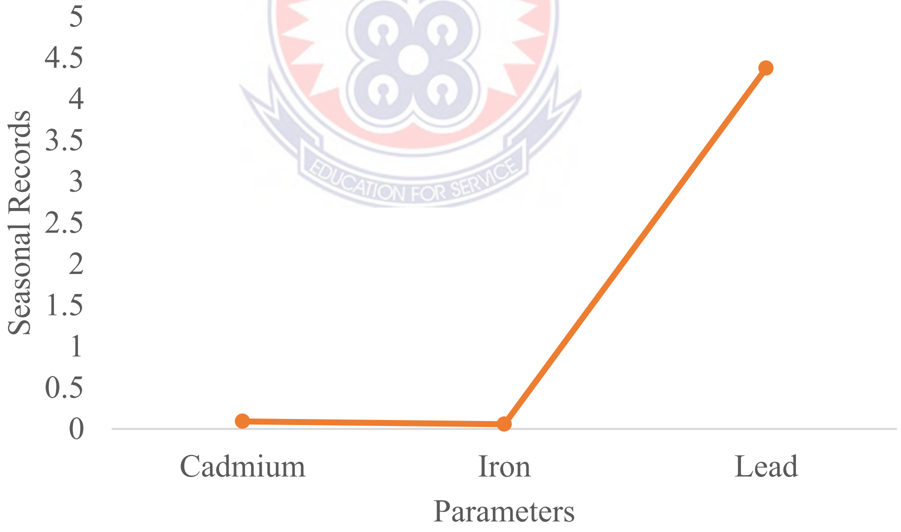

Figure 5: Graphical representation of the mean concentrations of the heavy metals during the wet season.

4.3.1 Iron

Iron is an important element contributing to the quality of water. In the study, iron concentration varied from 0.010 mg/L to 0.030 mg/L with a mean concentration of 0.023 mg/L and a standard deviation of 0.008. The minimum concentration was observed at Adaklu Waya and the maximum concentration was observed at Kpetoe, Wute, and Tordzinu sampling sites during the dry season (Table 4). In the wet season, the iron concentration detected from the various stations ranged from 0.030 mg/L to 0.080 mg/L. The mean concentration was 0.057 mg/L and a standard deviation of 0.021. The minimum iron concentration was observed at Tetemale sampling site with a concentration of 0.03 mg/L and the maximum value was recorded at Wute and Agbakope sampling stations with the value of 0.08 mg/L in the wet season (Table 5). All the iron concentrations detected for both seasons were all below the recommended guideline value for Indian surface water quality of 0.3 mg/L (Table 1). There was a statistically significant difference ($p = 0.001379 < 0.05$) between the two seasons with the higher peaks during the wet season. The runoff from domestic activities and pH levels recorded in the study during the wet season could be a contributing factor. The concentration of dissolved iron in water is dependent on the pH, redox potential, turbidity, suspended matter, the concentration of aluminium, and the occurrence of several heavy metals, notably manganese (Water Resources Commission, 2003). Generally, comparing the values observed in the present study to similar research conducted by Asiamah, (2013) on Owere River at Konongo observed the iron concentration ranging from 4.11mg/L to 6.36 mg/L, the values observed in the present study were far below the observed values by Asiamah.

4.3.2 Cadmium

The cadmium concentration observed in the water ranged from 0.002 mg/L to 0.004 mg/L during the dry season with a mean of 0.002 mg/L and a standard deviation of 0.001. The maximum concentration was recorded at the Tordzinu sampling station (Table 4). All the values observed for cadmium concentration in the dry season for all sampling stations were all below the recommended Indian surface water quality guideline value of 0.01 mg/L. During the wet season, the cadmium concentration ranged from 0.082 mg/L to 0.107 mg/L. The mean value observed was 0.091 mg/L and a standard deviation of 0.008 (Table 5). All the values detected during the wet season were above the Indian surface water quality standard recommended value. The high values of cadmium during the wet season could be the result of waste products from domestic and fertilizer from farmlands that have been washed into the river. Rivers containing excess cadmium can contaminate surrounding land, either through irrigation for agricultural purposes, dumping of dredged sediments, or flooding (WHO, 1992). Cadmium is a potent human carcinogen and has been associated with cancers of the lung, prostate, pancreas, and kidney (Flora, 2009). Statistically significant difference ($p = 2.453 \times 10^{-12} < 0.05$) between the two seasons were observed.

Research shows that Cadmium producing industries, electroplating, welding, by-products from the refining of Pb, Zn, and Cu, fertilizer industry, pesticide manufacturers, cadmium–nickel batteries, and nuclear fission plants contribute to the leaching of Cadmium into surface water (Abbas *et al*., 2016, Jamali *et al.,* 2007). Since the study areas happens to fall within farming communities, the high concentration could be attributed to the use of fertilizers for farming along the river banks of the water under study. Again, Domestic wastewater and the dumping of domestic and industrial sludge are the major artificial sources of cadmium (Cd). This assertion could be a contributing factor because the majority of houses in the study area are not having waste treatment systems such as septic tanks. Storm runoffs are also known contributors to high cadmium concentrations. A similar study conducted by Asamoah, (2012) on Birim reported a mean value of 0.01 mg/L at one of the sampling sites at Obronikrom which was not extremely above the guideline value.

4.3.3 Lead

Lead concentrations observed in water during the dry season ranged from 0.067 mg/L at Adaklu Waya to 0.107 mg/L at Adaklu Ablornu with a mean of 0.089 mg/L and standard deviation of 0.012. All the sampling sites recorded values less than the Indian surface water quality standard of 0.1 mg/L except the value recorded at Adaklu Ablornu (Table 4). During the wet season, the lead concentration observed in the water ranged from 4.215 mg/L to 4.733 mg/L. The mean concentration recorded was 4.373 mg/L with a standard deviation of 0.191. The minimum lead concentration was observed at Agbakope and the maximum observed at Adaklu Ablornu (Table 5). All the concentrations of lead observed during the wet season were above the recommended guideline value. The high concentration of lead observed during the wet season could be attributed to the use of pesticides by farmers since this metal can occur as impurities in fertilizers and in metal-based pesticides and compost manure, domestic waste and discharges, and storm runoffs because, during the wet season, there are a lot of water runoffs that washed lead into the river. In addition to that, during the wet season, the river water fills its course and flows out, covering the farmlands for some months, which also could be the cause of the increase in the concentration of the lead. These high levels shown by Pb may be attributed to the deposition of Pb particulates on the roads next to the rivers especially during precipitation.

Research conducted by Asamoah (2012), on River Birim, recorded the highest concentration of 0.014 mg/L in the water which was below the values recorded in this study during the rainy season. Similar research conducted by Gordon and Ansa-Asare, (2012) on Rivers; Densu, Birim, and Ayensu respectively recorded the mean lead concentration of the water to be 22.2 mg/L, 4.54 mg/L, and 7.58 mg/L which were relatively lower than the highest mean recorded in this study. There was a statistically significant difference ($p = 1.3746 \times 10^{-5} < 0.05$) between the dry and wet seasons. A high concentration of lead in drinking water poses a human health threat to humans and other living organisms.

4.4 Water Quality Index (WQI)

Water quality index (WQI) was 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. Surface water quality indexes are calculated based on critical physicochemical parameters for the River Tordzie. For the water quality index table, various physicochemical parameters were determined. The WQI was computed for 12 selected parameters that influence the quality of surface water in the river under study using the procedure outlined in the methodology. This study has revealed that using the WAWQI and NPI in evaluating the health of the River Tordzie, the calculated WQI from the study was 92.28 for the dry season (Table 6) and 1229.22 for the wet season (Table 7). These results showed that the river is of very poor quality and thus, undesirable for drinking and other intended uses (Table 8).

Table 6: Water quality index for River Tordzie during the dry season

Parameters	**Standards**	**$1/S_i$**	**Observed value (V_n)**	**W_n**	**qn = $100 \times \left(\frac{V_n - V_{io}}{S_n - V_{io}}\right)$**	**(q_nW_n)**
pH	8.5	0.118	7.1	0.0010	6.7	0.01
Colour (Hz)	10	0.100	286.86	0.0009	2868.6	2.51
TDS (mg/L)	500	0.002	83.9	0.0000	16.8	0.00
Chloride (mg/L)	250	0.004	7.14	0.0000	2.9	0.00
Sulphate (mg/L)	400	0.003	9.44	0.0000	2.4	0.00
Nitrate (mg/L)	20	0.050	4.21	0.0004	21.1	0.01
Total hardness (mg/L)	300	0.003	168.98	0.0000	56.3	0.00
BOD (mg/L)	2	0.500	293.14	0.0044	14657.0	64.09
DO (mg/L)	6	0.167	6.69			
Iron (mg/L)	0.3	3.333	0.023	0.0292	7.7	0.22
Cadmium (mg/L)	0.01	100.000	0.002	0.8745	20.0	17.49
Lead (mg/L)	0.1	10.000	0.089	0.0875	89.0	7.78
$K = \frac{1}{\sum\left(\frac{1}{Si}\right)} =$ 0.01		$\sum \frac{1}{Si}$ =114.346		$\sum W_n$ = 0.999	$\sum q_n$ = 17825.2	$\sum q_nW_n$ = 92.19
The WQI = $\frac{\sum(q_n \times w_n)}{\sum W_n} = \frac{92.19}{1}$ = 92.19						

Table 7: Water quality index for River Tordzie during the wet season

Parameters	Standards	$1/S_i$	Observed value (V_n)	Wn	$q_n= 100 \times \left(\frac{V_n - V_{io}}{S_n - V_{io}}\right)$	q_nW_n
pH	8.5	0.12	5.92	0.001	-72.00	-0.07
Colour (Hz)	10	0.10	671.38	0.001	6713.80	5.87
TDS (mg/L)	500	0.00	50.71	0.000	10.14	0.00
Chloride (mg/L)	250	0.00	17.34	0.000	6.94	0.00
Sulphate (mg/L)	400	0.00	11.90			
Nitrate (mg/L)	20	0.05	4.31	0.000	21.55	0.01
Total hardness (mg/L)	300	0.00	62.40	0.000	20.80	0.00
BOD (mg/L)	2	0.50	197.67	0.004	9883.50	43.22
DO (mg/L)	6	0.17	5.39			
Iron (mg/L)	0.3	3.33	0.06	0.029	19.00	0.55
Cadmium(mg/L)	0.01	100.00	0.09	0.875	910.00	795.83
Lead (mg/L)	0.1	10.00	4.37	0.087	4373.00	382.44
		$\sum \frac{1}{Si}$ =114.35		∑Wn =0.999	∑qn = 22028.38	∑qnWn =1227.84

$$K = \frac{1}{\sum\left(\frac{1}{Si}\right)} = 0.01$$

The WQI $= \frac{\sum q_n \times W_n}{\sum W_n} = \frac{1227.84}{1} = 1227.84$

Table 8: Water quality status

Water quality index range	Water quality status
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very poor
100 and above	Undesirable for drinking

[source: Chaterjee and Raziuddin, 2002]

4.5 Nemerow's Pollution Index (NPI)

The NPI was used to ascertain the parameters that are causing the quality of the river to deteriorate. The NPI results indicated the polluting effects of dissolved oxygen (DO), biological oxygen demand (BOD), colour, lead, and cadmium (Tables 9 and 10). In general, it can be concluded that the River Tordzie under study is not safe for drinking as specified earlier without treatment.

Table 9: Pollution index for the dry season

Parameters	**Agortime Kpetoe**	**Adaklu Waya**	**Adaklu Ablornu**	**Tetemale**	**Wute**	**Tordzinu**	**Agbakope**
pH	0.84	0.84	0.84	0.85	0.84	0.84	0.80
Colour (Hz)	**13.37**	**13.37**	**35.93**	**32.17**	**33.47**	**37.20**	**35.30**
TDS (mg/L)	0.18	0.16	0.13	0.17	0.18	0.17	0.17
Chloride (mg/L)	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Sulphate (mg/L)	0.02	0.03	0.04	0.02	0.02	0.02	0.03
Nitrate(mg/L)	0.16	0.21	0.22	0.22	0.23	0.24	0.22
Total hardness (mg/L)	0.58	0.50	0.56	0.54	0.56	0.62	0.57
BOD (mg/L)	**157.67**	**89.84**	**162.17**	**140.84**	**159.67**	**135.84**	**180.00**
DO (mg/L)	**1.15**	0.85	**1.22**	0.98	**1.21**	**1.04**	**1.37**
Iron (mg/L)	0.31	0.22	0.36	0.31	0.29	0.30	0.28
Cadmium (mg/L)	0.20	0.20	0.20	0.20	0.20	0.40	0.20
Lead (mg/L)	**250.00**	**257.00**	**247.00**	**248.00**	**250.00**	**245.30**	**250.30**
$\sum \boldsymbol{NPI}$	424.51	363.24	448.70	424.33	446.69	422.00	469.27

* All the figures highlighted boldly are above the standards.

Table 10: Pollution index for the wet season

Parameters	Agortime Kpetoe	Adaklu Waya	Adaklu Ablornu	Tetemale	Wute	Tordzinu	Agbakope
Ph	0.78	0.83	0.60	0.67	0.68	0.67	0.64
Colour (Hz)	**68.07**	**63.50**	**69.80**	**60.83**	**69.97**	**67.73**	**70.07**
TDS (mg/L)	0.16	0.15	0.07	0.06	0.10	0.06	0.09
Chloride (mg/L)	0.11	0.07	0.08	0.01	0.08	0.07	0.07
Sulphate (mg/L)	0.05	0.05	0.01	0.02	0.01	0.02	0.05
Nitrate (mg/L)	0.13	0.24	0.34	0.12	0.23	0.20	0.25
Total hardness (mg/L)	0.39	0.26	0.15	0.11	0.26	0.13	0.15
BOD (mg/L)	**82.50**	**132.50**	**94.17**	**115.17**	**57.50**	**112.50**	**97.50**
DO (mg/L)	**1.08**	0.95	0.72	**1.08**	0.72	**1.06**	0.69
Iron (mg/L)	0.13	0.20	0.23	0.10	0.27	0.13	0.27
Cadmium (mg/L)	**8.20**	**9.20**	**9.10**	**8.90**	**8.30**	**9.50**	**10.70**
Lead (mg/L)	**43.30**	**45.03**	**47.33**	**43.87**	**42.24**	**42.19**	**42.15**
$\sum NPI$	204.9	252.98	2262.6	230.94	180.36	234.26	222.63

* All the figures highlighted boldly were above the standards.

4.6 Descriptive statistics

In this section, the results that show the relationship between the dry season and wet season were analysed. First of all, before finding out whether a relationship exists between the dry season and wet season, line graphs were presented to visualise their relationship.

Figure 3 shows a graphical representation of recordings of the concentrations of the parameters of the dry season and wet season.

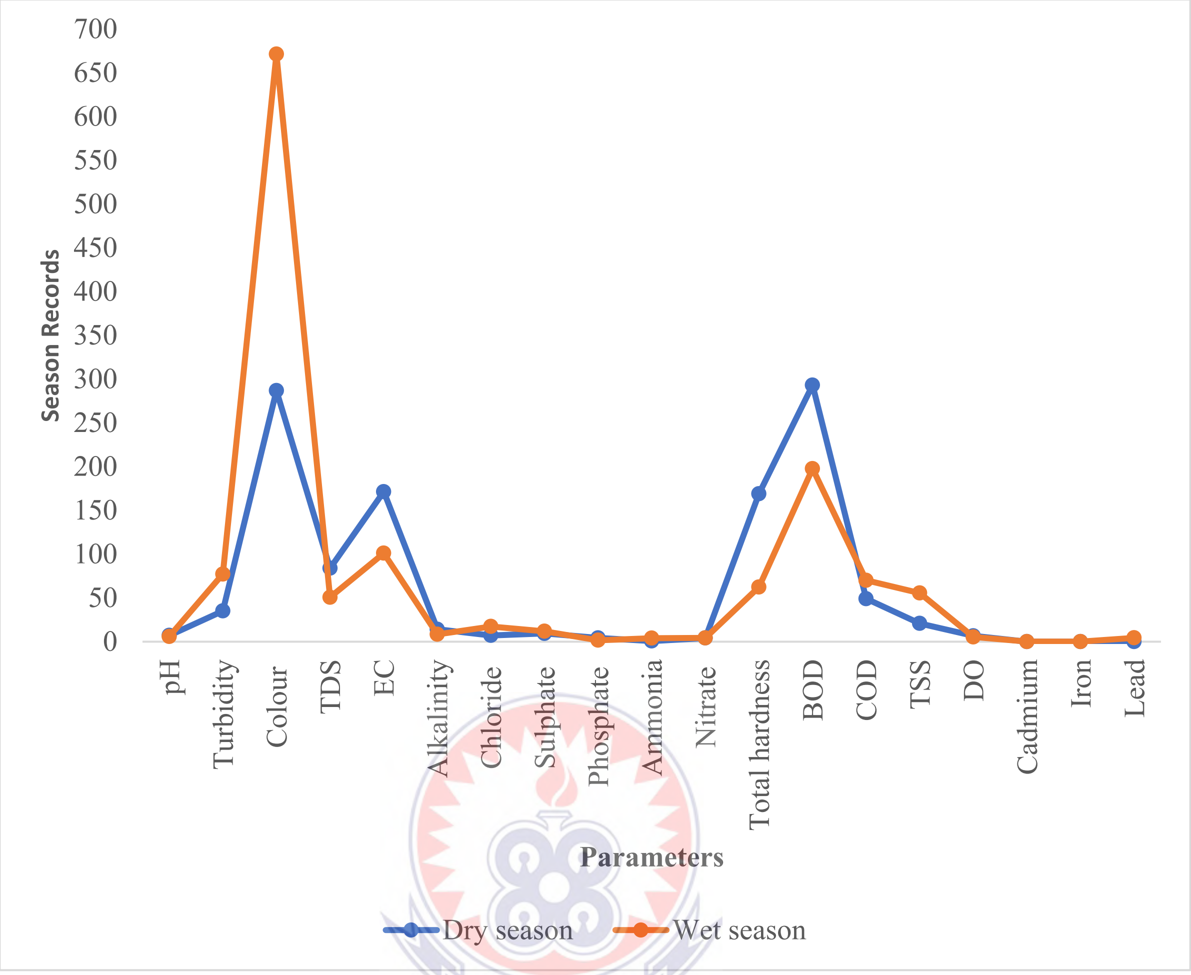

Figure 6: Graphical representation showing the seasonal variations of the mean values of the parameters during the dry and wet seasons of River Tordzie.

From Figure 6, the colour for the dry season was recorded at 286.86 whereas that of the wet season was recorded at 671.38 which tends to be the highest between the dry and wet seasons among the parameters. As shown in Figure 3, an increase in the record for the dry season leads to an increase for that of the wet season and vice versa. This shows that the above diagram has a direct relationship between the dry season and the wet season. This is an indication that seasonal variations affect the quality of River Tordzie.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study has provided information about the water quality status of River Tordzie. The River Tordzie has been subjected to physicochemical analysis and some selected metals analysis using WQI, and NPI for its suitability for domestic and other intended uses. The result of the mean pH, TDS, EC, Alkalinity, phosphate, nitrate, Total hardness, BOD, TSS, and DO for the dry season has been reduced during the wet season as a result of dilution of the water. The mean levels of other remaining physicochemical parameters showed an increase in the value from the dry season to the wet season. This can be attributed to human impact on the river; by using fertilizers and other agricultural products that are related to high concentrations which find their way into the river as a result of runoffs. The seasonal changes also had a major influence on the concentration and distribution of some of the parameters.

The results of the Water Quality Index (WQI); 92.28 for the dry season and 1229.22 for the wet season indicated that there were increased pollution loads of the river during the wet season. Therefore, the quality of the river was not of standard. The Nemerow's pollution index, NPI indicated that the high levels of colour, BOD, lead, and cadmium are the major parameters affecting the quality of River Tordzie making it unsafe for drinking. The sampling areas are mostly farming communities hence, it can be concluded that a variety of anthropogenic activities were the major contributing factors to the quality of River Tordzie. The analysis revealed that the water from the river needs some degree of treatment before consumption and also the banks of the river need to be protected from excessive human influence such as agricultural activities and domestic waste.

5.2. Recommendations

The river is utilized in many ways without treatment, including drinking, fishing, irrigation, and other domestic uses. Based on the results from the analysis, the study recommends the following:

1. To avoid large nutrient loads of the river, farmers should be assisted in fertilizer application by agricultural extension officers from the Ministry of Food and Agriculture.
2. All communities along the banks of the river should be properly educated on the effects of indiscriminate garbage discharge in water bodies and its health implications.
3. Water treatment facilities should be provided for the communities along the river.
4. Given the importance of the River Tordzie, constant efforts should be made to monitor the river's water quality as well as the surrounding terrain frequently to preserve the ecosystem.
5. Proper chemical treatment should be given to the water from the river before those living along the banks use it for their domestic activities.

REFERENCES

Abbas, A., Al-Amer, A. M., Laoui, T., Al-Marri, M. J., Nasser, M. S., Khraisheh, M., & Atieh, M. A. (2016). Heavy metal removal from aqueous solution by advanced carbon nanotubes: critical review of adsorption applications. *Separation and Purification Technology*, *157*, 141-161.

Abbaszadegan, M., Hasan, M. N., Gerba, C. P., Roessler, P. F., Wilson, B. R., Kuennen, R., & Van Dellen, E. (1997). The disinfection efficacy of a point-of-use water treatment system against bacterial, viral and protozoan waterborne pathogens. *Water Research*, *31*(3), 574-582.

Abdul-Razak, A., Asiedu, A. B., Entsua-Mensah, R. E. M., & deGraft-Johnson, K. A. A. (2010). Assessment of the water quality of the Oti River in Ghana. *West African Journal of Applied Ecology*, *16*(1).

Abou-Arab, A. A. K., Abou Donia, M. A., & Enab, A. K. (2016). Risk Assessment of Lead in Meat from Different Environments of Egypt. *International Journal of Nutrition and Food Engineering*, *10*(4), 257-261.

Abowei, J.F.N. & George, A.D.I., (2009**)**. Some physical and chemical characteristics in Okpoka creek, Niger Delta. *Research J. Environment and Earth Sci*., 1(2): 45-53.

Abowei, J.F.N., (2010). Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Adv. J. Food Sci. Technol*., 2(1): 16-21.

Abubakari, A., Oppong-Kyekyeku, A. F., Emmanuel, D., & Adiyiah, J. (2016). The Effect of Industrial Effluents on the Quality of Onukpawahe Stream, Tema-Ghana. *Journal of Environmental Science and Engineering*, *5*(1), 457-475.

Addy, K., Green, L., & Herron, E. (2004). pH and Alkalinity- University of Rhode Island, pp 1-4. http://www.uri.edu/ce/eq/.../pH&alkalinity (Accessed on October 15th, 2021).

Adeniran, A. (2018). Assessment of Water Quality in Slum Area Ibadan. Hydrol Current Res 9: 296. doi:10.4172/2157-7587.1000296.

African Water Development Report. (2006). Water for Sustainable Socio-Economic Development.http://www.uneca.org/awich/AWDR%202006/Introduction%20%20 Water%20for%20Socio-Economic %20Development.pdf], (accessed 11th November, 2021).

Agbaire, P. O., & Oyibo, I. P. (2009). Seasonal variation of some physico-chemical properties of borehole water in Abraka, Nigeria. *African Journal of Pure and Applied Chemistry*, *3*(6), 116-118.

Aglanu, L. M., & Appiah, D. O. (2014). The Korle lagoon in distress: The stress of urban solid waste on water bodies in Accra, Ghana. *International Journal of Innovation and Applied Studies*, *7*(2), 717.

Ahmed, J. B., Moumouni, A., & Musa, S. S. (2016). Influence of Abattoir Wastes on Groundwater Quality in Keffi, North Central Nigeria. *IOSR J. Environ. Sci. Toxicol. Food Technol*, *10*, 35-42.

Alabaster, J. S., & Lloyd, R. S. (2013). *Water quality criteria for freshwater fish* (No. 3117). Elsevier.

Alam, T. (2015). *Estimation of Chemical Oxygen Demand in Waste Water using UV-VIS Spectroscopy.* Master's thesis, Applied Sciences: School of Mechatronic Systems Engineering. Simon Fraser University, Bangladesh.

American Public Health Association (APHA). (1995). Standard methods for the examination of water and wastewater, (19th edn). American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC.

American Public Health Association (APHA). (1998). Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC.

American Public Health Association (APHA). (2003). Standard Methods for the Examination of water and Waste Water, 20th ed. Method 4500 E. American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC.

American Public Health Association (APHA). (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC.

American Water Works Association (AWWA). (1990). Water Quality and Treatment. A handbook of community water supply, 4th edn. McGraw-hill, Inc, Newyork.

Amosa, M. K. (2016). Sorption of water alkalinity and hardness from high-strength wastewater on bifunctional activated carbon: process optimization, kinetics and equilibrium studies. *Environmental technology*, *37*(16), 2016-2039.

Anantnarayan, H. S., Beretto, T., Desai, A., & Hegde, G. (2018). Water Qaulity Assesment of Kotithirta–A Holy Temple Lake of Gokarna, Karnataka. *Inter Res J EngiTechno (IRJET), 5 (4): 624*, *634*.

Anderson, D. (2003). Introduction to heavy metal monitoring. *Centre for Ecology and Hydrology, Natural Environment Research Council*, 1-9.

Anhwange, B. A., Agbaji, E. B., & Gimba, E. C. (2012). Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. *International journal of Science and Technology*, *2*(5), 248-254.

Anim-Gyampo, M., Zango, M. S., & Ampadu, B. (2014). Assessment of drinking water quality of groundwaters in Bunpkurugu-Yunyo District of Ghana. *Environment and Pollution*, *3*(3), 1.

Aniyikaiye, T. E., Oluseyi, T., Odiyo, J. O., & Edokpayi, J. N. (2019). Physico-Chemical Analysis of Wastewater Discharge from Selected Paint Industries in Lagos, Nigeria. *International journal of environmental research and public health*, *16*(7), 1235. https://doi.org/10.3390/ijerph16071235.

Anthemidis, A. N., Zachariadis, G. A., Kougoulis, J. S., & Stratis, J. A. (2002). Flame atomic absorption spectrometric determination of chromium (VI) by on-line preconcentration system using a PTFE packed column. *Talanta*, *57*(1), 15-22.

Antrade A. I. A. S. S. & Stiger T. Y. (2009). Multi-method assessment of nitrate and pesticide contamination in shallow alluvial groundwater as a function of hydrogeological setting and land use, Agricultural Waste Management, 96, 1751-1765.

Apau, J., Appiah, S. K., & Marmon-Halm, M. (2012). Assessment of water quality parameters of Kpeshie Lagoon of Ghana. *Journal of Science and Technology (Ghana)*, *32*(1), 22-31.

Armitage, P. D., Bowes, M. J., & Vincent, H. M. (2007). Long‐term changes in macroinvertebrate communities of a heavy metal polluted stream: the River Nent (Cumbria, UK) after 28 years. *River research and applications*, *23*(9), 997-1015.

Asamoah, E. (2012). The impact of small-scale gold mining activities on the water quality of River Birim in the Kibi traditional area. *Unpublished Master's Thesis. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*.

Asare-Bediako, L. (2008). Assessment of Drinking Water Quality of River Ofin at Kyereyiase in the Atwima Nwabiagye District. *BSc Dissertation*, Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, Ghana.

Ashton, P. J., Love, D., Mahachi, H., & Dirks, P. H. G. M. (2001). An overview of the impact of mining and mineral processing operations on water resources and water quality in the Zambezi, Limpopo and Olifants Catchments in Southern Africa. *Contract Report to the Mining, Minerals and Sustainable Development (Southern Africa) Project, by CSIR-Environmentek, Pretoria and Geology Department, University of Zimbabwe-Harare. Report No. ENV-PC*, *42*, 1-362.

Asiamah, G. (2013). *Heavy metal concentration in the Owere River at Konongo* (Doctoral dissertation, Msc. Thesis). *Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*.

ATSDR, U. (2007). Toxicological profile for lead. US Department of Health and Human Services, public health service, Agency for Toxic Substances and Disease Registry. *Atlanta (GA) available from www. atsdr. cdc. gov/toxprofiles/tp. asp. [Accessed in December, 2021]*.

Attua, E. M., Annan, S. T., & Nyame, F. (2014). Water quality analysis of rivers used as drinking sources in artisanal gold mining communities of the Akyem-Abuakwa area: A multivariate statistical approach. *Ghana Journal of Geography*, *6*, 24-41.

Awuah, E., & Anipa, H. (2002). Rainwater harvesting as a supplement of domestic water supply: Case study of Kotei. *Proceedings of the 2nd School of Eng. KNUST, Kumasi, research retreat, Elmina*, 19-21.

Baht, R. V., & Moy, G. G. (1997). Monitoring and assessment of dietary exposure to chemical contaminants. *World health statistics quarterly 1997; 50 (1/2): 132-149*.

Barrel, R. A. (2000). Community–Dis–Public Health. *Journal from University of Bern: Switzerland*, *8*, 13.

Becker, J. S. (2002). Applications of inductively coupled plasma mass spectrometry and laser ablation inductively coupled plasma mass spectrometry in materials science. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *57*(12), 1805-1820.

Bellinger, D. C. (2005). Teratogen update: lead and pregnancy. *Birth Defects Research Part A: Clinical and Molecular Teratology*, *73*(6), 409-420.

Bellingham, K. (2006). *Physicochemical Parameters of Natural Waters.* Stevens Water Monitoring Systems, Inc. 1–17.

Bernhardt, S. E., Band, L. E., Walsh, C. J., & Berke, P. E. (2008). Understanding, Managing, and Minimizing Urban Impacts on Surface Water Nitrogen Loading. New York: Academy of Sciences, Wiley.

Bhattacharya, S., Das, A., Prashanthi, K., Palaniswamy, M., & Angayarkanni, J. (2014). Mycoremediation of Benzo [a] pyrene by Pleurotus ostreatus in the presence of heavy metals and mediators. *3 Biotech*, *4*(2), 205-211.

Boah, D. K., Twum, S. B., & Pelig-Ba, K. B. (2015). Mathematical computation of water quality index of Vea dam in Upper East Region of Ghana. *Environ Sci*, *3*(1), 11-16.

Bogardi, I., & Kuzelka, R. D. (1991). Nitrate contamination: exposure, consequences and control, Springer-Verlag, Berlin Heidelberg, Germany.

Bollmann, A., & Revsbech, N. P. (2005). An NH_4^+ biosensor based on ammonia-oxidizing bacteria for use under anoxic conditions. *Sensors and Actuators B: Chemical*, *105*(2), 412-418.

Bonareri, S. P. (2013). *Effects of human activities on water quality of Rupingazi River, Embu County, Kenya* (Doctoral dissertation, Kenyatta University).

Boyd, C. E. (2020). Carbon Dioxide, pH, and Alkalinity. In *Water Quality* (pp. 177-203). Springer, Cham.

Boyles, W. (1997). The science of chemical oxygen demand. *Technical Information Series, Booklet*, (9), 24. http://www.hach.com/asset-get.download.jsa?id=7639984471.

Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index-do we dare. Water and sewage works, 117 (10).

Bruins, M. R., Kapil, S., & Oehme, F. W., (2000). Microbial resistance to metals in the environment. *Ecotoxicology and environmental safety*, *45*(3), 198-207.

Burt T. P. (1993). Nitrates, processes, patterns and management, John Wiley, Chichester, New York.

Catherine, E. C., Danmama, A. A., Emeka, A., Emeka, N. K., & Michael, O. R. (2021). Assessment of surface water quality of Onuiyieke River in Imo State, Nigeria. *GSC Biological and Pharmaceutical Sciences*, *16*(3), 071-084.

Catli, Y. (2009). Studying Electric Field Effect on Water by Analysing the Instrument "Hydronic". *University of Trento: Trento, Italy*.

Chapman, D. (1992). Water quality assessments: a guide to use of biota, sediments and water in environmental monitoring, 2nd edn. Chapman & Hall, London.

Chiras, D. D. (1998). *Environmental Science: A Systematic Approach to Sustainable Developmen*t (5th Edition). Washington D.C: Wadsworth Publishing Co.

Cleveland, A. J. (1998). Water What ifs–Water Quality and Dissolved Oxygen. *Science Junction*.

Colter, A., & Mahler, R. L. (2006). *Iron in drinking water*. Moscow: University of Idaho. Conservation Service, Washington, D.C.

Corcoran, E. (2010). Sick Water: The Central Role of Wastewater Management in Sustainable Development: a rapid response assessment. UNEP/Earth print.

Correia, P. R. M., Oliveira, E. D., & Oliveira, P. V., (2000). Simultaneous determination of Cd and Pb in foodstuffs by electrothermal atomic absorption spectrometry. *Analytica chimica acta*, *405*(1-2), 205-211.

Dafter, H., Kachingwe, R., Safuya, K., Chinoko, G., Mgemezulu, J., & Nkhoma, S. (2019). Effects of Agricultural Activities on Water Quality in Rural Area Rivers. Department of water resources, Malawi University of Science and Technology.

Dallas, H.F & Day, J.A., (2004). *The Effect of Water Quality Determination on Aquatic Ecosystems*: A Review. report Number: TT 224/04. Water Research Commission.

Daud, M. K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., Arshad, M. U., Chatha, S.A.S., Deeba, F., Murad, W., Malook, I., & Zhu, S. J. (2017). Drinking water quality status and contamination in Pakistan. *BioMed research international*, *2017*.

Delisle, C. E., & Schmidt, J. W. (1977). The effects of sulphur on water and aquatic life in Canada. *Sulphur and its inorganic derivatives in the Canadian environment. Ottawa, Ontario, National Research Council of Canada (NRCC No. 15015)*.

Department of Water Affairs & Forestry (DWAF), (1996). South African Water Quality Guidelines (second edn). Volume 1: Domestic use. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs (DWA), (2011). Water quality management in South Africa. Available at http://www.dwaf.gov.za/Dir_WQM/wqm.asp. [Accessed in November 2021].

Doe, H. W. (2007). *Assessing the challenges of water supply in urban Ghana: The case of North Teshie*. Kungliga Tekniska högskolan.

Duncan, A.E., Peprah, M.O. & Marfo, M.O. (2020). Unregulated Hand Dug Wells and Their Quality Threat: A Case Study in Cape Coast Metropolis. Open Access Library Journal, 7: e6482. https://doi.org/10.4236/oalib.1106482.

Duruibe, J. O., Ogwuegbu, M. O. C., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of physical sciences*, *2*(5), 112-118.

Edition, F., (2011). Guidelines for drinking-water quality. *WHO chronicle*, *38*(4), 104-108.

Eisler, R. (1985). *Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review* (No. 2). Fish and Wildlife Service, US Department of the Interior.

Eljaiek-Urzola, M., Romero-Sierra, N., Segrera-Cabarcas, L., Valdelamar-Martínez, D., & Quiñones-Bolaños, É. (2019). Oil and grease as a water quality index parameter for the conservation of marine biota. *Water*, *11*(4), 856.

Elser, J. J., Bracken, M. E.S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J.T., Seabloom, E.W., Shurin, J.B., & Smith, J. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology letters*, *10*(12), 1135-1142.

Emoyan, O. O., Ogban, F. E., & Akarah, E. (2006). Evaluation of heavy metals loading of River Ijana in Ekpan–Warri, Nigeria. *Journal of Applied Sciences and Environmental Management*, *10*(2).

Farajzadeh, M. A., & Fallahi, M. R. (2006). Simultaneous cloud-point extraction of nine cations from water samples and their determination by flame atomic absorption spectrometry. *Analytical sciences*, *22*(4), 635-639.

Farooq, S., Hashmi, I., Qazi, I. A., Qaiser, S., & Rasheed, S. (2008). Monitoring of coliforms and chlorine residual in water distribution network of Rawalpindi, Pakistan. *Environmental monitoring and assessment*, *140*(1), 339-347.

Fatoki, O. S., & Awofolu, R. J. W. S. (2003). Levels of Cd, Hg and Zn in some surface waters from the Eastern Cape Province, South Africa. *Water SA*, *29*(4), 375-380.

Fatoki, O. S., & Muyima, N. Y. O. (2003). *Situation analysis of the health-related water quality problems of the Umtata River*. Water Research Commission.

Ferrante, M., Conti, G. O., Rasic-Milutinovic, Z., & Jovanovic, D. (2013). Health Effects of Metals and Related Substances in Drinking Water: Research Report Series. IWA Publishing.

Fianko, J. R., Laar, C., Osei, J., Anim, K. A., Gibrilla, A. & Adomako, D. (2013). Evaluation of some heavy metal loading in the Kpeshi lagoon, Ghana. *Appl Water Sci.,* 3:311–319.

Flora, S. J. S. (2009). Metal poisoning: threat and management. *Al Ameen J Med Sci*, *2*(2), 4-26.

Food and Agriculture Organization of the United Nations, (2003). Review of world water resources by country. Report. ISSN 1020-1203.

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. W., Cowling, E. B., & Cosby, B. J. (2003). The nitrogen cascade. *Bioscience, 53* (4), 341–356.

Ganjo, D. G., Aziz, F. H., & Shekha, Y. A. (2006). An attempt for reuse of the wastewater of Erbil City for irrigation purposes. Erbil, Kurdistan Region of Iraq. I. Typha angustifolia L. macrophyte as a biological waste removal from wastewater. *Zanco Journal of Pure and Applied Sciences*, *18*(2), 148-175.

Garrick, D., Jacobs, K., & Garfin, G. (2008). Models, assumptions, and stakeholders: planning for water supply variability in the Colorado River Basin 1. *JAWRA Journal of the American Water Resources Association*, *44*(2), 381-398.

Ghosh, S., & Vass, K. K. (1997, March). Role of sewage treatment plant in Environmental Mitigation. In *Proceedings of the national seminar on changing perspectives of Inland Fisheries* (pp. 36-40).

Gordon, C., & Ansa-Asare, O. D. (2012). Water quality assessment of Densu, Birim and Ayensu Rivers in the Okyeman area. *West African Journal of Applied Ecology*, *20*(3), 53-64.

Guoqing, W.U., Weihong, B.I., Jiaming, L.V., & Guangwei, F.U. (2011). Determination of chemical oxygen Demand in water using infra-red transmission and UV absorbance method. *Chinese Optics letters* 09 (si): 3010705.

Gupta, C. P. (2014). Role of iron (Fe) in the body. *IOSR Journal of Applied Chemistry*, *7*(11), 38-46.

Gupta, D. P., Sunita, S. J., & Saharan, J. P. (2009). Physiochemical analysis of ground water of selected area of Kaithal city (Haryana) India. *Researcher*, *1*(2), 1-5.

Gupta, V. K., Sadegh, H., Yari, M., Shahryari, G. R., Maazinejad, B., & Chahardori, M. (2015). Removal of ammonium ions from wastewater a short review in development of efficient methods. *Global Journal of Environmental Science and Management 1*(2)*,* 149-158.

Hamid, A., Bhat, S. U., & Jehangir, A. (2020). Local determinants influencing stream water quality. *Applied Water Science*, *10*(1), 1-16.

Harrafi, H., Khedri, M., & Karaminejad, K. (2012). Determination of Chemical Oxygen Demand in Spent Caustic by Potentiometric Determination. *World Academy of Science, Engineering and Technology*, *6*(7), 190–192.

Hillel, D. (1991). Out of the Earth, Civilization and the Life of the Soil. University of California Press, Los Angeles. https://doi.org/10.1097/00010694-199108000-00014.

Hoko, (2008). An assessment of quality of water from boreholes in Bindura District, Zimbabwe. *Physics and Chemistry of the Earth, 33*, 824–828.

Howari, F. M., & Banat, K. M. (2001). Assessment of Fe, Zn, Cd, Hg, and Pb in the Jordan and Yarmouk River sediments in relation to their physicochemical properties and sequential extraction characterization. *Water, Air, and Soil Pollution*, *132*(1), 43-59.

Hussain, M., Ahmed S.M. & Abderrahman, W., (2008). Choter analysis and quality assessment of logges water at an irrigation project, eastern Saudi Arabia. *J. Environ. Manage 86, 297-307.*

Ibrahim, B., Auta, J., & Balogun, J. (2009). An assessment of the physico-chemical parameters of Kontagora Reservoir, Niger State, Nigeria. *Bayero Journal of pure and applied sciences*, *2*(1), 64-69.

Idoko, O. M., Ologunorisa, T. E., & Okoya, A. A. (2012). Temporal variability of heavy metals concentration in rural groundwater of Benue State, Middle Belt, Nigeria. *Journal of Sustainable Development*, *5*(2), 2.

Igwe, P. U., Chukwudi, C. C., Ifenatuorah, F. C., Fagbeja, I. F., & Okeke, C. A. (2017). A review of environmental effects of surface water pollution. *International Journal of Advanced Engineering Research and Science*, *4*(12), 237340.

Iqbal, J., Waseem Mumtaz, M., Mukhtar, H., Iqbal, T., Mahmood, S., & Razaq, A. (2010). Particle size distribution analysis and physico-chemical characterization of Chenab River water at Marala headworks. *Pakistan Journal of Botany*, *42*(2), 1153–1161.

Ireland Environmental Protection Agency, (2001). Parameters of water quality– interpretation and standards. *Environmental Protection Agency, Wexford*. http://www.yumpu.com/en/document/view.22995497/Parameters of Water Quality : Interpretation and Standards (yumpu.com), (Accessed 27th october, 2021).

Irenosen, O. G., Festus, A. A., & Coolborn, A. F. (2012). Water quality assessment of the Owena multi-purpose dam, Ondo State, Southwestern Nigeria. *Journal of Environmental Protection*, *3*(01), 14-25.

Issa, J. A., Babiker, M. O., Ohaj, M., Osman, M. E., Abdelrahman, M. A., & Abaker, A. M. (2013). Determination of some inorganic constituents of drinking water in zalingei town central darfur state, Sudan. *J Sci Technol*, *3*(12), 1208-14.

Jamali, M. K., Kazi, T. G., Afridi, H. I., Arain, M. B., Jalbani, N., & Memon, A. R. (2007). Speciation of heavy metals in untreated domestic wastewater sludge by time saving BCR sequential extraction method. *Journal of Environmental Science and Health Part A*, *42*(5), 649-659.

Jindal, R., & Wats, M. (2022). Evaluation of surface water quality using water quality indices (WQIs) in Lake Sukhna, Chandigarh, India. *Applied Water Science*, *12*(1), 1-14.

Kadlec, R.H. & Wallace, S.C., (2009). *Treatment Wetlands*(2ndEdition) Boca Raton: CRC Press.

Kamara, A. M., (2019). *Assessment of Heavy Metal Pollution in Soil and Surface Water in Mng-Gold, Kokoya District, Bong County, Liberia* (Doctoral dissertation). African University of Science and Technology, Abuja.

Kamble, R. K., Thakare, M. G., & Ingle, A. B. (2013). Iron in the Environment. *Indian Journal of Environment Protection*, *33*(11), 881-888.

Kanth, M. K., Singh, S. K., Kashyap, A., Kumari, A., & Puja, K. (2018). Physicochemical Assessment of Some Pond Water in Patna (India). *Asian Journal of Environment & Ecology*. 8(2): 1-8.

Kar, D., Sur, P., Mandai, S. K., Saha, T., & Kole, R. K., (2008). Assessment of heavy metal pollution in surface water. *International Journal of Environmental Science & Technology*, *5*(1), 119-124.

Karikari, A. Y., & Ampofo, J. A. (2013). Chlorine treatment effectiveness and physico-chemical and bacteriological characteristics of treated water supplies in distribution networks of Accra-Tema Metropolis, Ghana. *Applied Water Science*, *3*(2), 535-543.

Karikari, A. Y., & Ansa-Asare, O. D., (2006). Physico-chemical and microbial water quality assessment of Densu River of Ghana. *West African Journal of Applied Ecology*, *10*(1).

Kempster, P. L., Van Vliet, H. R., & Kuhn A., (1997). The Need for Guideline to Bridge the Gap between Ideal Drinking Water Quality and Quality which is Practicably Available and Acceptable. *Water SA* 23(2): 163–167.

Khatri, N., & Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, *8*(1), 23-39.

Kodom, K., Onoyinka, A. A., Mkude, I. T., Out, S. A., & Yeboah, J. O. (2018). Physicochemical parameters assessment and seasonal variations of surface water quality of the Volta Lake in Ghana. *International Journal of Research*, *5*(1), 989-1007.

Kontoghiorghe, C. N., & Kontoghiorghes, G. J. (2016). New developments and controversies in iron metabolism and iron chelation therapy. *World journal of methodology*, *6*(1), 1.

Krishnan, J. R. (2008). Investigation on hydrobiology and water quality parameters of Periyar Lake, Thekkady, Kerala. *Mahatma Gandhi University, Kerala, India*.

Kronvang, B., Bechmann, M., Lundekvam, H., Behrendt, H., Rubaek, G. H., Schoumans, O. F., Syversen, N., Andersen, H.E., & Hoffmann, C. C. (2005). Phosphorus losses from agricultural areas in river basins: Effects and uncertainties of targeted mitigation measures. *Journal of environmental quality*, *34*(6), 2129-2144.

Kross, B. C., Ayebo, A. D., & Fuortes, L. J. (1992). Methemoglobinemia: nitrate toxicity in rural America. *American family physician*, *46*(1), 183-188.

Kumar, M., & Puri, A., (2012). A review of permissible limits of drinking water. *Indian Journal of Occupational and Environmental Medicine, 16*(1), 40–44.

Kyekyeku, O. (2011). Impact of Chirano Gold Mines Operations on levels of As, Pb, Hg and Cd in the Suraw River and the Possible Health Implications on Downstream Communities, M. Sc Thesis. Department of Theoretical and Applied Biology. Kwame Nkrumah University of Science and Technology, Ghana.

Landrigan, P. J., Boffetta, P., & Apostoli, P. (2000). The reproductive toxicity and carcinogenicity of lead: A critical review. *American journal of industrial medicine*, *38*(3), 231-243.

Leroy, P. N., Mark, M. B., & John, W. D. (2002). Aquatic Ecosystems and Global Climate Change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. *Center for climatic and energy solution*, 1-2.

Levit, S. M., (2010). A literature review of effects of ammonia on fish. *JD Center for Science in Public Participation Bozeman, Montana*. November, 2010. Retrieved from http://www.rosemonteis.us/sites/default/files/references/045281.pdf.

Logeshkumaran, A., Magesh, N. S., Godson, P. S., & Chandrasekar, N. (2015). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Science*, *5*(4), 335-343.

Lomniczi, I., Boemo, A., & Musso, H. (2007). Location and characterisation of pollution sites by principal component analysis of trace contaminants in a slightly polluted seasonal river: A case study of the Arenales River (Salta, Argentina). *Water SA*, *33*(4).

Lory, J. A. (1999). Agricultural phosphorus and water quality (1999). *Soil and fertilizer management*. *University of Missouri Extension G9181*.

Lutz, D. S., Kahler-Royer, C., & Petersen, M. J. (1997). *Water Quality Studies: Red Rock and Saylorville Reservoirs, Des Moines River, Iowa*. Sanitary Engineering Section, Engineering Research Institute, Iowa State University.

Magna, E. K., Donkor, A., Dabi, M., Ansah, E., Kumassah, E., & Owusu, P. (2018). Assessment of the Impact of Solid Waste Disposal on the Portability of Surface Water and Groundwater Using Water Quality Index (WQI) in Kpassa, Nkwanta North District of Ghana. *Assessment*, *10*(9).

Mariraj, M. S., & Vanalakshmi, P. (2013). Assessment of water quality in Noyyal River through water quality index. *International Journal of Water Resources and Environmental Engineering*, *5*(1), 35-48.

Marx, J. J. M. (2002). Iron and infection: competition between host and microbes for a precious element. *Best practice & research Clinical haematology*, *15*(2), 411-426.

McLay, C. D. A., Dragten, R., Sparling, G., & Selvarajah, N. (2001). Predicting groundwater nitrate concentrations in a region of mixed agricultural land use: a comparison of three approaches. *Environmental pollution*, *115*(2), 191-204.

Medhi, B., Chakravartty, M., & Sharma, B. B. (2019). Groundwater Quality Assessment for Drinking Purpose Based on Water Quality Index in Gabharu River Basin, North-East, India. *Earth Science India*, *12*(2).

Mensah, M. K. (2011). Assessment of drinking water quality in Ehi Community in the Ketu-North District of the Volta Region of Ghana (Doctoral dissertation). *Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*.

Metcalf, L., Eddy, H. P., & Tchobanoglous, G. (1991). *Wastewater engineering: treatment, disposal, and reuse* (Vol. 4). New York: McGraw-Hill.

Meybeck, M., (1997). The assessment of the quality of the aquatic environment. *Rev. geol. Dyn Geogr. Phys*; 21, 215 – 246.

Mitharwal, S., Yadav, R. D., & Angasaria, R. C. (2009). Water Quality analysis in Pilani of Jhunjhunu District (Rajasthan)-The place of Birla's Origin. *Rasayan Journal of Chemistry*, *2*(4), 920-923.

Miyittah, M. K., Tulashie, S. K., Tsyawo, F. W., Sarfo, J. K., & Darko, A. A. (2020). Assessment of surface water quality status of the Aby Lagoon System in the Western Region of Ghana. *Heliyon*, *6*(7), e04466.

Mohanta, B. K., & Potra, A. K. (2000). Studies on the water quality index of River Sanamachhandana at Keonjar Garh, Orissa, India. *Pollution Research*, Vol. 19(3), pp. 377 385.

Mohsin, M., Safdar, S., Asghar, F., & Jamal, F. (2013). Assessment of drinking water quality and its impact on residents' health in Bahawalpur city. *International Journal of Humanities and Social Science*, *3*(15), 114-128.

Mushtaq, N., Singh, D. V., Bhat, R. A., Dervash, M. A., & bin Hameed, O. (2020). Freshwater contamination: sources and hazards to aquatic biota. In *Fresh Water Pollution Dynamics and Remediation* (pp. 27-50). Springer, Singapore.

Mustapha, A., & Gesto, B.U. (2014). Sources and pathway of environmental pollutants into surface water sources: A review. *Journal of environments*, *1*(2), pp 54 – 59.

Mwaura, F. (2005). Some aspects of water quality characteristics in small shallow tropical man-made reservoirs in Kenya. *African journal of science and technology*, 7(1).

National Geographic Society, (2022). Surface water. https://education.nationalgeographic.org/resource/surface-water.

Nduka, J. K., Orisakwe, O. E., & Ezenweke, L. O. (2008). Some physicochemical parameters of potable water supply in Warri, Niger Delta area of Nigeria. *Scientific Research and Essay, 3*(11), 547–551.

Nhapi, I., Wali, U. G., Uwonkunda, B. K., Nsengimana, H., Banadda, N., & Kimwaga, R. (2011). Assessment of water pollution levels in the Nyabugogo Catchment, Rwanda. *The Open Environmental Engineering Journal*, *4*(1).

Njue, N., Sirmah, P., Koech, E., & Hitimana, J. (2016). Influence of land use activities on riparian vegetation, soil and water quality: An indicator of biodiversity loss, South West Mau Forest, Kenya. O*pen Journal of Forestry*, *6*(5).

Nkansah, M. A., Boadi, N. O., & Badu, M., (2010). Assessment of the quality of water from hand-dug wells in Ghana. *Environmental health insights*, 4, EHI-S3149.

Nsubuga, F. N. W, Namutebi, E. N., & Nsubuga-Ssenfuma, M. (2014). Water resources of Uganda: An assessment and review. *Journal of Water Resource and Protection*, *6*(14), 1297.

Nyantakyi, J. A., Fei-Baffoe, B., & Akoto, O. (2020). Seasonal variations in physicochemical and nutrient water quality of River Tano in Ghana. *International Journal of Environmental Chemistry*, *4*(1), 1-1.

Nyatuame, M., & Agodzo, S. (2017). Analysis of extreme rainfall events (drought and flood) over Tordzie Watershed in the Volta Region of Ghana. *Journal of Geoscience and Environment Protection*, *5*(9), 275-295.

Nyenje, P. M., Foppen, J. W., Uhlenbrook, S., Kulabako, R., & Muwanga, A. (2010). Eutrophication and nutrient release in urban areas of sub-Saharan Africa-a review. *Science of the total environment*, *408*(3), 447-455.

Nziguheba, G., & Smolders, E. (2008). Inputs of trace elements in agricultural soils via phosphate fertilizers in European countries. *Science of The Total Environment, 390*(1), 53-57.

Obiri, S., Addico, G., Mohammed, S., Anku, W. W., Darko, H., & Collins, O. (2021). Water quality assessment of the Tano Basin in Ghana: a multivariate statistical approach. *Applied Water Science*, *11*(2), 1-8.

Odiyo, J.O., Chimuka, L., Mamali, M.A., & Fatoki, O.S. (2012). Trophic status of Vondo and Albasini Dams; impacts on aquatic ecosystems and drinking water. *International Journal of Environmental Science and Technology, 9*, 203–211.

Omer, N. H. (2019). Water quality parameters. *Water quality-science, assessments and policy*, 18.

Owusu, P. A., Asumadu-Sarkodie, S., & Ameyo, P. (2016). A review of Ghana's water resource management and the future prospect. *Cogent Engineering*, *3*(1), 1164275.

Pal, S., & Chakraborty, K. (2017). Different aspects of chloride in freshwater: A review. *International Journal of Current Trends in Science and Technology*, *7*(8), 20295-20303.

Parr, J. F., Papendick, R. I., Hornick, S. B., & Meyer, R. E. (1992). Soil quality: Attributes and relationship to alternative and sustainable agriculture. *American Journal of Alternative Agriculture*, *7*(1-2), 5-11.

Pati, R. C., & Rout, S. P. (2018). Water Quality Status of Rushikulya River Basin, Odisha, India. *Asian Journal of Research in Chemistry*, *11*(2), 221-231.

Patil, G., & Ahmed, I. (2011). Heavy metals contamination assesment of Kanhargaon Dam water near Chhindwara city. *Acta Chimica and Pharmaceutica Indica*, *1*(1), 7-9.

Penn, M. R., Pauer, J. J., & Mihelcic, J. R. (2009). Biochemical oxygen demand. *Environmental and ecological chemistry*, *2*, 278-297.

Perera, P.A.C.T., Sanadarabarathy, T.V., & Edirisinghe, U. (2014). Seasonal Varaiation of Water Quality Parameters in different Geomorphic Channels of Upper Malwathu Oya in Anuradhapura, Sri Lanka. *Tropical Agricultural Research,* 25 (2), 158-170.

Peters, N. E., & Meybeck, M. (2000). Water quality degradation effects on freshwater availability: Impacts of human activities. *Water International*, *25*(2), 185-193.

Petts, J. (1994). Effective waste management: Understanding and dealing with public concerns. *Waste management & research*, *12*(3), 207-222.

Pink, S. (2006). The future of visual anthropology*:* Engaging the senses. Routledge. London.

Prud'Homme, A. (2012). *The ripple effect: The fate of freshwater in the twenty-first century*. Simon and Schuster. New York, London.

Puri, P. J., Yenkie, M. K. N., Sangal, S. P., Gandhare, N. V., Sarote, G. B., & Dhanorkar, D. B. (2011). Surface water (lakes) quality assessment in Nagpur city (India) based on water quality index (WQI). *Rasayan journal of chemistry*, *4*(1), 43-48.

Ramachandra, T. V., & Solanki, M. (2007). Ecological assessment of lentic water bodies of Bangalore. *The Ministry of Science and Technology*, *25*, 96.

Raymond, P. A., Oh, N. H., Turner, R. E., & Broussard, W. (2008). Anthropogenically enhanced fluxes of water and carbon from the Mississippi River. *Nature*, *451*(7177), 449-452.

Reddy Annem, S., Babu Amari, R., Elkhatib, E., & Sowa, J. (2017). Determination of Iron in Water.

Reichenberger, S., Bach, M., Skitschak, A., & Frede, H. G. (2007). Mitigation strategies to reduce pesticide inputs into ground-and surface water and their effectiveness; a review. *Science of the Total Environment*, *384*(1-3), 1-35.

Rim-Rukeh, A. (2016). Assessment of water quality in a Tidal River system using River Pollution Index (RPI). *Journal of Environ. Sci. and Pollut. Res*, *2*, 72-75.

Ritter, L., Keith, S., Sibley, P., Ken, H., Patricia, K., Gevan, M., & Beth Linton, L. (2002). Sources, pathways, and relative risks of contaminants in surface water and groundwater: A perspective prepared for the Walkerton inquiry. *Journal of Toxicology and Environmental Health Part A*, *65*(1), 1-142.

Roosbroeck, V., & Amlalo, D. S. (2006). Country Environmental Profile of Ghana. *Final Draft Report). (Ref: MWH 47501004.001 rev. 0)*.

Roxas, D.M. & Salgados, J.A.B. (2014). *Quality determination of total hardness in drinking water by complexometric EDTA titration*. National Institute of Molecular Biology and Biotechnology, University of the Phillipines, Quezon City, Phillipines.

Saana, S. B. B. M., Fosu, S. A., Sebiawu, G. E., Jackson, N., & Karikari, T. (2016). Assessment of the quality of groundwater for drinking purposes in the Upper West and Northern regions of Ghana. *SpringerPlus*, *5*(1), 1-15.

Sall, M., & Vanclooster, M. (2009). Assessing the well water pollution problem by nitrates in the small-scale farming systems of the Niayes region, Senegal. *Agricultural water management*, *96*(9), 1360-1368.

Samah, O. H. (2012). Microbiological and physico-chemical assessment of surface water quality along Asukawkaw River in the Volta Region. *Master of Science thesis, Kwame Nkrumah University of Science and Technology, Kumasi*.

Samlafo, B. V., & Adakwah, D. (2021). Evaluative Study of River Birim in Denkyembuor, Ghana, Using Water Quality Indices. *Chemical Science International Journal,* 30(9): 39-51.

Samuel, A. (2013). *Assessing The Water Quality Of River Asuotia And Six Hand-Dug Wells At Wamfie In The Dormaa East District Of Brong Ahafo Region, Ghana* (Doctoral Dissertation, Department Of Environmental Science, Kwame Nkrumah University Of Science And Technology, Kumasi).

Sankar, T. R., & Rao, P. P. (2014). Heavy metal assessment in industrial groundwater in and around Vijayawada, Andhra Pradesh, India. *European Chemical Bulletin*, *3*(10), 1008-1013.

Saviour, N. M. (2012). Environmental impact of soil and sand mining. *International Journal of Science, Environment and Technology*, *3*, 221-216.

Schaefer, M. (2008). Water Technologies and the Environment: Ramping up by Scaling Down. *Technol. Soc., 30*, 415–422.

Schueller, T. R., & Holland, H. (2000). Microbes and urban watersheds: concentrations, sources, and pathways. *The Practice of Watershed Protection*, 74-84.

Schweitzer, L., & Noblet, J. (2018). Water contamination and pollution. In *Green chemistry* (pp. 261-290). Elsevier.

Selvanayagam, M., & Abril, R. (2015). Water quality assessment of Piatua River using macroinvertebrates in Puyo, Pastaza, Ecuador. *American Journal of Life Sciences*, *3*(3), 167-174.

Sen, B., Alp, M. T., Sonmez, F., Kocer, M. A. T., & Canpolat, O. (2013). Relationship of algae to water pollution and waste water treatment. *Water treatment*, 335-354. InTech publication, Croatia.

Sharpley, A. (1999). Environment and health-symposium: Reducing the environmental impact of poultry production: focus on phosphorus-agricultural phosphorus, water quality, and poultry production: are they compatible? *Poultry Science*, *78*(5), 660-673.

Shittu, O. B., Olaitan, J. O., & Amusa, T. S. (2008). Physico-chemical and bacteriological analyses of water used for drinking and swimming purposes in Abeokuta, Nigeria. *African Journal of Biomedical Research*, *11*(3).

Shivdas, N. S. (2014). *Interaction of Haloarchaea with* Fe^{2+} *and* Mn^{2+} *ions* (Doctoral dissertation, Goa University).

Silva, E. L., dos Santos Roldan, P., & Giné, M. F. (2009). Simultaneous preconcentration of copper, zinc, cadmium, and nickel in water samples by cloud point extraction using 4-(2-pyridylazo)-resorcinol and their determination by inductively coupled plasma optic emission spectrometry. *Journal of Hazardous Materials*, *171*(1-3), 1133-1138.

Soni, N., & Bhatia, A. (2014). Analysis of Quality of Drinking Water of Private Bore-well and Piped Water Supply in Jaipur city, Rajasthan, India. *Research Journal of Recent Sciences Res. J. Recent. Sci*, *4*, 313–316.

Stone, N., Shelton, J. L., Haggard, B. E., & Thomforde, H. K. (2013). Interpretation of Water Analysis Reports for Fish Culture. *SRAC Publication*, *4606*(4606), 1–12.

Sugimoto, J. D., Koepke, A. A., Kenah, E. E., Halloran, M. E., Chowdhury, F., Khan, A. I., & Longini Jr, I. M. (2014). Household transmission of Vibrio cholerae in Bangladesh. *PLoS neglected tropical diseases*, *8*(11), e3314.

Suseela, K., Devika, B. M., & Prasad, B. D. V. (2020). Potential waste water reuse. *Glob Res Dev J Eng*, *1*(6), 20-28.

Swaroop, G. S., Reddy, P. R., & Teja, M. K. R. (2010). Hygieia-domestic online monitor of water pollution. In *2010 IEEE International Conference on Electro/Information Technology* (pp. 1-6). IEEE.

Swathi, S., & Umesh, S. (2015). Nemerow's pollution index: for ground water quality assessment. *J Environ Sci Pollut Res*, *1*, 23-31.

Symons, J.M., Bradley, L. C. Jr., & Theodore, C. C. (2000). *The Drinking Water Dictionary,* American Water Works Association.

Tahershamsi, A., Bakhtiary, A., & Mousavi, A. (2009). Effects of seasonal climate change on Chemical Oxygen Demand (COD) concentration in the Anzali Wetland (Iran). In *Eighteenth World IMACS/MODSIM Congress* (Vol. 2769).

Talib, A., & Amat, M. I. (2012). Prediction of chemical oxygen demand in Dondang River using artificial neural network. *International journal of information and education technology*, *2*(3), 259-261.

Talling, J. F. (2010). pH, the CO_2 system and freshwater science. *Freshwater Reviews*, *3*, 133–146.

Tauxe, R. V., Mintz, E. D., & Quick, R. E. (1995). Epidemic cholera in the new world: Translating field epidemiology into new prevention strategies. *Emerging Infectious Diseases*, *1*(4), 141.

Tavakoly Sany, S. B., Monazami, G., Rezayi, M., Tajfard, M., & Borgheipour, H. (2019). Application of water quality indices for evaluating water quality and anthropogenic impact assessment. *International Journal of Environmental Science and Technology*, *16*(7), 3001-3012.

Team, C. W. (2009). Colour of Water Fact Sheet. *State Water Resources Control Board*. California.

Tech, E. T. (2013). Determination of some heavy metals in wastewater and sediment of artisanal gold local mining site of Abare Area in Nigeria. *J. Environ. Treat. Tech*, *1*, 174-182.

Tessema A., Mohammed A., Birhanu, T., & Negu, T. (2014). Assessment of Physico-chemical Water Quality of Bira Dam, Bati Wereda, Amhara Region, Ethiopia. J Aquac Res Development 5: 267. doi:10.4172/2155-9546.1000267.

Tikariha, A., & Sahu, O. (2014). Study of characteristics and treatments of dairy industry waste water. *Journal of applied & environmental microbiology*, *2*(1), 16-22.

Tjandraatmadja, G., & Diaper, C. (2006). Sources of Critical Contaminants in Domestic Wastewater- A Literature Review. CSIRO: Water for a Healthy Country National Research Flagship.

Tucker, M. R. (1999). *Essential plant nutrients: their presence in North Carolina soils and role in plant nutrition*. Department of Agriculture and Consumer Services, Agronomic Division.

Tudoreanu, L., & Phillips, C. J. C. (2004). Modeling cadmium uptake and accumulation in plants. *Advances in Agronomy 84, 121-157.*

Tundu, C., Tumbare, M. J., & Kileshye Onema, J. M. (2018). Sedimentation and its impacts/effects on river system and reservoir water quality: Case study of Mazowe catchment, Zimbabwe. *Proceedings of the International Association of Hydrological Sciences*, *377*, 57-66.

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of water resources*, *1*(3), 34-38.

Uchida, R. (2000). Essential nutrients for plant growth: nutrient functions and deficiency symptoms. *Plant nutrient management in Hawaii's soils*, *4*, 31-55.

Uddin, M. G., Nash, S., & Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, *122*, 107218.

UNEP-GEF Volta Project*,* (2010). Volta Basin Transboundary Diagnostic Analysis: National.

UNICEF & WHO (2008*). Progress on Drinking Water and Sanitation: Special Focus on Sanitation.* UNICEF, New York and WHO, Geneva.

UNICEF & WHO. (2012). *Progress on Drinking Water and Sanitation: 2012 Update.*WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.United States of America.

United Nations (UN). (2014). Water resources management. Retrieved December 2021, from http://www.unwat er.org/topic s/water -resou rcesmanagement /en.

U.S. Environmental Protection Agency (USEPA) (1976). Office of Water Regulations and Standards. *Quality criteria for water*. EPA-440/9-76-023, Washington, DC.

U.S. Environmental Protection Agency. (2022). National Aquatic Resource Survey. https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus.

U.S. Environmental Protection Agency. (1991). Guidance for water quality-based decisions: The TMDL process. *Assessment and Watershed Protection Division, US Environmental Protection Agency*.

van Dam, J. W., Negri, A. P., Uthicke, S., & Mueller, J. F. (2011). *Chemical pollution on coral reefs: exposure and ecological effects* (Vol. 9, pp. 187-211). Bentham Science Publishers Ltd.

Verma, P. U., Chandawat, D. K., & Solanki, H. A. (2013). Pollution status of Nikol Lake located in Eastern Ahmedabad, Gujarat-India. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(8), 3603-3609.

Water Resources Commission (WRC)**,** (2000). *Water Resources Management Problems Identification, Analysis and Prioritization*. Final Report. WRC, Accra, Ghana.

Water Resources Commission (WRC), (2003). *Ghana Raw Water Criteria and Guidelines,* Vol. 1. *Domestic Water.* CSIR-Water Research Institute, Accra, Ghana.

Water Resources Commission, (2010). Annual Report.

Weiner, E. R., & Group, F. (2007). Applications of Environmental Aquatic a Practical Guide. *Applications of Environmental Aquatic Chemistry A Practical Guide*.

WHO., (1992). *Cadmium: Environmental aspects*. World Health Organization.

WHO., (1993). *Guidelines for Drinking Water Quality*. World Health Organisation. Geneva, Switzerland.

WHO., (1996). *Guideline for Drinking Water Quality*, *2nd ed. Vol. 2*. World Health Organization, Geneva.

WHO., (2003). *Acceptable aspects*. In Guidelines for Drinking Water Quality, World Health Organization, Geneva.

WHO., (2004). *Guidelines for Drinking-Water Quality* (3rdEdition), Volume 1 Recommendations, Geneva.

WHO., (2006). *Guidelines for Drinking –Water Quality*. Seconded Health Criteria and Other Supporting Information, vol.2 WHO, Geneva, Switzerland.

WHO., (2008). *Guidelines for Drinking Water Quality*. In 3rd (Ed.). WHO Press ,Geneva, Swizerland.

WHO., (2011). *Guidelines for drinking water quality 4th edn*. World health organization. Geneva, Switzerland.

Yeung, A. T., & Hsu, C. (2005). Electrokinetic remediation of cadmium contaminated clay. *Journal of Environmental Engineering 131, 131*, 298-304.

Yilma, M., Kiflie, Z., Windsperger, A., & Gessese, N. (2019). Assessment and interpretation of river water quality in Little Akaki River using multivariate statistical techniques. *International journal of environmental science and technology*, *16*(7), 3707-3720.

Yogesh, S., & Pendse, D. C. (2001). Hydrological study of Dahikhura reservoir. *J. of Environmental Biology*. 22(1) 67-70.

Zhang, Z., Tao, F., Du, J., Shi, P., Yu, D., Meng, Y., & Sun, Y. (2010). Surface water quality and its control in a river with intensive human impacts–a case study of the Xiangjiang River, China. *Journal of environmental management*, *91*(12), 2483-2490.

Zhu, Y., Yang, Y., Liu, M., Zhang, M., & Wang, J. (2015). Concentration, distribution, source, and risk assessment of PAHs and heavy metals in surface water from the Three Gorges Reservoir, China. *Human and Ecological Risk Assessment: An International Journal*, *21*(6), 1593-1607.

APPENDIX

SUMMARY OF T-TEST RESULTS FOR EACH PARAMETER FOR THE SEASONS

Parameters	**p-value**	**t-stats**
pH	0.00089	4.383
Turbidity	0.01096	-3.0048
Colour	9.8956×10^{-7}	-9.094
TDS	0.00175	4.003
EC	0.000799	4.446
Alkalinity	0.00045	4.776
Chloride	0.00503	-3.425
Sulphate	0.45798	-0.7668
Phosphate	1.3746×10^{-5}	7.0304
Ammonia	0.006144	-3.317
Nitrate	0.8794	-0.1549
Total hardness	1.7299×10^{-6}	8.623
BOD	0.005948	3.334
COD	0.222277	-1.287
TSS	0.01211	-2.951
DO	0.0425	2.269
Cadmium	2.453×10^{-12}	-28.197
Iron	0.001379	-4.136
Lead	3.6045×10^{-6}	-59.148