UNIVERSITY OF CAPE COAST

# ASSESSING SURFACE WATER QUALITY IN THE BIRIM NORTH DISTRICT OF GHANA USING SPATIAL MODELLING

ABDUL-RAHAMAN AFITIRI

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# ASSESSING SURFACE WATER QUALITY IN THE BIRIM NORTH DISTRICT OF GHANA USING SPATIAL MODELLING

BY

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A Thesis submitted to the Department of Environmental Science of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of a Master of Philosophy (M.Phil.) degree in Environmental Science

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# DECLARATION

## Candidate's Declaration

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

Candidate's Signature…… Date……

Name: ABDUL-RAHAMAN AFITIRI

## Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature……..... Date……

Name: PROFESSOR FREDERICK ATO ARMAH

Co-Supervisor's Signature……..... Date……...

Name: MR. ERNEST AMANKWA AFRIFA

## ABSTRACT

Surface water quality considerations are becoming increasingly important in Ghana due to anthropogenic activities which affect their benefits to humans and aquatic life but studies on spatial modelling to assess surface water quality in Ghana are nascent. This study explores surface water quality in the Birim North District of Ghana using spatial modelling. Using a cross-sectional study design, 540 surface water samples were collected from 15 rivers and streams in 2018. Surface water quality was studied through 31 indicators. Landsat satellite images (2019) of the study area was analysed for environmental and NDVI data. The data was fitted to Pearson's product moment correlation, principal component analysis (PCA) and linear regression. The correlation coefficient (*r*) among selected water properties showed a number of strong associations. PCA output showed the data is a six-component system that explains 78.2% of the total variance in the data. The major indicators of water quality in the study area are DO, calcium, manganese, magnesium, phosphate, iron, arsenic, copper and BOD and account for 25.7% variance. The major sources of pollutants emanated from agriculture, mining, soluble rocks/soil and sewage. The quality of the water was better during the dry season compared to the wet season. The magnitude of independent variables in increasing order of predicting WQI was: Buffer, Cultivated area, Built-up, Forest, Rivers and streams cluster, Elevation, Season. The results inform that management interventions for surface water ecosystems should be targeted temporally and spatially to the key areas which are necessary from both practical and economic perspectives.

**KEY WORDS**

Surface water quality

Birim North District

Spatial Modelling

Land use land cover

Pollutants

Season

Water quality indicators

Principal component analysis

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## DEDICATION

I dedicate this work to my wife Amina Abu and all in the Afitiri family. I love you all.

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| | |
|---|---|
| AMD | Acid Mine Drainage |
| APHA | American Public Health Association |
| $NH_4^+$ | Ammonium |
| As | Arsenic |
| AAS | Atomic Absorption Spectrophotometer |
| Cd | Cadmium |
| Ca | Calcium |
| COD | Chemical Oxygen Demand |
| $Cl^-$ | Chlorides |
| Cr | Chromium |
| Cu | Cupper |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| EDTA | Ethylenediaminetetraacetic acid |
| FA | Factor Analysis |
| GIS | Geographic Information Systems |
| Fe | Iron |
| KMO | Kaiser-Meyer-Olkin |
| LULC | Land Use Land Cover |
| Pb | Lead |
| LI | Legislative Instrument |
| Mg | Magnesium |
| Mn | Manganese |
| MSA | Measure of Sampling Adequacy |
| MF | Membrane Filter |
| Hg | Mercury |
| Ni | Nickel |
| $NO_3^-$ | Nitrate |
| $NO_2^-$ | Nitrite |

| | |
|---|---|
| $N_2$ | Nitrogen Gas |
| NMDS | Non-Metric Dimensional Scaling |
| NDVI | Normalized Difference Vegetation Index |
| OLS | Ordinary Least Squares |
| K | Potassium |
| PC | Principal Component |
| PCA | Principal Component Analysis |
| QA | Quality Assurance |
| QC | Quality Control |
| ROI | Representative Region of Interest |
| Na | Sodium |
| SPSS | Statistical Package for Social Sciences |
| $SO_4^{-2}$ | Sulphates |
| TDS | Total Dissolved Solids |
| TH | Total hardness |
| TSS | Total Suspended Solids |
| UTM | Universal Transverse Mercator |
| WFD | Water Framework Directive |
| WQI | Water Quality Index |
| WRC | Water Resource Commission |
| Zn | Zinc |
| Cond. | Conductivity |
| Alk | Alkalinity |
| Turb | Turbidity |
| TH | Total hardness |
| TrC | True colour |
| ApC | Apparent colour |
| T. Phos. | Total phosphate |
| T.col | Total coliform |
| F. col | Faecal coliform |

# CHAPTER ONE

# INTRODUCTION

Assessing surface water quality is critical in Ghana and globally. However, applications of spatial modelling in assessing surface water quality in Ghana are limited. Investigating the relationships between water quality and environmental factors in river and stream ecosystems alongside incorporating GIS data and analysis with statistical methods gives novel insights in water quality studies (Varanka, 2016). Several anthropogenic and natural landscape factors (such as eutrophication, pollution and climate change) are thought to influence rivers and other water bodies. Various studies had reported a degradation of most water bodies (Death et al., 2018; Whitehead et al., 2009a) as well as a decrease in biodiversity of fresh water bodies (Heino et al., 2009).

Surface water quality consideration is critical to national development especially, for Ghana, given the spate of pollution of rivers and streams during the past five years by artisanal gold mining activities, urban and industrial pollution problems and agricultural development.

## Background to the Study

Surface waters are the most important natural resources of a country and the entire humanity and their judicious exploitation primarily defines the prosperity of a nation (Gajendran et al., 2013). Water indeed, is known as the primary wealth of a nation (Gajendran, 2011) and the quality of water resources has become a serious concern for policy makers and environmental managers in

all areas of human settlement (Hajigholizadeh, 2016). Surface waters are significant with magnificent, diverse biota facilitating numerous benefits to aquatic biota and humans (Allan & Castillo, 2007; de Groot, Alkemade, Braat, Hein, & Willemen, 2010). Again, surface water help in the assimilation and transportation of industrial wastewater and runoff from agricultural lands (Shrestha & Kazama, 2006). The necessary utilities and several services derived from surface water make them one of the most exploited ecosystems by humans (Varanka & Hjort, 2016; Malmqvist & Rundle, 2002). Majority of surface water originates from precipitation runoff from surrounding land areas (catchment) and ground water. Surface water quality is judged to deteriorate in the face of current global climate change, eutrophication and pollution (Henriques et al. 2015; Varanka, 2016; Whitehead et al. 2009a).

Areas of higher population density are usually seen around river basins because of the availability of fertile lands, water for irrigation (Vega et al., 1998; Withers et al., 2014), industrial/mining, drinking purposes, and efficient means of transportation (Mehaffey et al., 2005; Miserendino et al., 2011; Versace et al., 2008). Processes such as changing land use and land cover (Meybeck 2003; Palmer et al. 2008; Whitehead et al. 2009a), surface runoff, seasonal variations, interflow (Vega et al., 1998) as well as hydrological regimes (Henriques et al., 2015; Shrestha & Kazama, 2007), affect river and stream flow and eventually, on pollutants levels in the waters. In the long run, these processes are likely to cause variations in the structure and function of the aquatic ecosystems (Lindell et al., 2010). This association signifies that without abatement efforts, increases in

development can lead to decreases in water quality, which affects safe drinking water availability, recreational opportunities, floodplains, and habitats (Heathwaite, 2010; Mehaffey et al., 2005; Miserendino et al., 2011; Versace et al., 2008).

Albeit the joint management of land and water resources of many countries and states throughout the world over the years has gained recognition to ensure a healthy water body as surface water ecosystems are increasingly threatened (Allan & Castillo, 2007). For instance, The Water Resources Commission (WRC) established by an Act of Parliament (Act 522 of 1996) in Ghana, the National Community Water and Sanitation Program policy (Owusu et al., 2016), the Federal Water Pollution Control Act (commonly referred to as the Clean Water Act) in the United States (Public Law 95–217 1977) (Varanka, 2016) and the Water Framework Directive (WFD) in Europe (European Commission, 2000) among many others from several countries are legislative instruments aiming to restore and rehabilitate water resources. These actions of protecting, restoring and enhancing surface waters will demand increasing levels of knowledge about the factors and their interactions thereof influencing surface water ecosystems together with cost efficient modeling techniques (Varanka, 2016; Wetzel, 2001).

Surface and groundwater are the most important water sources in the natural environment. Land use and seasonal factors play an important role in influencing the quality of these water sources. An in-depth understanding of the role of these two influential factors can help to implement an effective catchment

management strategy for the protection of these water sources. Illegal mining activities, improper agricultural activities, urban and industrial pollution, climate change and seaweeds are the major factors affecting the quality of Ghana's surface water ecosystems (Owusu et al., 2016).

It is an established fact that mining operations, a major anthropogenic operation, whether small or large scale, are intrinsically disruptive to the environment, producing extensive quantities of waste can have detrimental impact for decades (Kitula, 2006). The impacts of mining on water resources affect both the quality and quantity of water within the catchment area of the mine (Armah et al., 2010). Several mine wastes are produced from operations, including mine tailings, waste rock and slag (Roussel et al., 2000). Water resources are affected at all stages of the development of the mine through acid mine drainage, heavy metal pollution, processing chemical pollution and erosion as well as sedimentation of water bodies (MINEO Consortium, 2000; Roussel et al., 2000; Falkenmark, Rockström & Karlberg, 2009; Armah et al., 2010).

A major impact of concern is the elevated levels of heavy metals that are often associated with mine water (Armah & Kyere-Gyeabour, 2013). Water draining from mining operations frequently contains sulphuric acid and heavy metals at high levels which could contaminate streams and the terrestrial environment when the mine water gets into contact with the terrestrial and aquatic ecosystems (Nartey, 2011; Jennings et al., 2008). The entry of mine-originated contaminants into the ecosystem may also occur during heavy rainfall events that cause over-bank flooding. Elevated concentrations of heavy metals in streams and

rivers accompanied by high acidity will enhance the uptake of heavy metals by aquatic organisms and eventually man, which poses a significant health risk (Jennings et al 2008; Armah & Kyere-Gyeabour, 2013). The severity of the impacts of mining on water resources will depend on factors such as the sensitivity to the local terrain, composition of minerals being mined, type of technology employed, skill, knowledge and environmental commitment of mining company and lastly, the ability to monitor and enforce compliance with environmental regulations (Armah et al., 2010; Armah & Kyere-Gyeabour, 2013; Nartey, 2011; Tamstorf, Aastrup & Tukiainen, 2003).

In Ghana, there are still continuous and vast areas of primary vegetation that hold a unique biodiversity and an ecological and biogeochemical complexity. Agricultural activities are at higher rates in rural setting (WRC, 2015) and have the potential to impact on freshwater bodies. The impact of land development on natural systems is frequently quantified by examining the relationship between land cover and streams and river bodies (Reimann et al., 2009, Cunningham et al., 2010; Tran et al., 2010; Utz et al., 2011). Vegetation clearing and burning of biomass causes hydrochemical changes in ground water (Williams et al., 1997) and surface water (Lindel & Obeng, 2010), through liberation and leaching of nutrients stored in the above ground vegetation and increased surface runoff and erosion, causing elevated export of solids and solutes (Lee et al., 2009; Paul & Meyer, 2001; Tsegaye et al., 2006; Zeilhofer, et al., 2010). This alters nitrogen and phosphorus cycles and inflows of major ions such as Na, K, $SO_4$ and Cl

(Ballester et al., 2003), increased water temperatures and decreased oxygen levels as well as translocation of Hg (Millard & Neerchal, 2000; Palmer et al. 2008).

The seasonal variations in natural factors affect the concentrations of different pollutants in surface water that receive water from rainfall and surface runoff (Hajigholizadeh, 2016). Studies reveal that surface water quality measurement for a specific water body changes according to the seasonal variation and the influencing land cover of the area (Rothwell et al., 2010; Wang et al., 2013). Where there are considerable variations in precipitation and temperature, constituent concentrations alter due to flow regimes (Pratt & Chang, 2012). Seasonal regimes therefore need to be accounted for when studying particulate and other pollutants in order to account for dilution and runoff (Tsegaye et al., 2006; Kang et al., 2013).

Water quality measures, such as phosphorus and stream water temperature, peak during the dry season (low flow), contrary to many other parameters that vary based on runoff (Pratt & Chang, 2012). Hence, to better explore and evaluate surface water quality, the study of temporal variations alongside spatial variations of water quality is unavoidable (Hajigholizadeh, 2016).

The scale of analysis is found to be necessary in water quality studies as it informs the area researchers use to link land cover with surface water (stream and river bodies), chemical, biological and physical variables. By using the watershed

scale, an area not located along or even near the water body might be attributed to being the source of a pollutant (Pratt & Chang, 2012).

Spatial statistical analysis is argued to have the potential to assess and develop novel insights in predicting un-sampled locations of a water body as well as develop efficient monitoring strategies at relatively low cost on streams and rivers with available data (Armah et al., 2010; Bowes et al., 2015). Application of models and simulations has become common and widespread since they have been found to provide better understanding of complexities in nature that stem from variability of factors that influence surface water quality (Zeigler et al., 2000; Wikle & Royle, 2002). However, scientific models are not perfect but provide opportunity for characterization of knowledge through which decisions can be made under conditions of inadequate knowledge and resources (Cressie & Chan, 2012). In such instances, spatial statistical models can be featured as predictive models. Spatial analysis techniques provide avenues for users to quickly and efficiently view and analyze geographic data, which includes, water quality, climate, topographic, and landscape variables (Pratt & Chang, 2012).

The concepts of model description, simplification, validation, simulation and exploration are not available for just a single area of study but cut across many disciplines (Zeigler, et al., 2000; Wikle & Royle, 2002). Consequently, spatial statistical modeling has been applied in studies that range from distribution of species, agricultural land abandonment and forest re-growth, to relationships among landscape variables (Gellrich & Zimmermann, 2007; Hong & Jeon, 2017).

Spatial statistical models make use of the relationship between an occurrence of a phenomenon and its location and relation in a geographic space in predicting future events. For example, shallow landslides caused by heavy rainfalls can be predicted using spatial statistical models that relate geomorphic attributes to landslide occurrence (von Ruette, et al., 2011). Spatial-based statistical modeling provides a framework for river, water resources and land use management in a country and helps to predict global change impact on water quality, as it establishes several methods which test suitable to predict such impacts (Varanka, 2016).

Tong and Chen (2002) asserted that watershed hydrology is determined by climate, land use, soil and other factors, a perspective held by many. For instance, agricultural and impervious lands usually have higher deposits of nitrogen and phosphorous than other lands (Varanka, 2016). These deposits can wash off into a surface ecosystems; indicating a relationship between soil conditions, watershed and environmental variables.

Geographic Information Systems (GIS) serve as useful tools to identify problematic areas for land managers to develop projects to improve river and stream health (Kang et al., 2010; Mehaffey et al., 2005; Rothwell et al., 2010; Tu, 2011; Versace et al., 2008). GIS serve as useful tools and powerful modeling environments for analyzing a wide range of spatial phenomena and data (Varanka, 2016).

By using satellite images of an area, it is possible to determine, for example, the proportions of land use variables in a specific spatial unit, commonly in a catchment area. In addition, remote sensing-based vegetation indices such as the normalized difference vegetation index (NDVI) can be calculated from it (Soininen & Luoto, 2012; Pratt & Chang 2012). Consequently, GIS data offers an efficient framework for analyzing water quality-environment relations at different scales, especially when combined with statistical modeling (Varanka, 2016).

**Statement of the Problem**

Surface water quality considerations are becoming increasingly important in Ghana due to mining activities, urban and industrial pollution problems and agricultural development. Reliable data on water quality is of importance for proper management and thereby the protection and development of surface water resources for the future (Owusu et al., 2016).

Degradation of river and stream water resources and ecosystems in terms of their health and quality is a global concern. Studies and concerns about surface water ecosystems, their condition and quality have increased during the past decades (Armah et al., 2010; Bowes et al., 2015; Karikari & Ansa-Asare, 2006; McGarvey et al., 2008; Sponseller, Benfield, & Valett, 2001; Yidana, Ophori, & Banoeng-Yakubo, 2008; Ansah-Asare, & Asante, 2000). Rivers and streams are progressively investigated from several perspectives to ascertain their quality and health status. These among many others include landscape (Allan, 2004; Robinson et al., 2002), and geomorphological (Varanka, Hjort & Luoto, 2015)

perspectives. However, studies on spatial modeling to assess surface water quality in Ghana and more specifically the Birim North District are nascent.

Surface water quality-environment relationships has been reportedly known to be influenced by environmental variables ( Chang, 2008; Nielsen et al., 2012), and seasonal variation (Zhang et al., 2014) in rivers and streams flow. Land use type including agriculture activities (Evans, et al., 2014) and built-up areas (Carroll et al., 2013) are important factors affecting surface water quality. Natural environmental factors are equally found to have great impact on surface water quality and health, for instance soil and bedrock properties (Agren & Lofgren, 2012; Brown et al., 2011). Nonetheless, studies that jointly consider water quality determinants from different environmental variable groups are limited (Jarvie et al., 2002, Varanka, 2016). Likewise few studies are based on several surface water bodies and their catchments area across extensive areas (Nielsen et al., 2012; Stendera & Johnson, 2006). On the other hand, some, studies are usually limited to a few sub-catchments (Gonzales-Inca, et al., 2015; Meynendonckx et al., 2006), or main catchments (Lindell et al., 2010; Young et al., 2005).

This therefore gives the foundational basis for this study to assess surface water quality in the Birim North District using spatial modeling. To do this, robust and quick-witted methods are required to investigate the complex, spatio-temporally dependent relationship(s) between water quality and environmental factors across large areas.

**Purpose of the Study**

To investigate the relationship between environmental variables and surface water quality in the Birim North District of Ghana using spatial modelling.

**Objectives**

To meet the purpose of this study, a number of specific objectives were formulated. These include to;

1. Determine the most important water quality indicator(s) that account for the most variations in quality of surface waters (rivers and streams) in the Birim North District.
2. Identify the source(s) of the water quality indicator(s) that explain the most variations in surface water quality in the Birim North District.
3. Evaluate the quality of surface water in the study area across river and stream clusters.
4. Evaluate the influence of seasonal variation on rivers and streams in predicting surface water quality-environment relationships.
5. Determine the spatial scale (buffer) around rivers and streams catchment that predicts surface water quality most in surface water quality-environmental relationships.
6. Model the relationship between water quality and environmental variables from different groups to find out the order and most important variable(s)

that largely predicts surface water quality better in surface water quality-environment relationships.

**Research Questions**

The study was guided by the following research questions in order to achieve the set objectives:

1. Which water quality indicators account for the most variability in surface water quality in the Birim North District?

2. What are the source(s) of the water quality indicator(s) that explain the most variation in surface water quality in the Birim North District?

3. Does the quality of surface water in the study area vary across river and stream clusters?

4. What is the influence of seasonal variation on rivers and streams in predicting surface water quality-environmental relationships?

5. Which spatial scale(s) around study rivers and streams catchment predicts better the quality of surface water in surface water quality –environment relationships?

6. Which environmental variable(s) explain surface water (streams and rivers) quality most in surface water quality-environment relationships?

**Hypotheses**

1. $H_0$: Nutrients and trace metals are not the major water quality indicators that account for the variability in surface water quality in the Birim North District.
2. $H_1$: Nutrients and trace metals are the major water quality indicators that account for the variability in surface water quality in the Birim North District.
3. $H_0$: Agriculture and mining activities are not the sources of the water quality indicators that explain the most variation in surface water quality in the Birim North District.
4. $H_1$: Agriculture and mining activities are the sources of the water quality indicators that explain the most variation in surface water quality in the Birim North District.
5. $H_0$: The quality of surface water in the study area does not vary across river and stream clusters.
6. $H_1$: The quality of surface water in the study area varies across river and stream clusters.
7. $H_0$: Seasonal variation has no influence on surface water quality in surface water quality-environment relation.
8. $H_1$: Seasonal variation influences surface water quality in surface water quality-environment relation.
9. $H_0$: The 100m buffer scale around a surface water catchment does not predict the quality of the surface water most.

10. $H_1$: The 100m buffer scale around a surface water catchment predicts the quality of the surface water most.
11. $H_0$: Land use variables do not explain surface water quality most.
12. $H_1$: Land use variables explain surface water quality most.

**Significance of the Study**

The assessments of environmental factors-surface water quality relationships are important in the milieu of appreciating the various impacts of natural and anthropogenic factors and the interactive effects of the two on surface water ecosystems. These are useful for the assessment of the sustainability, protection and management of water resources.

Moreover, quantitative studies of surface water quality and environmental variables relationships are necessary to improve the understanding of the phenomenon. The assessments of environmental factors-surface water quality relationships in other places are well known (Varanka, 2016; Tong & Chen, 2002). Nonetheless, little is known for surface water ecosystems in Ghana as the aforementioned studies were done outside the Ghanaian settings. Hence, the current study will generate data on water quality-environment relationships in Ghana as well as identify research gaps for future research in this area.

Also, the study has national and ecological importance, in that recommendations are made (where necessary) which can be considered when developing conservation planning for surface water and improving river and

stream water quality in Ghana. These recommendations will ultimately reduce the burden of surface water ecosystems management in the country.

Other significance of this study includes the ability to demonstrate the immense potential of the use of applied methods in surface water studies, such as, application of statistical methods as first-filter estimate of water quality-environment relationships.

**Delimitations**

The research was delimited to only major rivers and streams in the Birim North District in the Eastern region of Ghana. It hinges on a whole year data (two seasonal data) for surface water quality. There are several surface water bodies in Ghana, but in this study, the Birim North District was chosen because of the large number of surface water bodies coupled with the diverse anthropogenic activities that could largely impact on the quality of the water bodies (GSS, 2010). This makes the assessment of environmental factors on water quality possible. Chemical oxygen demand (COD), a water quality indicator was excluded during the laboratory analysis of surface water samples.

The study is equally delimited to the Nwi sub-drainage basin which is drained by several streams and rivers including the Suten, Sakapea, Nwi, Nyanoma, Aprokoma and Asuabena.

Natural factors such as temperature and precipitation for each surface water body were not easily assessable but rather were available for the whole study area. This does not bring variation in the obtained data and hence, making it

impossible to explore the effects of natural factors on surface water quality in the study area.

**Limitations**

The use of spatial-based statistical modeling in environmental relations exploration is an efficient method however, the approach is being influenced by many uncertainties beginning from the choice of the most applicable modelling technique to use. Moreover, although OLS are flexible methods, they might not be flexible enough, as the processes and factors influencing surface water quality form a complex system (Varanka, 2016).

Again, some LULC classes such as built-up and bareland were classified together as one class because, the resolution of the satellites images (30m) was not high enough to enable the separation of these LULC types. Similar studies also put the two LULC types in one class (Ashiagbor et al., 2019).

**Definition of Terms**

*Catchment*: Refers to an area of land that is drained by tributary streams merging into a main channel, river (Wetzel, 2001).

*Catchment area*: Refers to a topographically determined area where precipitation falls before draining into a river (Varanka 2016).

*Eutrophication*: Refers to the process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of algae and other aquatic plant life (Haggarty, 2012).

*Pollutant*: This is generally any substance when introduced into the environment in excess quantities of the natural background concentrations, adversely affects the usefulness of a resource or the health of humans, animals, or ecosystems.

*Pollution*: In relation to a water resource, refers to any direct or indirect alteration of the physical, chemical or biological properties of the water resource so as to make it less fit for any beneficial purpose for which it is or may reasonably be expected to be used; or harmful to the welfare, health or safety of human beings, any aquatic or non-aquatic property or the environment.

*Quality assessment*: It refers to the assessment of the overall precision and accuracy of study data, after all the analyses are conducted (USEPA, 2015).

*Quality assurance (QA)*: Generally refers to a broad plan for maintaining quality in all aspects of a research study. It describes how monitoring efforts are observed and proper documentation of all procedures, training of volunteers, study design, data management and analysis, and specific quality control measures (Chapman, 2016).

*Quality control (QC)*: Consists of a series of technical activities to control the quality of the data generated (Chapman, 2016). It consists of the steps a researcher observes to determine the validity of specific sampling and analytical procedures (USEPA, 2015).

*Research design*: Refers to plans and procedures for research that maximize control over factors that could invalidate the findings of a study and most likely help achieve the intended goal (Dulock, 1993).

*Riparian habitat*: The dynamic complex of plant, animal and micro-organism communities and their non-living environment adjacent to and associated with a watercourse.

*River* - A river is a system comprising the main course and tributaries, carrying one-way flow of a significant load of matter in dissolved and particulate phases from interactive natural and anthropogenic sources (Shrestha & Kazama, 2007).

*River basin*: The land area drained by a river and its tributaries or the land area surrounding one river from its headwaters to its mouth.

*Spatial analysis*: In broad terms refers to the quantitative study of phenomena that are located in space (Bailey et al., 1995) or the "general ability to manipulate spatial data into different forms and extract additional meaning as a result" (Bailey, 1994).

*Stream*- Is a body of water with surface water flowing within the bed and banks of a channel. It encompasses surface and groundwater fluxes that respond to geological, geomorphological, hydrological and biotic controls (USEPA, 2015).

*Surface water*: Water that flows above the earth, including lakes, oceans, rivers, streams, wetlands and in reservoirs constructed by man.

*Water quality*: It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It includes the chemical, physical, biological, and radiological characteristics of water (Diersing & Nancy, 2009; Johnson, 1997).

## Organization of the Study

This thesis is presented in six chapters. Chapter one considered the general introduction to the study and encompasses background to the study, statement of the problem, purpose of the study, objectives, hypotheses, research questions, significance of the study, delimitation and limitations of the study, definition of terms, and organization of the study.

Chapter two also examined existing literature related to the subject under study including the concepts underpinning the study and many others. Chapter three explored the research methods. It included the Research Design, Study Area, Sampling Procedure, Data Collection Instruments, Data Collection Procedures, Data Processing and Analysis.

Chapter four presented the description, interpretation, and presentation of results. Chapter five presents the discussion of the findings while chapter six included the summary and conclusions of the study as well as recommendation emanating therefrom.

# CHAPTER TWO

# LITERATURE REVIEW

This study assesses surface water quality in the Birim North District of Ghana using spatial modelling. The study is set to unveil the most important water quality variables and their possible sources that explain the most variation in the quality of surface waters (rivers and streams) around the study area, assessed the quality of river and stream clusters across the study area, and determined the influence of seasonal variation on rivers and streams quality in surface water-environment relationships. Furthermore, the study investigated the spatial scale(s) that best predict river and stream quality and modelled the relationship between water quality and environmental variables to find out the order and most important variable(s) that largely predicts surface water quality.

This chapter of the study critically reviews related literature in relation to the studied topic. The review includes sub-themes such as surface water quality indicators, environmental variables determining surface water quality, relationship between surface water quality and environmental variables, influence of flow discharge periods (seasonal variation) of rivers and streams water bodies in surface water-environment relationships as well as the importance of different spatial scales in examining surface water quality-environment relation.

## Indicators of Surface Water Quality

The quality of surface water is very crucial as it forms part of the major sources of drinking water to a majority of people, especially, rural folks in most

developing countries. However, the susceptibility of surface waters to physical, chemical and biological factors that could potentially compromise their quality is very high compared with groundwater (Mathebula, 2015). The quality of a water body differ from another due to natural attributes such as catchment characteristics thus, soil, vegetation and bedrock as well as significant anthropogenic pressure from abstraction of surface water, pollution, energy production, river channelisation and damming (Brown et al., 2011; Malmqvist & Rundle, 2002; Sliva & Williams, 2001; Varanka, 2016).

Several physical, chemical and biological constituents are therefore used to define the spatial and temporal structure of surface water and surface water quality (Chiverton, 2015; Kang et al., 2010; Miller et al. 2014). Surface water quality is studied through multifarious indicators and the selection of water quality elements largely depend on the purpose or objective of the study (Quevaulviller at el., 2006; Varanka, 2016). The indicators are affected by pollutants from natural and anthropogenic sources. These indicators at any time inform the state of a freshwater ecosystem.

The quantity or concentration of phosphorus, nitrogen, pH value, alkalinity and oxygen in surface water are key indicators when exploring the state of an ecosystem (Withers & Jarvie, 2008). Water colour (true and apparent colour), total suspended solids, total dissolved solids, and turbidity are visual indicators of water quality and are connected to substantial movement of materials into surface water (Galbraith & Burns, 2007; Vinogradoff & Oliver, 2015). Electrical conductivity, an approximate measure of total dissolved ions is

key in water quality studies (Allan & Castillo, 2007). Investigating the constitution and concentration of dissolved major ions and heavy metals in water are also important as those have been attributed both to natural and anthropogenic catchment factors such as land use and geology of water basin (Armah et al., 2010; Jarvie et al., 2002; Lindell et al., 2010) and as their availability in water can influence aquatic life adversely. Total coliform, and faecal coliform levels in water quality studies are necessary especially when the water serves as source of drinking water or recreational activities like swimming (Armah, 2014; Wade et al., 2008).

## Physical Indicators of Water Quality

### pH

The pH of water refers to the measure of hydrogen ions in the water, thus a measure of how acidic or basic it is on a scale of 0 to 14, with 7 being neutral (Mosimanegape, 2016). pH is generally defined as the negative logarithm of the hydrogen ion ($H^+$) concentration in a given solution (Varanka, 2016; Wetzel, 2001). Availability and solubility of nutrients and how they can be used by aquatic organisms are largely affected by the pH of the water (Stone et al., 2013). The pH value can considerately indicate variations in water quality and is affected by dissolved substances (Mosimanegape, 2016; WHO, 2006). For surface water of pH range 1 to 6 (acid water), carbon dioxide ($CO_2$) and carbonic acid ($H_2CO_3$) are known to dominate whereas surface water of pH range 8 to 14 (basic water) are dominated by carbonates ($CO_3^{2-}$) and bicarbonates ($HCO_3$) (Allan & Castillo,

2007).

Surface waters can be naturally acidic; however, anthropogenic impacts intensify acidification of surface waters (Falkenmark et al., 2003). In addition, acidity has been connected to increased discharge (Saarinen et al., 2010) and runoff (Toivonen et al., 2013). Bedrock composition is equally noted to have a relation with surface water pH (Brown et al., 2011; Young, et al., 2005). Diurnal changes in surface water pH is controlled by the $CO_2$ level, which is consumed by plants through photosynthesis during the day and increased by respiration at night (Neal et al., 2002). pH determination just like nutrients in surface waters, is essential when evaluating the quality of surface water ecosystems (Toivonen et al. 2013).

**Turbidity and Total Suspended Solids (TSS)**

Turbidity is the measure of the amount of suspended material that interferes with light penetration in the water column. It can lead to temperature and dissolved oxygen (DO) stratification in surface water ecosystems (Tessema et al., 2014). Turbidity of water is determined by the concentration and nature of Total Suspended Solids (TSS) and is extremely influenced by rainfall at a particular time (Mosimanegape, 2016).

TSS contains soluble organic compounds as well as fine particles of organic and inorganic matter (Matta, 2014). TSS and turbidity varies with time based on biological activity in the water system and type of sediments carried by surface run-off (Mosimanegape, 2016).

High TSS levels in surface water absorb heat from sunlight, which increases water temperature and decreases levels of dissolved oxygen. This leads to the water body losing the potential to support aquatic life (Iqbal et al., 2010).

**Total Dissolved Solids (TDS) and Electrical Conductivity (EC)**

Total dissolved solids and electrical conductivity of a water body are interrelated and one can be used to estimate the other (Mosimanegape, 2016). Higher TDS in water indicates the ability of the water to dissolve salts and minerals. This in the long run produce undesirable taste in water (Mohsin et al., 2013). In literature, TDS value in mg/L is about half of the electrical conductivity (μS/cm) (Stone et al., 2013; Mosimanegappe, 2016).

Electrical conductivity (EC) in general measures the ionic process of a solution that enables it to transmit current (Mohsin, Safdar, Asghar, & Jamal, 2013). Electrical conductivity of water refers to the measure of the amount of dissolved solids in the water (Anhwange et al., 2012; Mohsin et al., 2013; Mosimanegape, 2016) hence; increase in ions concentration increases the electrical conductivity of water.

**Dissolved Oxygen (DO)**

Dissolved oxygen (DO) is an important indicator of surface water quality and therefore necessary to include when evaluating surface water quality (Abdul-Aziz & Ishtiaq, 2014; Abdul-Razak et al., 2009). Generally, DO concentrations in surface water ecosystems designate the health of aquatic ecosystems as these organisms depend on the oxygen for survival (Abdul-Aziz & Ishtiaq, 2014;

Harvey et al., 2011; Varanka, 2016).

The primary oxygen inputs from atmosphere and photosynthesis and the outputs through respiration and decomposition of organic material delineate the concentration of oxygen in water (Best et al., 2007; Harvey et al., 2011). DO of surface waters decrease together with increasing water temperature and salinity (Best et al., 2007; Varanka, 2016).

DO cycle in surface water differs both spatially and temporally as biochemical processes as well as hydro-climatic processes including discharge and organic waste influence its concentration in surface water bodies (Varanka, 2016). Changes in DO concentration in surface water are also attributed to photosynthesis during the day and respiration during the night (Harvey et al., 2011).

Additionally, DO is an essential factor moderating the nutrient cycle in surface water (Harris et al., 2015; Seitzinger et al., 2006) such as anaerobic conditions caused by eutrophication (Varanka, 2016). This leads to the release of phosphorus from bottom sediments, consequently, impairs surface water quality especially in rivers and streams (Spears et al., 2007).

**Colour (Apparent and True)**

The colour of surface water indicates the concentration of dissolved and suspended materials in the water and its value is established by comparing a water sample with a known concentration of coloured solution such as the platinum-cobalt method (Niemi & Raateland, 2007). The colour of water informs the

amount of light being scattered from the water, which could be in short wavelengths (such as blue), or longer wavelengths (such as red). However, short wavelengths are scattered more as compared to longer wavelengths (mostly absorbed) and therefore making clear water often look bluish (Varanka, 2016; Wetzel, 2001).

Factors that largely influence surface water colour encompass naturally occurring metallic ions, especially iron and manganese, humus and other materials discharged from marshlands, plankton, and municipal and industrial wastewaters (Niemi & Raateland, 2007). As the proportion of surface mining which releases considerable amount of trace metals into the environment in the Birim North District is substantial, alongside humus production, studying water colour is an important indicator of surface water quality.

**Chemical Indicators of Water Quality**

**Phosphate**

Phosphate is a compound resulting from the different chemical arrangement of phosphorus ions produced by natural processes (Haggarty, 2012). Phosphorus usually occurs as phosphate, either organically bound as polyphosphates or as soluble orthophosphate. Phosphorus is an essential nutrient for plants and animals growth and aquatic plants may be stimulated to increase nuisance levels when sufficient phosphorus is present (Mosimanegape, 2016). Excess nutrients from phosphorus and nitrogen in surface waters result in eutrophication (Haggarty, 2012; Withers, et al., 2014) and consequently algal

production (Lutz & Cummings, 2003). However, phosphates stimulate the growth of plankton and aquatic plant life which provides food for fish.

A major anthropogenic sources of this compound in surface waters are diffuse pollution such as overland run-off of agricultural fertilizers which are often associated with sediment (Smith et al., 1999) as well as point sources such as sewage treatment plant effluent and various food processing plant discharges (Hoff, 2013). Catchment geology and the geochemistry of river sediments are known to be natural sources of phosphorus (Withers & Jarvie, 2008) which is released from sediments as a result of bioturbation and anaerobic conditions (Allan & Castillo, 2007; Wetzel, 2001).

**Nitrate**

Nitrate is a form of the element nitrogen. There are copious amounts of nitrogen gas ($N_2$) in the atmosphere. However, it is substantially inaccessible to most organisms in this form (Vitousek et al., 1997). Nitrogen in surface water occurs in the form of dissolved inorganic nitrogen like nitrate ($NO_3^-$), nitrite ($NO_2$) and ammonium ($NH_4^+$) and as dissolved or particulate organic nitrogen (Allan & Castillo, 2007). Nitrates, like phosphorus, are known for their ability to stimulate the growth of plankton and aquatic plants that provide food for fish hence are essential for sustaining life and explaining mostly the biological productivity in the ecosystems (Elser et al., 2007). Nitrates are significant components of agricultural fertilizers with its largest contribution in water environments from diffuse sources of pollution as opposed to point sources of

pollution (EEA, 2010). The other forms of nitrogen enter surface waters from atmospheric deposition, nitrogen fixation and terrestrial inputs (Vitousek et al., 1997). Denitrification, sedimentation and biological uptake are key processes through which nitrogen is removed from surface waters (Hejzlar et al, 2009; Seitzinger et al., 2006).

**Alkalinity**

Alkalinity essentially is the measure of the ability of a water source to maintain its pH level from continuous variation. Alkalinity refers to the acid-neutralizing ability of water and is usually expressed in mg/l $CaCO_3$ (Mosimanegape, 2016). Alkalinity is affected by differences in flow regimes and its natural unevenness is linked to the presence or absence of rocks, which contain carbonate, bicarbonates and hydroxide compounds (Dladla, 2009; Haggarty, 2012). These compounds are in turn influenced by $CO_2$ from living organisms as they respire (Verma et al., 2013).

It is important to understand that alkalinity is not a pollutant; however, it is a measure of substances within the water that has neutralizing ability (Haggarty, 2012). It is a key component for fish and aquatic life since alkalinity acts as a buffer to changes in pH and provides protection from sudden shifts (EPA, 1976). Some natural sources of alkalinity include rocks, which contain carbonate, bicarbonate, and hydroxide compounds (Haggarty, 2012).

**Magnesium (Mg)**

Magnesium (Mg) is formed by the weathering of rocks having Mg

minerals and from some $CO_3$ rocks (Gupta et al., 2009). In surface water ecosystems, magnesium is derived from silicates, magnesium calcite or dolomite (Ganjendran, 2011). The presence of silicates in water arises from mica through intensive weathering of mafic rocks and from pyroxene and amphiboles.

**Total hardness (TH)**

Total hardness in surface water ecosystems measures the concentration of multivalent metallic cations in solution, of which calcium and magnesium are the most abundant ions (Gajendran, 2011). Bicarbonates and carbonates of Ca and Mg are known in literature to impart temporary hardness, while, sulphates, chlorides and other anions contribute to permanent hardness (Aher & Deshpande, 2011; Uchchariya & Saksena, 2012). The sources of these ions include various types of rocks, agricultural runoff, industrial waste and sewage (Gupta et al., 2009).

The hardness in surface water is a derivative from the solution of carbon dioxide released by bacterial action in the soil, in percolating rainwater (Gajendran, 2011).

**Chlorides ($Cl^-$)**

Chlorides equally influence surface water quality and occur in most fresh waters as salts of sodium or calcium (Mosimanegape, 2016). Chloride bearing rock minerals such as Sodalite and Chlorapatite, which are minor constituents of igneous and metamorphic rocks, are minor sources of chloride in surface water ecosystems (Gajendran, 2011).

Chloride salts, being extremely soluble and free from chemical reactions with minerals of reservoir rocks, remain stable once they enter into solution (Gajendran, 2011). Most chlorides in surface water are present in sodium chloride, but the chloride content may exceed the sodium due to base-exchange phenomena. Calcium and magnesium chloride waters are rather rare (Gajendran, 2011).

Chloride levels in surface water can be used as an important indicator for detection of contamination by sewage, prior to other tests like BOD and COD (Mosimanegape, 2016; Verma et al., 2013). Chloride in excess imparts salty taste to water and beverages (WHO, 2011). High chloride content in water sample may be due to the pollution from chloride rich effluent of sewage and municipal waste.

**Sodium (Na) and Potassium (K)**

One of the most abundant elements on earth that affect surface water is sodium (Na) and is highly soluble in surface water (Gajendran, 2011). Increased levels of Na in surface waters may occur from anthropogenic sources such as sewage, industrial effluents, and occasionally as a result of domestic activities and naturally from sodium salts percolated from rocks. Also, it could result from industrial and domestic activities (WHO, 2011).

Generally, Potassium (K) levels in surface water bodies are low as compared to Na since potassium salts are uncommon in rocky deposits (Uchchariya & Saksena, 2012). Potassium salts are broadly used in agriculture and the industry. K deposits in surface water are largely through industrial

discharges and run-off from cultivated fields (Mustapha & Usman, 2014).

**Sulphates ($SO_4^{-2}$)**

Sulphates exist naturally in surface waters as sulphate ions ($SO_4^{-2}$) and are formed as a result of the leaching of sulphur compounds, sulphate or sulphide minerals such as gypsum and pyrite (Woli et al., 2008). Sulphur is readily soluble in water in its stable and oxidised form (Mosimanegape, 2016). Industrial discharges into surface waters and agricultural runoff are the major anthropogenic sources that significantly contribute to sulphate levels in surface water ecosystems (Georgieva et al, 2010; Mosimanegape, 2016).

**Calcium (Ca)**

Calcium is one of the elements that largely influence surface water quality due to its abundance in nature. Carbonate rocks are the chiefly known sources of calcium in natural water and account for about 80% of the calcium in surface waters (Gajendran, 2011). Other sources of calcium include silica mineral groups such as plagioclase, pyroxene and amphibole among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks.

Compounds of Ca turn out to be stable when $CO_2$ is present in water, but lowered when $CaCO_3$ precipitates due to rise in water temperature (Gupta et al., 2009). Even though silicate minerals are not soluble in water, weathering breaks them down into soluble calcium products and clay minerals. The carbonates and sulphates of calcium however, are soluble in water (Gajendran, 2011).

## Trace Metals

### Lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn), Arsenic (As), Iron (Fe), Manganese (Mn), Mercury (Hg), Nickel (Ni), Chromium (Cr)

Trace metals in surface water ecosystems originate from both natural and anthropogenic sources. Soil geology, weathering of the bedrock and retention processes in catchments are the natural sources through which trace metals get into water bodies (Niemi & Raateland, 2007) with notable anthropogenic sources such as mining (Armah et al., 2010) and industries (Niemi & Raateland, 2007). Anthropogenic deposition intensifies natural concentrations (Niemi & Raateland, 2007).

Tarvainen et al. (1997) asserted that the concentration of chromium in surface water is high due to rich humus materials. Surface waters with low pH have elevated zinc concentrations and tend to be controlled by acidity (Niemi & Raateland, 2007).

Higher iron concentrations are mostly seen in acid waters (with low pH) and waters from swamps and peat bogs, nonetheless, a reduction in iron content can be observed by aeration of waters containing ferrous iron (Gajendran, 2011).

The amount of manganese is influenced by residual deposits such as laterite and soil (Gajendran, 2011). Oxides, hydroxides, carbonates and silicates are the commonly bearing minerals. Reduced conditions in a water body can result in low amounts of manganese while in low pH water; higher manganese content may be reached (Gajendran, 2011).

Nickel, Arsenic, Mercury, Copper and Lead concentrations are usually due to anthropogenic origins (Armah et al., 2010). The highest arsenic concentrations are usually found in areas with greenstone and arsenic-rich black schists. Cadmium is released to the atmosphere from zinc and cadmium refineries, and from iron and steel industries. Stream waters with high zinc, copper and arsenic concentrations usually have a large proportion of arable land in their catchments, with the source of zinc and copper probably being fertilizers (Niemi & Raateland, 2007).

**Biological Indicators of Water Quality**

**Faecal Coliform**

One of the useful indicators of water bodies' ecosystems is faecal coliform. It indicates the contamination of water resources by mammals and birds faecal waste (Nkrumah, 2011) and indicate the possible presence of pathogenic bacteria and viruses which are responsible for water-related diseases such as cholera, typhoid and other diarrhoeal-related diseases (Fewtrel & Bartram, 2001). One gram of faeces is reported to contains millions of viruses and bacteria, thousands of parasite cysts and eggs (Yamaguchi & Wesselink, 2000).

**Total Coliform**

Total coliform has long been recognized as a suitable microbial indicator of surface water quality. The term "total coliform" denotes Gram-negative, rod-shaped bacteria that grow in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties and able to ferment lactose at 35–

37°C with the production of acid, gas, and aldehyde within 24–48 hours (Morita, 1997; Nkrumah, 2011). The group is as varied as their habitats from which they originate. The total coliform group as indicated by Nkrumah (2011) should not be considered as an indicator of organisms exclusively from faecal origins especially in hot countries where coliforms of non-faecal origins are common.

Measurement of faecal coliforms is a better indicator of general contamination of faecal origin and in the presence of organic material and under suitable conditions, coliforms multiply. Faecal coliforms differ from the other members of the total coliform groups as they are able to withstand and grow at higher temperatures of 44-45 $^{o}$C (Nkrumah, 2011). The presumptive Escherichia coli species is one of the common permanent species among the faecal coliforms (Szewzyk et al., 2000).

**Environmental Variables Determining Surface Water Quality**

Hydromorphology, often used to describe the hydrological (water flow, energy, distribution) and geomorphological processes and attributes of surface water bodies is necessary in understanding the environmental variables that influence surface water quality. According to Leemans & Kleidon (2002), intense rainfall and flooding could lead to increased loads of suspended solids, sediment yields, *E. coli* and contaminant metal fluxes, associated with soil erosion and fine sediment transport from the land. This is an implication of changes in the surface water regime, the velocity of water flow, hydraulic pressure and levels of water among other factors (Whitehead et al., 2009). Surface water catchment area

characteristics also influence the hydromorphology of the water body (Allan, 2004).

Topography and landscape factors play crucial roles in the physical properties, flow dynamics and the content of surface water over time. Studies over the past recognized the influence of landscapes on rivers and streams through which they flow (Allan, 2004; Varanka, 2016). However, the underlying geology of surface water cannot be overlooked as it is well linked to the hydromorphologic characteristics of the water, contributing significantly to its quality. The underlying formation directly influences the kind of organisms that can thrive, and be sustained by the water. This also largely predicts the physical and chemical properties of the water.

There is copious literature (Luke et al. 2007; Yidanaa, et al., 2008) giving credence to the fact that the chemistry of natural waters is strongly tied to the reaction of these waters with sediments or rocks through which they flow. These studies have been very significant in building the body of knowledge on water-sediment interactions and water quality. Yidanaa et al., (2008), emphasizes that the solubility of minerals in water places an upper limit on the maximum amounts of certain species of chemicals in natural waters.

The atmospheric chemistry around a surface water body influences the quality of the water both directly via atmosphere-water surface interactions and indirectly via chemical processes in mileu. Water soluble atmospheric constituents, in this scenario, play a crucial role in determining their

concentrations in surface water despite the unarguable contribution of other auxiliary factors such as seasonality and contextual anthropogenic activities.

Environmental factors significantly predict, abruptly or subtly, the quality of surface water. Surface water has recently been extensively explored giving insight to a good number of environmental variables known in literature to affect surface water quality. These factors broadly originate from two major sources (natural factors and anthropogenic factors) which are further sub-grouped based on the purpose of this study, into three, thus, climate variables (precipitation, temperature), land use factors (cultivated lands, built-up, forest) and others (normalized difference vegetation index, NDVI). These environmental variables vary through a river (Varanka, 2016).

**Climate Variables**

**Climate and Temperature**

Water is highly susceptible to constantly changing climatic conditions (Misra, 2014). Climate change is a major threat to surface water and food security. Changes in temperature affect the variability of rainfall which in turn alters the salinity levels of surface water (Trenberth, 2005). Precipitation varies from year to year and over decades, and changes in amount, intensity, frequency, and type (snow and rain) affect the environment especially surface water bodies. Steady moderate rains soak into the soil and benefit plants, while the same rainfall amounts in a short period of time may cause local flooding and runoff, leaving soils much drier at the end of the day (Trenberth, 2005).

Surface water temperature is directly dependent on surface air temperature as the interface naturally provides a close equilibrium (European Environment Agency, 2018). The temperature of surface water affects both chemical and biological processes occurring in the water, especially, flora and fauna (Delpla et al., 2009; Yidanaa et al., 2008). This close link is important in defining a major pathway on how climate change (projected temperature rise) could drastically affect surface water quality. The IPCC indicates that climate change in high-latitude areas is expected to be substantial, through changes in the hydrological regime, causing, together with land use, water quality degradation (IPCC, 2014). Surface water temperatures have been reported to have risen in some geographical locations already. Bates et al. (2008) suggest that atmospheric warming in relation to solar radiation increase resulted in a rise in surface water temperatures. North America and Asia have reportedly known to have recorded an increase of 0.2–2 °C in surface water temperature, mainly due to climate change (Delpla et al., 2009). An average 2 °C temperature increase recorded in the Rhine river by Zwolsman and van Bokhoven (2007) and Meuse river by VanVliet and Zwolsman (2008) revealed a corresponding increase in the pH level (reflecting a decrease in $CO_2$ concentration), and a decrease in dissolved oxygen (DO) solubility in the water bodies. These together highlight the close linkages between these variables and how changes in one affect the others.

Through hydrological and other biogeochemical cycles, climate change, thus, global warming is able to impair water quality especially, through extreme

weather events resulting in several biochemical reactions (Delpla, et al., 2009; Khan et al., 2017).

**Precipitation**

Precipitation, a natural phenomenon is equally known in literature to adversely influence surface water quality. Changes in the patterns and amount of precipitation significantly influences surface water quality as this largely determines the volume of water in a particular surface water body and thus has the potential to cause dilution effect of some physico-chemical and biological parameters of the water (Georgieva et al, 2010; Giri et al. (2019).

Conlan *et al*. (2007) asserted that BOD, DO, nitrate, ammonia, phosphorus, and temperature levels would be greatly altered due to precipitation in surface water bodies.

**Land Use**

Several studies have been carried out on the connection between water quality and land use type and have established that there is a relationship between the two (Ding et al., 2015; Varanka, 2016). It has been detected that land use greatly impacts the water quality of surface water systems. The distribution of different land use patterns is crucial to consider as different factors can influence surface runoff and surface water quality. Land use is a key anthropogenic induced and modified landscape feature affecting surface water quality (Carroll et al., 2013; Mosimanegape, 2016; Zampella et al. 2007). For example, industrial wastewaters are typical point sources of anthropogenic inputs (Withers & Jarvie,

2008) degrading water quality whereas agricultural activities are typically located along river channels causing significant non-point pollution to rivers (Withers et al., 2014). Agricultural activities, (Evans et al. 2014; Withers, et al., 2014) urban land use (Pratt & Chang, 2012) and forests (Chithra, Nair, Amarnath, & Anjana, 2015; Singh & Mishra, 2014) affect water quality.

**Agricultural Activities**

The fact that runoff influences water quality by introduction of sediments and fertilizers into water bodies, leading to algal blooms and suspended solids was highlighted after Chithra et al., (2015) executed their study on impacts of impervious surfaces on the environment. Dube et al. (2014) studied land cover changes around Lake Mutirikwi in Zimbabwe from 1984 to 2011. The study found that forest and shrubs were reduced from 310.8 km2 in 1984 to 77.3 km2 in 2011, cultivation increased by 51.44% between 1984 and 2011 and ascribed Lake enrichment to runoff from surrounding farms.

Zamani et al. (2012) assessed land-use change and its impacts on surface water quality in the Ziarat Catchment in Iran and revealed that about 980 ha of forests were converted to other classes of land use such as croplands, residential areas and roads. This is therefore a clear indication that land-use change is one of the key factors causing water quality changes in the study area.

Previous research on the impact of land use change on surface water quality include (Dube et al., 2014; Gumindoga, 2010; Kibena et al., 2014), point to the fact that land use is a determinant of surface water quality. Gumindoga

(2010) investigated the impacts of land use changes on runoff generation in the Upper Gilgel Abay River Basin in Ethiopia. The study found that increases in agricultural land coincided with increase in annual runoff volume. Kibena et al. (2014) revealed that the land use and the runoff changes in the same basin affect the water quality of lakes Chivero and Manyame and their tributaries after assessing the relationship between water quality parameters and changes in land use patterns in the Upper Manyame River, Zimbabwe.

Hoff (2013) carried out a study to establish the source and degree of pollution in Kranji Reservoir in Singapore. The findings from the study indicated high levels for nutrients and bacterial concentration in the downstream which is attributed to an intensive cropping vegetable production operation around the reservoir. Nyakungu et al., (2013) examined the impacts of human activities along Manyame River and its tributaries (Mukuvisi, Marimba, Ruwa and Nyatsime rivers) in Zimbabwe. The study established that the contamination of the river and its tributaries are as a result of agricultural activities among other sources.

Varanka, (2016) researched on multiscale influence of environmental factors on water quality in boreal rivers in Finland. The results highlighted the impact of agricultural activities on water quality as nutrients and pH increased. Especially, total phosphorus and nitrogen were related positively to agriculture in GLMs and GAMs. In addition, pH value was observed to increase together with the cover of pastures in the catchments. The study equally revealed that when determinants of water quality were studied as a group, natural factors explained

water quality better than land use/cover. A higher level of nitrogen and phosphorus in surface water has been attributed to specialized agriculture and animal husbandry as well as runoff from pastures (Withers & Jarvie, 2008).

Additionally, several other studies support the fact that agriculture serves as a significant source of nutrients entering surface waters and application of manure as fertilizer causes significant nutrient leaching risk from soils (Evans et al., 2014; Granlund et al. 2005; Nielsen et al., 2012). Agricultural activities such as tillage can cause mineralisation as microbial activity increases and decrease the capacity of soils to infiltrate (Evans et al., 2014).

**Mining Activities**

Surface water bodies in the proximity to mining activities or industries are at a great risk of contamination due to waste discharges from mining activities (Armah et al., 2010; Armah & Gyeabour, 2013). Mining industries require different amounts of water based on their operations and the end products of mining come with lot of wastewater that ends up being discharged into surface water bodies (Nartey, 2011; Jennings et al., 2008). Entry of mine-originated contaminants into agricultural soils and streams during heavy rainfall events causes over-bank flooding (Ochieng, et al., 2010). Elevated concentrations of heavy metals in the soils and streams, accompanied with acidic pH, are likely to enhance uptake of heavy metals by plants and man, which poses a high health risk to the people who consume the contaminated agricultural products (Boularbah et al., 2006).

Ochieng et al. (2010) in their study on impacts of mining on water resources in South Africa, reported that acid generation and metals dissolution are the primary problems associated with pollution from mining activities with effects on the environment such as the release of many chemical contaminants into water resources turning them acidic which results in acid mine drainage (AMD). The study revealed an increase in AMD incidence in the streams/rivers which threatens the scarce water resources of South Africa, human health and food security in mining areas. The inference of the analysis was that the pumping of the extraneous water from underground mine workings into rivers had a foremost impact on the deterioration of surface water quality. It was shown that the discharge of untreated acid mine drainage into Wonderfonteinspruit and Klip River has a negative impact on the water quality in these rivers.

Other studies carried out with respect to impacts of mining on surface water resources include Caruso et al., (2012) who investigated the impacts of mining on water quality in the Caucasus Mountains in Georgia. High concentrations of iron and manganese were detected on rivers downstream the mining industrial discharges and concentrations of manganese, iron and nickel were detected from public water supplies. Nganje et al. (2010) analyzed the influence of mine drainage on water quality along river Nyaba in Nigeria and brought to the fore that the river water quality was bad due to the presence of heavy metals such as manganese, nickel and chromium whose values were above WHO maximum permissible limits.

**Forest**

Researched works on the impact of forests on surface water quality have produced diverse results. Lepistö et al. (2006) carried out a study in Finland on nitrogen in river basins which focused on the sources, retention in the surface waters and peatlands, and fluxes to estuaries and found that forests are a major source of nitrogen. The study indicated a 9% (11 000 tonnes N $a^{-1}$) input of nitrogen from forestry to river systems. In addition, negative correlations between forest cover and water quality have been observed (Ye et al., 2009; Miller et al., 2011; Tu, 2013).

Trees and other vegetation can decrease surface runoff and increase infiltration and water retention capacity as well as prevent erosion by stabilising soil (Varanka, 2016). These factors can decrease the rates of particulate matter with the adsorbed nutrients draining into surface waters, which impacts positively surface water quality. The relationship between forests and surface water quality is also affected by the anthropogenic impacts and the age of the forest as Singh & Mishra (2014) ascribed uninterrupted and old forests to enhanced surface water quality through water quality indicators such as pH and turbidity. On the other hand, an increase in the cover of forest in a catchment likely follows a reduction in the proportion of agricultural areas, which would result in a positive relation between forests and surface water quality.

Forests generally are affected by humans especially fringing communities as they obtain most of their socio economic needs from them. Activities such as

clear cutting can impact surface water quality, for instance, by increasing nutrient leaching into surface waters (Löfgren et al. 2014; Varanka, 2016). Overall, it is obvious that forests have an impact on water quality but their ability is also affected by other factors such as study area, forest type and age together with management practices (Varanka, 2016).

Allan et al., (1997) who researched on the influence of catchment land use on stream integrity across multiple spatial scales at Michigan reported that an increase in forested land cover had resulted in dramatic declines in runoff and nutrient yields hence had influenced the quality of the stream water bodies.

**Normalized Difference Vegetation Index (NDVI)**

The normalized difference vegetation index (NDVI) is a different approach to relating land cover derived from satellite or airborne sensors (Griffith, Martinko, Whistler, & Price, 2002). The NDVI is widely used, has become a standard for band ratio applications, and has a long history of use in remote sensing, ecology, and geography to study characteristics of vegetation, including amount (biomass), type, and condition (Lauver & Whistler, 1993; Singh, Jakubowski, Chidister, & Townsend, 2013). NDVI has been also considered to predict the richness and composition of aquatic communities (Soininen, Bartels, Heino, Luoto, & Hillebrand, 2015). The NDVI is a reflection of biophysical conditions of a watershed's vegetation cover, which in turn affects surface water runoff and quality (Griffith et al., 2002). Different approaches to the linkages among land cover, plant physiology and surface water quality exist. One of such

approaches is that NDVI is indicative of land cover and land use, but shows the biophysical condition of watersheds as well (Griffith, 2002).

Griffith et al., (2002) argues that increased higher NDVI at a certain time of the year is an indication of an intensively agricultural watershed, or may be revealing increased fertilizer or chemical applications and that the connection of NDVI providing an indication of the land cover classification along with intensity of agriculture is one of the approaches that best fit the analysis of watersheds across a large spatial entity.

Whistler (1996) in his study titled "A phenological approach to land cover characterization using Landsat MSS data for analysis of nonpoint source pollution" explored NDVI values derived from Landsat Multi-Spectral Scanner (MSS) imagery as a surrogate for biomass and hypothesized that they would have stronger relationships with water chemistry parameters than land cover proportions derived from the same imagery. The study found significant relationships between NDVI and selected water quality parameters that in fact were stronger than relationships to land use land cover (LULC) in many cases. Besides the NDVI values, a suite of metrics describing vegetation phenology can be derived from NDVI time-series data (Reed et al., 1994).

Varanka (2016) in his study found that all other water quality variables considered in the study except nitrogen were related to NDVI, especially during high-flow periods. It was also shown that the effect of NDVI depends on the seasonal variations in river flow conditions as the connection between water

quality variables and NDVI during the high-flow period in autumn was highlighted. Moreover, this refers to a delay between catchment productivity in the growing season and its effect upon surface water quality.

**Seasonal Variation Impact on Surface Water Quality**

Seasonal variability in surface water quality is the result of interactions between many processes caused by variations in climate (Araoye, 2009). Degradation of surface water quality by surface runoff has been associated to high-flow and low-flow discharge periods (Carroll et al., 2013; Dou, Zhang, Zuo, & Mi, 2015). Degradation is seen in forms like high nutrients (Bechmann, 2014; Withers & Jarvie, 2008) and acidity (Toivonen et al. 2013).

Overland flow into surface water bodies is equally observed when infiltration is limited by low soil permeability or its saturation causing water to flow over the landscape surfaces increasing discharge in the receiving surface water bodies (Winter 2001; Dosskey et al. 2010). As surface runoff cause soil erosion and the delivery of eroded sediments and contaminants into surface water ecosystems, it influences their quality (Bechmann, 2014). The degrees of surface runoff and discharge are dependent on the proportion of precipitation and evapotranspiration (Winter 2001), which change throughout the year.

Bormann & Klaassen (2008) explains that soil hydraulic and hydrological processes are not constant throughout the year; hence, the infiltration ability of soil fluctuates according to the season and soil characteristics. The ability of vegetation to uptake nutrients and retain water, and therefore to reduce surface

runoff, changes throughout the year as well (Sambou, et al., 2008). Valtanen et al., (2014) asserted that modifications in these processes are highlighted in cold climate areas.

Varanka (2016) investigated the multiscale influence of environmental factors on water quality in boreal rivers in Finland. The connection between water quality and environment was strongest during high-flow discharge periods.

Studies done by Pratt & Chang, (2012) on effects of land cover, topography, and built structure on seasonal water quality at multiple spatial scales found that depending on the type of analysis being performed and the parameter itself being examined, the season does affect the results. The time period where the water quality parameter had higher concentration levels usually improved model strength. The study revealed that while most wet season water quality parameters were associated with urban land covers, most dry season water quality parameters are related to topographic features such as elevation and slope. This therefore insinuates that topographic variables clearly appear to be important in determining water quality parameters during the dry season.

**Spatial Scales in Examining Surface Water Quality- Environment Relationship**

The quality of surface water resources differs spatially and temporally together with the processes affecting water quality (Miller et al., 2014). Environmental conditions and pollution sources are not same for all surface water bodies. The distribution of different land use patterns at different spatial scales is

essential to consider as different factors are known to affect water quality. Conclusions about the most important spatial scale in relation to water quality have varied as processes behind water quality vary.

Several literature works indicate that the variations in different water quality indicators have been explained the most by the characteristics of the entire catchment (Sliva & Williams 2001; Nielsen et al. 2012). However, Chang (2008) and Roberts & Prince (2010) in their studies established that the areas closest to the river channel largely explain water quality. Allan et al., (1997) who researched on the influence of catchment land use on stream integrity across multiple spatial scales at Michigan reported that habitat quality and biotic integrity varied widely among individual stream sites in harmony with patterns in land use/cover. Extent of agricultural land at the sub catchment scale was the best single predictor of local stream conditions.

On the other hand, the study of Meynendonckx et al. (2006) on effects of watershed and riparian zone characteristics on nutrient concentrations in the River Scheldt Basin in Belgium revealed that environmental conditions near the river were not critical factors in water quality modeling. Riparian areas are essential spatial features in relation to water quality as they are considered a transition zone between terrestrial and aquatic ecosystems (Luke et al. 2007; Soininen et al. 2015) and have a significant role in nutrient and energy flux between these two systems (McClain et al., 2003).

Other advantage of the Riparian vegetation reported in literature is its ability to increase infiltration and stabilize stream banks and soil, which in the long run reduces soil erosion and the loading pressure on surface water ecosystems (Dosskey et al. 2010). Hence, riparian zone management has become an important part in watershed and river management (Gumiero et al. 2013). Nonetheless, the riparian vegetation can also affect surface water quality negatively depending on the conditions in the riparian area. Hence, it is imperative to know if areas close to the river channels determine water quality (Varanka, 2016).

Between six metres based on stream shading (DeWalle, 2010) and 100 m based on processes that need protection (Allan et al., 1997) are the typically recommended riparian zone essential in respect to surface water quality since water flows through these areas to join surface water bodies (Dosskey et al. 2010). For instance, riparian vegetation is reportedly known to reduce the amount of nutrients entering rivers by direct chemical uptake in root zones (Dosskey et al., 2010; Sahu & Gu, 2009; Mayer et al., 2010).

In their study, Lindel et al. (2010) found that watershed scale deforestation has not resulted in measurable impacts on stream water chemistry which is dominated by the spatial variation in natural controls. According to Varanka (2016), in the scale studies, nutrients and water colour were best explained by the characteristics of the entire catchment but pH was mostly predicted by the characteristics of the 50 m riparian zone.

The study by Chang (2008) submits that land cover and other topographic and soil factors at the riparian buffer scale better explain the variations in BOD, COD, SS, TP, and TN for their study in the Han River basin, South Korea. Temperature variations in the 1990s and DO variations over the whole study period (1993-2002) however, are better explained by landscape factors at the whole basin scale. Moerke and Lamberti (2006) also report similar outcomes in Michigan streams, USA, where temperature variations were better explained by land cover at the whole watershed scale, while specific conductivity and turbidity were better explained by urban or agricultural land covers at the riparian buffer scale. Based on the findings therefore, maintaining riparian vegetation extent is significant to reduce fine sediments and other pollutants delivery to streams.

**GIS and Statistical Modeling of Surface Water Quality- Environmental Relationships**

GIS is a very valuable and common tool in water quality studies (Mosimanegape, 2016; Varanka, 2016). The integration of models and geographical information systems (GIS) data is effective in addressing the problem of spatial and temporal variability of the different parameters involved in environmental processes (Verro et al., 2002). GIS technology applications and modeling has provided a plausible technique for breaking the complexities and improving our understanding of how environmental factors affect surface water quality (Evans et al., 2014; Xia et al., 2018).

Several benefits accrue in applying statistical modeling in surface water studies (Varanka, 2016). Statistical modeling boost the objectivity of the studies as hypotheses can be tested quantitatively. Additionally, it enables simplification of complex systems and hence provides deeper meanings about the environmental systems and processes (Hjort & Luoto, 2013). Fronzek et al., (2010) adds that statistical modeling aids in predicting how climate change will affect environmental phenomena. Moreover, catchments can be broad and cannot easily be studied *in-situ* to completely achieve results. However, the combination of multivariate statistical techniques and effective data procurement and management techniques overcomes this challenge as it enables the investigation of extensive and remote areas and surface water resources (Varanka, 2016). Statistical modeling usage therefore makes it possible to study phenomena across scales from local to global (Hjort & Luoto, 2013).

Generally, a variety of comprehensive statistical methods exist to choose from to explore environmental phenomena especially surface water quality. Statistical modeling has been used in exploring factors affecting water quality. Among others include simple linear regression (Woli et al., 2008; Evans et al., 2014) and multiple regression analysis (Uuemaa et al., 2007; Rothwell et al. 2010a; Pratt & Chang, 2012), the use of ordination methods such as redundancy analysis (Johnson et al. 1997; Sliva & Williams, 2001) and principal component analysis (Galbraith & Burns, 2007; Andersson & Nyberg, 2009). Multivariate regression model provide avenue for researchers to assume a diverse array of

landscape parameters in order to derive the causes of pollutants (Sliva & Williams, 2001).

Pratt & Chang (2012) found that the relationship among land cover, topography, built structure and stream water quality in the Portland Metro region of Oregon and Clark County, Washington areas, USA, when analyzed using ordinary least squares (OLS) and geographically weighted (GWR) multiple regression models which took into consideration local relations of spatial autocorrelation, had stronger results than OLS regression models. In the multiple regression models of the same study, sectioned watershed results were consistently better than the sectioned buffer results, except for dry season pH and stream temperature parameters. This suggests that while riparian land cover does have an effect on water quality, a wider contributing area needs to be included in order to account for distant sources of pollutants. The finer resolution of their data, both in terms of spatial as well as categorically, indicated that general land cover categories, thus, urban, do not capture key variances in land uses affecting water quality. The study conclude that, street density, urban and residential land covers, as well as topographic variables played key roles in predicting stream water quality.

Lee et al. (2009) reported similar finding from their studies, where analysis of land use patterns suffered due to poor spatial resolution and the generalization of urban land cover.

## Chapter Summary

This chapter has analytically reviewed a number of comprehensive concepts related to surface water quality. The included sub-themes encompasses surface water quality indicators (Physical, chemical and biological), environmental variables determining surface water quality, relationship between surface water quality and environmental variables, influence of flow discharge periods of rivers and streams water bodies in surface water-environment relationships as well as the importance of different spatial scales in examining surface water quality- environment relation. The next chapter of the study presents the research methods.

# CHAPTER THREE

# MATERIALS AND METHODS

## Introduction

This chapter of the study presents the research methods employed by the researcher. It explains in details the sub-themes under which the research methods were grouped including the research design, study area, population, sampling procedure, data collection procedures, data processing and analysis.

## Research Design

Research designs in general terms refers to plans and procedures for research that maximizes control over factors that could invalidate the findings of the study and most likely help achieve the intended goal (Levin, 2005). It serves as the structural framework within which the study is implemented to obtain answers to the research questions or for testing the hypothesis (Polit & Beck, 2009) and defines the methods used to analyse the data (Levin, 2005). Often, there is more than one approach to carry out a study. However, a poorly designed study can lead to erroneous results, or it may not answer the research question(s) presented (Levin, 2005). It is therefore imperative to consider the design of a study with a view to knowing how the data will later be analyzed to answer the research questions presented.

The study employed a cross-sectional study design in the assessment of surface water quality through field sampling of surface water bodies. The cross-

sectional study design gives clear meaning of events and explains prevailing conditions of a given ecosystem on the basis of data gathered at a particular point in time (Levin, 2006). In this study design, either the entire population or a subset thereof is selected, and data are collected to help answer research questions of interest. It is called cross-sectional for the reason that the information about X and Y that is collected signifies what is going on at only one point in time (Olsen & St George, 2004). One powerful advantage of the cross-sectional study design is that it can encompass a broad scale of information (Levin, 2005).

**Study Area**

The study area, Birim North District, is located within latitude 6.15$^{o}$N - 6.35$^{o}$N and longitude 0.20$^{o}$W - 1.05$^{o}$W. It is at the western end of the Eastern Region of Ghana (Nartey et al., 2011).

The Birim North District of the Eastern region of Ghana has a land area of approximately 566.48 square km (GSS, 2010). The District shares boundaries with Akyemansa District to the south, to the north with Kwahu West Municipal, to the east with Atiwa District and to the west with Asante Akim South. The District emanated from the former Birim District Council in 1987 which was established by Legislative Instrument (L.I) 1923. The Birim North District was established as part of the government's decentralization programme to facilitate effective decentralized governance and development of the area (GSS, 2010).

The Birim North District lies within the semi-equitorial climatic zone and experiences a double maxima rainfall pattern (late March to early July and August

to late October) with rainfall values between 1500mm and 2000mm and a relative humidity of about 55-59 percent during the year (Dickson & Benneh, 1988; GSS, 2010). Temperatures range between a minimum of 25.1 degree Celsius and a maximum of 27.9 degree Celsius. The district lies within the Semi-deciduous forest belt of Ghana (Hall & Swaine, 1981) comprising tall trees with evergreen undergrowth. It contains large species of economic trees valuable for the timber industry. Anthropogenic activities such as lumbering, mining and many others however continue to degrade the forest. The District is home to nine forest reserves. Has a lot of undergrowth but the rapid expansion of the cocoa and oil palm industries, coupled with the activities of the illegal chain saw operators, illegal mining activities and frequent bushfires is fast changing the original forest into a secondary type. The underlying rock formation is mainly made up of Upper Biriman rocks consisting of predominantly volcanic lava, schist, hyalites and greywacke (GSS, 2010).

The area lies within the Pra River basin of Ghana and is drained by the Pra river together with its tributaries such as the Nwi, Mamang, Adechensu, Sukrang and Afotosu rivers. All these rivers and streams flow generally from the north east to the south west to join the Pra which flows southwards and enters the sea at Shama in the Western Region. The study area however lies in the Nwi sub-drainage basin and is drained by several streams and rivers including the Suten, Sakapea, Nwi, Nyanoma, Aprokoma and Asuabena.

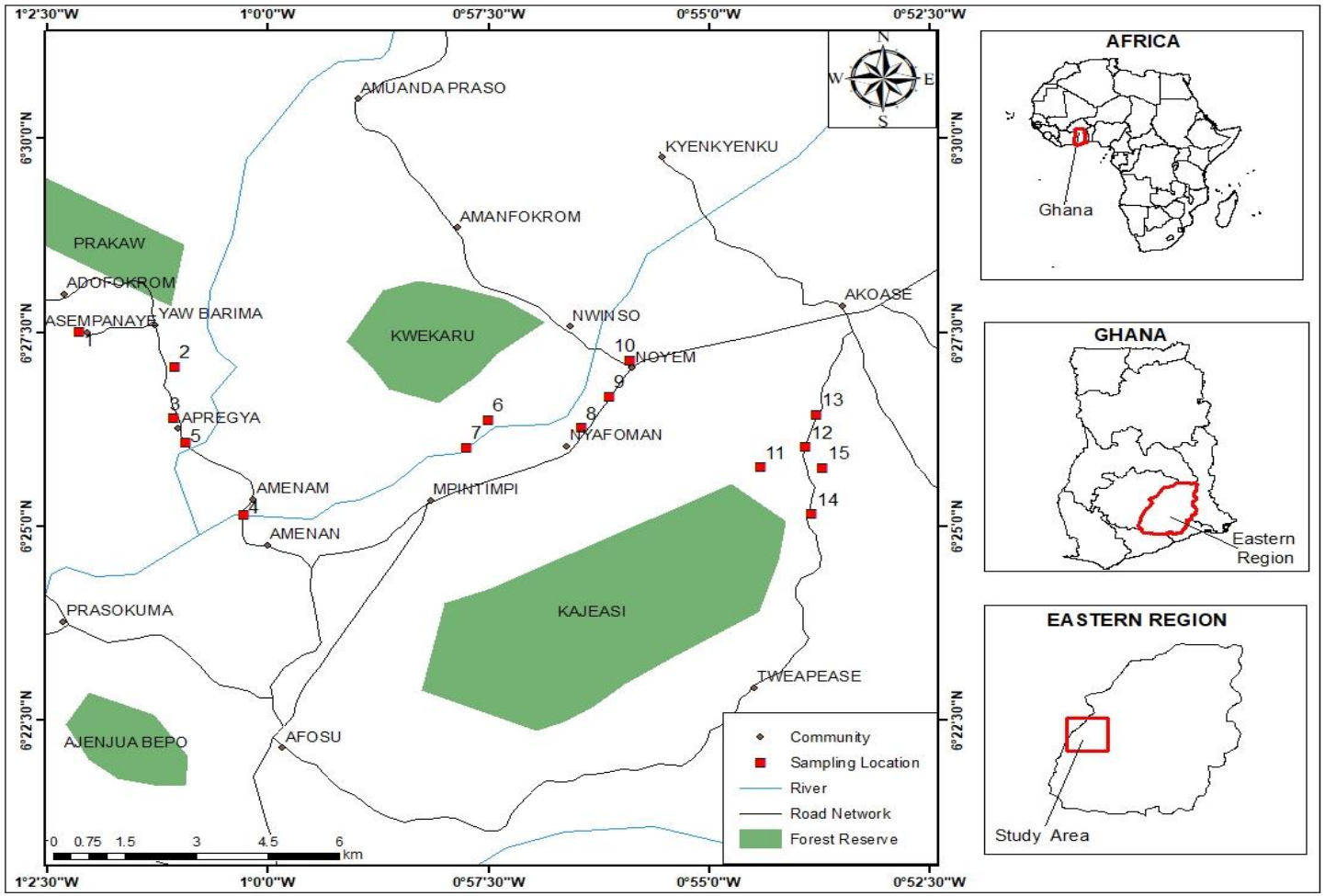


*Figure 1*: Map of the study Area and Sampled Locations.

**Population**

A (statistical) population includes all the individuals or units of interest in a study (Hanlon & Larget, 2011). It embodies the set of measurements corresponding to the entire collection of units for which inferences are to be made (Johnson & Bhattacharyya, 1992). The population always represents the target of an investigation. The population in this study therefore refers to surface water bodies in the Birim North District. The district is mainly drained by the Pra and its tributary the Birim. The tributaries of these rivers in the district include the Nwi, Suten, Mamang, Adechensu, Sukrang, Nkwasua, Nyanoma, Afosu, etc. (Nartey et al., 2011).

**Sampling Locations**

A total of fifteen surface water sampling points were randomly selected using the Geospatial Modelling Environment (GME) an extension in ArcGIS 10.3 software (Appendix A). Altogether, five hundred and forty (540) samples were collected in both seasons from January 2018 to December 2018. Two hundred and seventy (270) samples each were collated in the dry and wet seasons. The surface water bodies in the study area were studied to identify the major rivers and streams before the commencement of sampling. The sampling locations (points) were chosen to be as representative of the study area as possible. The sample locations included Asuoabena around Asempanaye, Asuoabena near pillar P18, Tributary of River Pra after Apragya, River Nwin near Amenam, Pra River at Apragya, River Nwin near Nyamebekyere high tension line, Tributary of Nwin

river at Dadekurom, Nsuten along main road, Nsuten near the exclusion zone, Aprokroma stream along the main road, Sakapea stream at Domeabra, Nsuten along Domeabra - Nyafoman road, Nyanoma along Domeabra - Nyafoman road, Nsuten near Odumase, Nsuten near Nsiasakuraa, River near Mpintimpi, River between Amenamti and Mpintimpi. At each surface water body, eighteen samples were taken during each season (dry and wet seasons) for the whole study period with three replicate samples at every period of sampling.

The various sampling locations and their GPS coordinates together with their descriptions are shown in Appendix A.

**Data Collection**

Figure 2 shows the schematic summary of the study steps including the used data, scales and the main methods. Surface water bodies were studied through biological, physical and chemical water quality variables. Environmental data included land use; climate and NDVI extracted at 100m, 200m and 300m scales around sampled points. The methods are purely GIS and surface water quality and environmental data was subjected to PCA, Pearson's moment product collection and OLS analysis.

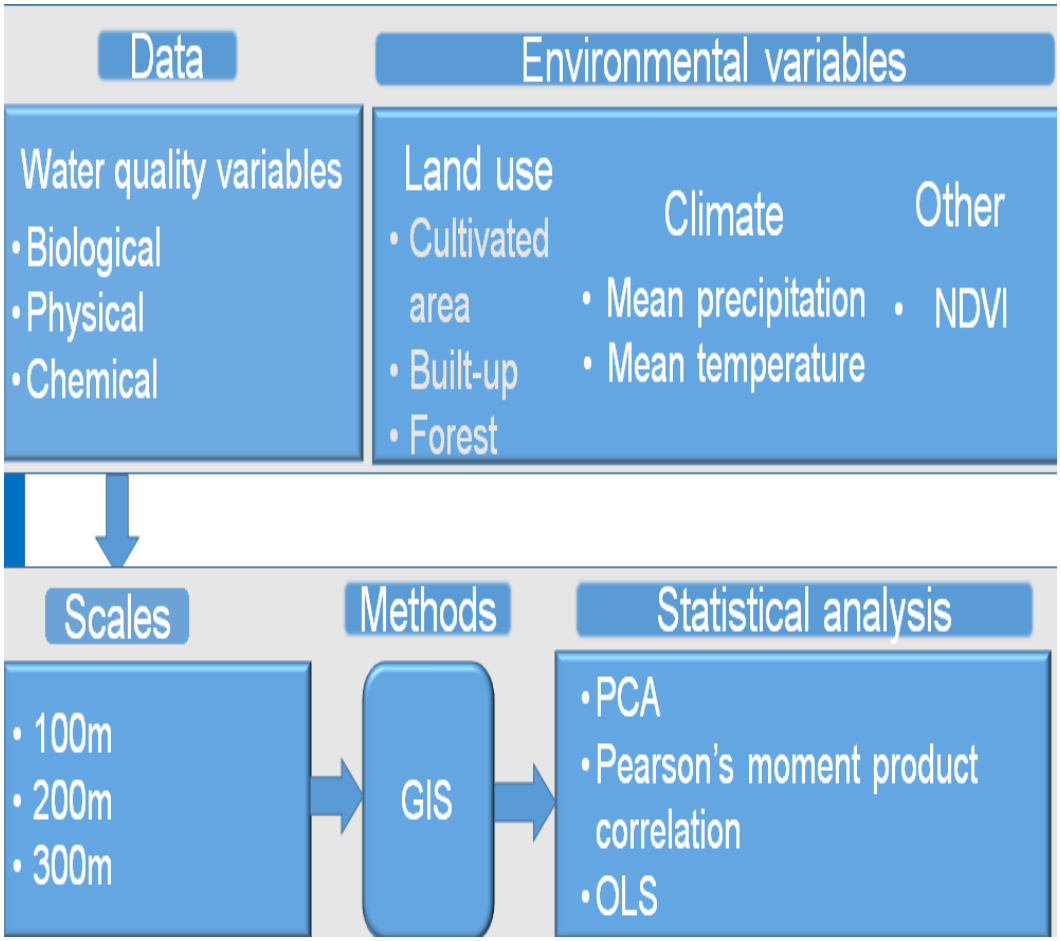


*Figure 2*: A schematic summary of the study steps including the used data, scales and the main methods.

**Water Sampling**

Water quality was studied through physical, biological and chemical parameters. Water quality data covered the year 2018. Field sampling of surface water bodies was done from January, 2018 to December, 2018. The sampling methods followed the protocols developed by the American Public Health Association (APHA) (1998) and the Australian and New Zealand guidelines (2000) for fresh and marine water quality.

Sampling bottles (plastic bottles) were prewashed with detergents and rinsed with 10% hydrochloric acid and double-distilled water prior to sampling. At each of the sampling locations, the bottles were rinsed three times with the water to be collected to reduce or completely eliminate any contaminations that might be introduced.

Surface water was sampled by gently lowering the sample bottle horizontally into the water with the mouth of the bottle directed upstream, taking reasonable measures to avoid suspended/floating debris. Thus, surface water samples were collected at the subsurface in order to avoid the colloidal layer as this can influence the concentration of certain parameters. Every attempt was made to minimise or avoid personnel entry into the water body. 1500 mL of water was collected at each location into a two blackened, clearly labelled plastic bottles and were kept under dry ice in an ice chest. This procedure averts microbial growth, flocculation and reduce any adsorption on container surfaces, processes which could affect the results (Armah et al., 2010; Berg, 1992; Keith, 2017).

The water samples collected during the dry season were labelled from S1D to S15D and S1W to S15W for wet season samples. However, as a result of the intense dry season experienced at the time of sampling, most of the streams were stagnant and in some cases ponded and thus no flow dynamics could be assessed. The water samples were transported to the environmental laboratory of Envaserv Research Consult, Accra for analysis.

**Field Analysis**

Conductivity, pH, Turbidity, dissolved oxygen and temperature were the parameters measured in situ during the sampling process. Most calibrations were conducted in the field at the sample site. The pH probe was calibrated with pH 7 and 10 buffer solutions on the day of sampling. The Geosatellite positioning (fixed with a Garmin EtrexGPS) of all sampling locations were also taken.

**Quality Control (QC), Quality Assurance (QA) and Quality Assessment**

Quality Control (QC) generally refers to the steps a researcher observes to determine the validity of specific sampling and analytical procedures and Quality assessment is the assessment of the overall precision and accuracy of study data, after all the analyses are conducted (USEPA, 2015). Quality assurance/quality control as indicated by Chapman (2016) ensures that measures are taken to demonstrate the accuracy (how close to the real result you are) and precision (how reproducible your results are) of a study. Quality Assurance (QA) generally borders on the broad plan for maintaining quality in all aspects of a research study. It describes how monitoring efforts are observed and proper documentation of all procedures, training of volunteers, study design, data management and analysis, and specific quality control measures (Chapman, 2016; USEPA, 2015).

To guarantee the quality of the data, field and laboratory procedures were optimized. In consequence, sampling bottles were properly washed with diluted hydrochloric acid and later rinsed with de-ionized water in the laboratory prior to the field sampling. At each sampling location, the bottles were rinsed with the

water to be collected to eliminate any introduced contamination. All the water samples were collected at subsurface to avoid the superficial colloidal layer, which could influence the concentration of certain parameters. Samples collected were put into ice-chests containing ice cubes to reduce biological and chemical processes. Replicate samples were collected at all stations to inform of any procedural errors in the laboratory. Laboratory blanks were run to check the quality of reagents/chemicals used in activating reactions/analysis.

Reproducibility and recovery studies were carried out. 1.0 mg/L standard solutions of each trace metal were measured (10 times) using flame Shimadzu model 6401F with respect to the reproducibility studies. The proportion (%) of trace metals recovered in the recovery studies ranged between 92.5 to 99.4% (standard error ± 0.005 to 0.570). The standard error is less than 1, which suggests that the analytical methods used for the samples were reproducible (Armah et al., 2010). The detection limit of heavy metals except mercury, cadmium, lead and chromium is 0.01 mg/L. The detection limit for mercury, cadmium, and chromium is 0.002 mg/L and that of arsenic is 0.001 mg/L, lead is 0.005.

**Laboratory Analysis**

All laboratory tests were conducted in accordance with "Standard Methods for the Examination of Water and Wastewater" of the American Public Health Association, 1998 Edition and the Australian and New Zealand guidelines (2000) for fresh and marine water quality. Samples collected for each season were

analyzed separately for the considered biological, physical and chemical indicators.

Homogenized subsamples were filtered, and acid-digested following the USEPA protocol 2002 (USEPA, 1991) and analyzed for total As, Fe Cd, Mn, Cu, Pb, and Cr using flame atomic absorption spectroscopy (AAS) following USEPA protocol 2007 (USEPA, 1991). Mercury was determined by cold vapor atomic absorption spectrometry. Unprocessed water samples were also analyzed for electrical conductivity, and for chloride, sulphate, nitrate, phosphate, and alkalinity and cyanide concentrations. Faecal coliform and total coliform bacteria were also determined by the membrane filtration technique. The parameters analysed are shown in Table 1. Laboratory determination of water quality indicators are elaborated below.

**Laboratory Determination of Phosphorus**

Three techniques for colorimetric analysis of phosphorus exist, the Vanadomolybdophosphoric acid method, the stannous chloride method and the ascorbic acid method. Nonetheless, the study made use of the ascorbic acid method in phosphorus determination. This technique has the potential to determine concentrations of orthophosphate in most waters and wastewater in the range from 0.01 - 6 mg P/L (APHA, 1998).

Table 1: *Surface Water Quality Parameters Analyzed*

| Chemical Indicators | Physical Indicators | Biological Indicators |
|---|---|---|
| Conductivity (µS/cm), pH (pH unit) $NO_3^-$(mg/L), Cadmium (Cd) mg/L Copper (Cu) mg/L Lead (Pb) mg/L Total Hardness (TH) (mg/L) Magnesium (Mg) mg/L Alkalinity (ALK) (mg/L) Chloride ($Cl^-$) (mg/L) Sodium (Na) mg/L $PO_4^{3-}$ (mg/L) $SO_4^{2-}$ (mg/L) Biochemical Oxygen Demand (BOD) mg/L Manganese (Mn) mg/L Nickel (Ni) mg/L Potassium (K) mg/L Mercury (Hg) (ug/L) Arsenic (As) (ug/L) Iron (Fe) mg/L Calcium (Ca) mg/L Zinc (Zn) mg/L Chromium (Cr) mg/L | Apparent Colour (TCU) Turbidity (FAU) True Colour (TCU) (count/100mL) Total Suspended Solids (TSS) (mg/L) Dissolved Oxygen (DO) (ppm) Total Dissolved Solids (TDS) (ppm) | Feacal Coliform (count/100mL) Total Coliform (count/100mL) |

The principle underlying this method is that, ammonium molybdate and potassium antimonyl tartrate reacts in acid medium with orthophosphate to form a heteropoly acid-phosphomolybdic acid- that is reduced to intensely colored molybdenum blue by ascorbic acid (APHA, 1998).

Phosphorus in surface water samples was determined by adding ammonium molybdate and antimony potassium tartrate. These reacted under an acidic medium with dilute solutions of orthophosphate-phosphorus to form an intensely colored antimony-phospho-molybdate complex. The complex is reduced to an intensely blue-colored complex by ascorbic acid. The color is proportional to the phosphorus concentration. The complex is not stable and hence, analysis was performed within 30 minutes of adding the ammonium molybdate and antimony potassium tartrate. The analysis followed detailed descriptions from APHA 4500P document.

**Procedure**

50 mL of water sample was measured into a 125 mL Erlenmeyer flask and 0.05 mg P was added. 0.05 mL phenolphthalein indicator was added which lead to a red colouration. 5N $H_2SO_4$ solution was added dropwise to discharge the colour. 8.0 mL combined reagent (APHA 4500 P document) was added and mixed thoroughly. A blank was prepared where 50 mL distilled water was substituted for the sample without ascorbic acid and potassium antimonyl tartrate. After 10 minutes absorbance of sample was measured at a wavelength of 880 nm using blank as reference. The phosphorous concentration was then determined using the equation below.

$$\text{Phosphorus (mg P/L)} = \frac{mg\ P\ (in\ 58\ mL\ final\ volume) \times 100}{mL\ sample} \quad \text{……Equation 1}$$

**Determination of Alkalinity**

Alkalinity of water samples was determined by titration method described in APHA 2321 document (APHA, 1998). The titration method operates with the principle that hydrolysis or dissociation of solutes in a sample produces hydroxyl ions which react with additions of standard acids through titration. Alkalinity thus depends on the end-point pH used (APHA 2320B document).

**Procedure**

50 mL of water sample was pipetted into a 250 mL conical flask and two drops of methyl orange was added and swirled to give a homogeneous mixture. The resulting solution was then titrated against a 0.02M HCl standard solution which gave a pink colouration at the point. The titre value was recorded. This procedure was repeated for the surface water samples. The alkalinity concentration was then determined using the equation below

$$\text{Alkalinity concentration} = \frac{A \times 1000\ mL}{mL\ sample} \quad \ldots\ldots\ldots\ldots\text{Equation 2}$$

Where:

A = mL standard acid used (titre value)

**Nitrates**

In the determination of nitrate concentration in surface water samples, the cadmium reduction method was used with the principle that cadmium metal reduces nitrate in the sample to nitrite and the nitrite ion reacts in an acidic medium (sulfanilic acid) to form an intermediate diazonium salt, which combines

with gentisic acid to form an amber coloured solution (Hach Company/Hach Lange GmbH, 2014).

**Procedure**

The PHARO 300, Direct Reading Spectrophotometer was used. A 10 mL of water sample was pipetted into a square sample cell and one NitraVer 5 Nitrate reagent powder pillow was added. The cell was swirled to dissolve. A blank sample was prepared by filling a second sample cell with 10 mL of distilled water and NitraVer 5 Nitrate reagent powder pillow was added to the content. After a minute of reaction, the blank sample was inserted into the cell holder of the spectrophotometer and zeroed to display 0.0 mg/l $NO^-_3$-N at 500 nm. The prepared sample cell was cleaned and inserted into the cell holder and the reading was read in mg/l $NO^-_3$-N.

**pH**

The pH was determined *in situ* using the multimeter (HORIBA water quality monitor) after it was calibrated. The electrode was initially cleaned with distilled water to remove impurities that could potentially affect the pH of the sampled water. The probe was then inserted into the sample and the reading for pH was recorded upon stabilization. The pH of the rest of the samples was determined following same procedure *in situ*. This was repeated for the rest of the samples. The in situ data collated helped to check if any changes occurred during the analysis in the laboratory.

The pH of water samples was equally determined in the laboratory using the electrometric method where equilibrium between electrodes and sample was established after the calibration of the instrument by stirring sample to insure homogeneity. Procedures described in APHA 4500-$H^+$B was followed in the determination of samples pH. Stirring was gently done to minimize carbon dioxide entrainment. The electrodes are conditioned after cleaning by dipping them into sample for 1 min, blot dry, immerse in a fresh portion of the same sample, and the pH value read.

**Temperature**

Temperature of surface water samples was determined *in situ* with a multimeter (Horiba water quality monitor). The probe calibrated before use and was rinsed with the respective sample and the probe inserted in the sampled water. The on button on the probe was pressed and allowed for at least three minutes before the reading is recorded. The probe is afterward rinsed with distilled water. Same was done at all surface water sampling locations.

**Electrical Conductivity**

Electrical conductivity of water samples was determined in situ and ex situ (in the Laboratory). All points of determination used a probe (Multimeter and DDS–12DW Microprocessor Conductivity meter, respectively).

With regards to the in situ determination of electrical conductivity, the instrument was calibrated and rinsed with the sampled water. The multimeter was then inserted into the sample and operationalized to display the conductivity of

the water. It was rinsed with distilled water after recording the value. Same was done with all samples from the sampling water bodies.

Laboratory procedures include calibrating the instrument according to the manufacturer's instructions and water samples were adjusted to room temperature (23 to 27$^{o}$C). The probe was then rinsed with distilled water, inserted into the water sample and stirred gently for a homogenous solution. The instrument was then operationalized and result value recorded after a stable value was displayed by the instrument. Similar was repeated for the other samples.

**Total Hardness**

The EDTA titrimetric method in determining total hardness was adopted in determining the total hardness of the samples. Detailed description of the method is in APHA 2340C document (APHA, 1998). Ethylenediaminetetraacetic acid (EDTA) and its sodium salts form a chelated soluble complex when added to a solution of certain metal cations. Small amounts of Eriochrome Black T or Calmagite when added to an aqueous solution containing calcium and magnesium ions at a pH of 10.0 ± 0.1 turns the solution wine red. When EDTA is added as a titrant, the calcium and magnesium will be complexed, and when all of the magnesium and calcium has been complexed the solution turns from wine red to blue, marking the end point of the titration (APHA, 1998).

**Procedure**

The pH of water samples were adjusted to 10 ± 0.1. 20 mL of the buffered (pH 10.1) sample was measured into a 250 ml Erlenmeyer conical flask. 2 mL of

Eriochrome Black T solution was added and swirled to mix. EDTA was used as titrant to reach end point (thus, a colour change from wine red to blue). The procedure was carried out for all other samples. The total hardness concentration was then determined using the equation below

$$\text{Hardness (EDTA) as mg } CaCO_3/L = \frac{A \times B \times 1000}{mL\ sample} \quad \ldots\ldots\ldots \text{Equation 3}$$

Where:

A= mL titration for sample and

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

**Determination of Total Suspended Solids (TSS)**

The photometric method described in APHA 2540D (APHA, 1998) document was used to determine TSS in water samples.

**Procedure**

A vacuum filtration apparatus was assembled and a 0.4 µM pore size filter paper was placed on Teflon-faced glass filter holder and then wetted by filtering 20 ml reagent-grade water using the vacuum filtration. The wet filter paper was removed carefully using a pair of a stainless steel of plastic forceps and placed on an aluminum weighing dish as a support and dried for at least 1 h at 103 to 105°C in an oven, cooled in a desiccator to balance temperature, and weighed.

Sample was stirred with a magnetic stirrer at a speed to shear larger particles, to obtain a more uniform (preferably homogeneous) particle size. While

stirring, a measured volume was pipetted from the approximate midpoint of container onto the seated glass-fiber filter.

The filter was washed with three successive 10-mL volumes of reagent-grade water, allowing complete drainage between washings, and suction continued for about 3 min after filtration is complete. Filter was carefully removed from the filtration apparatus and transferred to an aluminum weighing dish as a support and dried for at least 1 h at 103 to 105°C in an oven, cool in a desiccator to balance temperature, and weighed. The cycle of drying, cooling, desiccating, and weighing was repeated until a constant weight is obtained or until the weight change is less than 4% of the previous weight. This procedure was repeated for the rest of the water samples. The TSS concentration was then determined using the equation below.

$$\text{TSS (mg/L)} = \frac{W2 - W1 \times B \times 100}{V2} \quad \text{.....Equation 4}$$

Where:

$W_2$= weight of the filter paper and solids only,(in grams),

$W_1$= weight of the filter paper only, (in grams).

$V_s$= volume of test sample, (in ml).

**Colour**

The spectrophotometric method was used to determine surface water samples. Samples were prepared following the procedures elaborated in APHA

2120 document (APHA, 1998). Excessive quantities of materials were removed by centrifuging.

**Procedure**

A 0.1 g filter aid was thoroughly mixed with 10 ml portion of centrifuged sample and filtered to form a precoat in the filter crucible. Another 40 mg filter aid is mixed with 35 ml portion of centrifuged sample. With the vacuum still on, the mixture is filtered through the precoat and waste flask until clear.

The clear filtrate is directed to the clean flask by means of three-way stopcock and 25ml of sample is collected for the transmittance determination following the steps laid in APHA 2120 document (APHA, 1998).

**Faecal Coliform**

In the determination of faecal coliform, the membrane filtration method was adopted following the procedures established in APHA 9221 document (APHA, 1998). A-1 broth agar was used in the detection and enumeration of faecal coliform using the membrane filtration method.

**Procedure**

The medium was heated to dissolve all solid ingredients. Polyethylene glycol p-isooctylphenyl ether was added and pH adjusted to 6.9 ± 0.1. A-1 tubes were inoculated and incubated for 3h at 35$^{o}$C. The tubes were transferred to a water bath at 44.5$^{o}$C and incubated for additional 21± 2h. Gas production in any A-1 broth culture within 24h or less is a positive reaction indicating coliforms of

faecal origin. Faecal coliform is then calculated from the number of positive A-1 broth tubes using the Most Probable Number (MPN) table.

**Total Coliform**

The membrane filter (MF) technique was used to determine the concentration of total coliform in surface water samples. The MF technique is highly reproducible, can be used to test relatively large volumes of sample, and yields numerical results more rapidly as compared to the multiple-tube procedure (APHA, 1998).

**Procedure**

25 mL of surface water sample was measured into an erlenmeyer flask. Using a sterile forceps, a sterile membrane filter was placed over porous plate of receptacle. A matched funnel unit was placed over receptacle and locked. Water sample was then filtered under partial vacuum. With filter still in place, the funnel was rinsed by filtering 15- to 20- mL portion of sterile dilution water. After completion of final rinse and the filtration process, the vacuum was disengaged, unlocked, and the funnel removed. Filter membrane was immediately removed and placed on selected medium with a rolling motion to avoid entrapment of air. A sterile rinse water sample (100 mL) was inserted after filtration of series of 10 samples to check for possible cross-contamination or contaminated rinse water. The control membrane culture was incubated under the same conditions as the sample.

Colony counts on membrane filters were determined using a low-power (10 to 15 magnifications) binocular wide-field dissecting microscope which had pink to dark-red colour with a metallic surface sheen. The total coliform density was determined using the equation below.

$$\text{Total coliform/100 mL} = \frac{coliform\ colonies\ counted \times 100}{mL\ sample\ filtered} \quad \ldots\ldots\text{Equation 5}$$

**Chloride**

Indophenol method was used to determine chloride concentration in surface waters (USEPA/Hach Company/Hach Lange GmbH, 2014). The underlying principle with regards to this method is that, the addition of Freechlor F reagent solution and Monochlor F reagent pillows in surface water samples will produce a green colouration indicating the presence of chloride ions in the water sample. Chloride levels in surface water samples were determined in the laboratory by using the PHARO 300 spectrophotometer.

**Procedure**

Two sample cells were filled with 10 mL of surface water sample and distilled water. The cell with the distilled water was labelled blank. 5 drops of Freechlor F reagent were added to the samples. The stopper was placed on the sample cell and invert to mix. One Monochlor F Reagent Powder Pillow was added to each sample cell, closed and swirled to dissolve. The blank was cleaned, inverted and inserted into the cell holder. The ZERO button was pushed which displayed 0.00 mg/L $Cl_2$. The prepared sample was also inverted to mix, cleaned

and inserted into the cell holder. The READ button was pressed and the result was showed mg/L $Cl_2$. This process was repeated for all the surface water samples.

**Dissolved oxygen (DO)**

The iodometric test is based on the addition of divalent manganese solution, followed by strong alkali, to the sample in a glass-stoppered bottle. DO rapidly oxidize an equivalent amount of the dispersed divalent manganous hydroxide precipitate to hydroxides of higher valency states. In the presence of iodide ions in an acidic solution, the oxidized manganese reverts to the divalent state, with the liberation of iodine equivalent to the original DO content. The iodine is then titrated with a standard solution of thiosulfate and the titration end point can be detected visually, with a starch indicator, or electrometrically, with potentiometric or dead-stop techniques (APHA, 1998).

**Procedure**

250 mL of water sample was pipetted into a 300-mL BOD capacity bottle. 1 mL $MnSO_4$ solution was added, followed by 1 mL alkali-iodide-azide reagent. The bottle was stoppered carefully to exclude air bubbles and content mixed by inverting bottle a few times. When precipitate settled sufficiently (to approximately half the bottle volume) to leave clear supernate above the manganese hydroxide floc, 1.0 mL conc $H_2SO_4$ was added, re-stoppered and mixed by inverting several times until dissolution is complete. A volume corresponding to 200 mL sample was titrated with 0.025M $Na_2S_2O_3$ solution to a pale straw color. The DO concentration was then determined using the equation below.

For titration of 200 mL sample, $1\ mL\ 0.025M\ Na2S2O3\ =\ 1\ mg\frac{DO}{L}$ ……Eqn 6

**Sulphate ($SO_4^{2-}$)**

The SulfaVer 4 method was used to determine the concentration of sulphate (USEPA/Hach Company/Hach Lange GmbH, 2014). The underlying principle with respect to the determination of sulphate is that sulphate ions in water sample react with barium in the presence of SulfaVer 4 sulphate reagent powder pillow to form a barium sulphate precipitate. The amount of turbidity formed is relative to the amount of sulphate concentration.

**Procedure**

10 mL of surface water sample was introduced into a sample cell. SulfaVer 4 reagent powder pillow was added and swirled to dissolve. The sample was allowed to react for 5 min. A second cell was filled with 10 mL sample of blank without reagent. After 5 min, the blank was used to zero the spectrophotometer (PHARO 300 spectrophotometer), set at 450 nm, as 0 mg/$SO_4^{2-}$. The sample was then inserted and the concentration of the sample read. The process was done for the rest of the water samples.

**Total Dissolved Solids (TDS)**

The total dissolved solids (TDS) of the water samples were measured using the handheld HORIBA water quality monitor. 50ml of the water was measured into a pre-rinsed beaker using a measuring cylinder. The rinsing of the glass wares was done using distilled. The probe of the meter was then submerged into the water sample and the total dissolved solid (TDS) readings was taken and

recorded in mg/L. The same procedure was repeated for the other water samples to determine the TDS.

**BOD**

Surface water samples were stirred and five sample volumes (1 mL 5 mL 10 mL 15 mL 20 mL), were prepared and pipetted into to five 30- mL BOD bottles. Each bottle was filled with prepared dilution water down the inner surface to prevent air bubbles. A stopper was carefully inserted in each bottle to prevent trapped air bubbles. The stopper was pushed down and the bottles inverted several times to mix. A blank was filled in a 300 mL BOD bottle with the prepared dilution water.

The probe was rinsed with deionized water and dried with a lint-free cloth. The probe was kept in the blank and the button on the top of the probe was pushed to start the stir paddle. The Read button is pushed and a progress bar appeared. When the value became stable, it was read and recorded. Same was done for the prepared samples. A cap was added to each bottle to prevent evaporation. The prepared samples were incubated at 20$^{o}$C for 5 days. After 5 days the remaining dissolved oxygen in each of the bottles were measured. The BOD of surface water samples was calculated using the equation below.

$$BOD_5 \text{ mg/L} = \frac{(D1-D2)}{P} \quad \text{.....Equation 7}$$

Where:

$BOD_5$ = BOD value from the 5-day test (mg/L)

$D_1$ = DO of the prepared sample immediately after preparation (mg/L)

$D_2$ = DO of the prepared sample after incubation in mg/L

P = Volumetric fraction of sample used

**Turbidity**

Turbidity of the water samples were measured using the Nephelometric method following the procedures discussed in APHA 2130B document (APHA, 1998). Before the turbidity of the samples was determined, the turbidimeter was calibrated based on the manufacturer's operation instructions.

The samples were thoroughly shaken and allowed for air bubbles to disappear. Water sample was then poured into the turbidimeter tube and immersed in an ultrasonic bath for 1 to 2 s, causing complete bubble release. The turbidity of the water sample is read from the instrument scale and the procedure repeated for all the other samples.

**Trace/Heavy Metals (As, Fe, Ca, Zn, Cd, K, Na, Ni, Mn, Mg, Cu, Pb, and Cr)**

A flame Atomic Absorption Spectrophotometer (AAS) Shimadzu model 6401F was used for analysis of the samples for trace/heavy metals concentration after preparation of appropriate calibration standards and homogenized subsamples were filtered, and acid-digested. Mercury was determined by cold vapor atomic absorption spectrometry

Due to expected low concentrations of the metals in the natural water samples and limited instrument sensitivity, pre-concentration of the water samples

was done by evaporating 100 ml of the water to 4 ml on a hot plate. The digestion of the water samples was then achieved by adding 5 ml of 11.1 M $HNO_3$ and heating on the hot plate for 30 min. Some 10 ml of 16.3 M HCl was added and digestion continued until the solution remained light brown or colorless.

Table 2: *Laboratory Methods and Reference Materials Used For Water Quality Determination*

| **Analyses** | **Laboratory Method** | **Method Reference** |
|---|---|---|
| Phosphorous | Colorimetric | APHA 4500P |
| BOD | Sensor System | APHA 5210D |
| Color | Photometric | APHA 2120 |
| Turbidity | Nephelometric | APHA 2130B |
| | | US EPA Method |
| Trace/heavy metals | Acid Digestion/ASV | 3005A/APHA 3130 |
| DO | Iodometric test | APHA 4500-O |
| Hardness | Colorimetric | APHA 2340C |
| Alkalinity | Titration | APHA 2320B |
| Conductivity | Probe | US EPA Method 120.1 |
| pH | Probe | APHA 4500-$H^+$B |
| Total Coliforms | Membrane Filtration | APHA 9222 |
| Nitrate | Colorimetric | APHA 4500N |
| TSS | Photometric | APHA 2540D |
| Faecal Coliforms | Membrane Filtration | APHA 9221E |
| Chloride | Indophenol Method | USEPA Hach Method 10241 |
| BOD | Probe | USEPA Hach Method 10360 |

**Environmental variables**

Environmental factors are largely found to explain surface water quality, which are relatively easy to define from a local to global scale (Varanka, 2016). The study considered some environmental variables. More specifically, the environmental factors consisted of data from NDVI, and land use type (cultivated areas, built-up, forest) around rivers and streams catchment.

**Landsat Satellite Image Acquisition and Classification**

Landsat satellite data has been produced and made available for use by the United States Geological Survey Department since 1972. Landsat satellite images for 2019 of the study area were downloaded from the United States Geological Survey Earth Resources Observation and Science Data Centre (http://www.usgs.gov). Table 6 elaborates the details of the Landsat satellite images.

Lu et al. (2012) posit that in land use land cover classification, selection of sufficient number of training and test samples cannot be underestimated. Existing topographic maps and Google Earth images of the study area was used as reference data for the classification of the Landsat satellite images. With the help of processed field GPS coordinates of the studied surface water bodies, training samples were collected. Representative Region of Interest (ROI) polygons was developed from the training areas. The satellite images were pre-processed by stacking the individual bands and projected into the Universal Transverse Mercator (UTM) projection system (zone: 30N, datum: WGS84). Ramsar site

maps from the Coastal Wetlands management Plans: Ghana (Ntiamoa-Baidu & Gordon, 1991) was adopted to delineate the boundary of the study. The Landsat satellite images were classified using Supervised Classification with Maximum Likelihood Classifier (Lu et al., 2012). Maximum Likelihood Classifier (Ahmed & Quegan, 2012) considers the variability of the various classes and assigns pixels to class of highest probability. The accuracy assessment of the classified images was performed using samples from UAV and Google Earth image data.

The classified images results were statistically compared to the reference data using Error matrices. Kappa test was carried out to measure the agreement between the classification results and the reference image (see Gomez & Montero, 2011) which ranges from 0 to 1. A Kappa coefficient of 0 means there is no agreement between the classified image and the reference image. ENVI v. 15 image analysis software was used for the image classification.

Table 3 shows the description of the various land use-land cover types adopted in the study and Figure 3 is the satellite image used for the extrapolation of LULC and NDVI data.

Table 3: *Land Use Land Cover Classification Scheme*

| Land use- Land cover type | Description |
|---|---|
| Forest | Vegetated lands that are not cultivated such as grassland, shrubs, forest and other natural vegetation |
| Cultivated area | Areas used for farming and degraded lands |
| Built-up | Areas used for residential lands and bare lands |
| Water | All surface water bodies including rivers and streams |

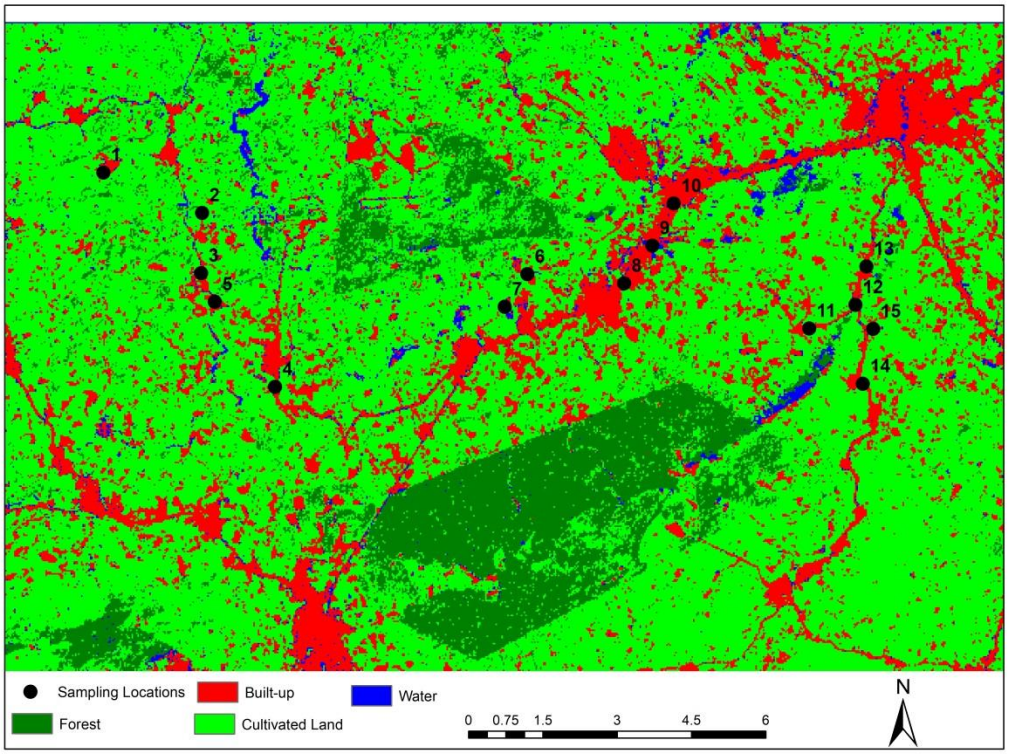


*Figure 3*: Satellite Image for Land Use Land Cover and NDVI Classification.

**Spatiality and Temporality**

For the spatiality study, buffer zones of 100 metres (m), 200m and 300 m around sampled location were considered. In the temporal study, the entire year was grouped into two. The dry season which was observed between January and February and November to December and the wet season observed in late March to October.

**Data Processing and Analysis**

Microsoft Excel 2010 was used to code all data. The data were screened in the Microsoft Excel and imported into the Statistical Package for Social Sciences

(SPSS), version 21 and Stata 13 MP (StataCorp, College Station, TX, USA) for statistical analysis. ENVI v. 15 image analysis software was used for the image classification. The main analytical methods the data was subjected to included Principal Component Analysis (PCA), Pearson's product moment correlation Kruskal-Wallis test, Ordinary least square regression in order to achieve the specific objectives of the study.

Multivariate analysis of surface water data was operationalized through Principal Component Analysis (Millard & Neerchal, 2000; Yidana et al., 2008). PCA/FA is a statistical analysis that reduces the dimensionality of a data set with a large number of interrelated variables, in a manner that minimum original information is lost (Miller et al., 2002). PCA/factor analysis (FA) is commonly used for data structure determination, and to afford qualitative information about potential pollution sources (Varanka, 2016).

**Chapter Summary**

The study was undertaken to assess surface water quality in the Birim North District of Ghana using spatial modeling. This chapter of the study therefore explored the research methods which gave an in-depth description of the sub-themes the research methods was categorized into comprising, the research design, study area, population, sampling procedure, data collection procedures and data processing and analysis. The cross-sectional study design was considered in this study to evaluate surface water quality through field sampling of surface water bodies. This study design gives clear meaning of events

and explains prevailing conditions of a given ecosystem on the basis of data gathered at a particular point in time. Surface water quality was studied through physical, chemical and biological parameters both in situ and ex situ. Sampling and analytical methods of surface water bodies followed the protocols developed by the American Public Health Association (APHA) (1998) and the Australian and New Zealand (2000) guidelines for fresh and marine water quality.

Environmental data were equally explored comprising land use, and NDVI data. ENVI v. 15 image analysis software was used for the image classification and computation. All data originating from the study was entered into Microsoft Excel 2010 and screened. The data were imported into the Statistical Package for Social Sciences (SPSS), version 21 and Stata 13 MP (StataCorp, College Station, TX, USA) for statistical analysis. The next chapter of the study focused on the results derived from the study.

# CHAPTER FOUR

## RESULTS

This study was undertaken to explore the application of spatial statistical modelling to assess the effects of environmental factors on surface water quality in the Birim North District of Ghana. The study purely made use of a quantitative research method where the descriptive cross-sectional study design was employed in sampling surface water bodies in the Birim North District of Ghana. Sampling and analytical methods of surface water bodies were carried out following the protocols developed by the American Public Health Association (APHA) (1998) and the Australian and New Zealand guidelines (2000) for fresh and marine water quality.

Five hundred and forty surface water samples were collected from fifteen surface water bodies (rivers and streams) in the Birim North District from January 2018 to December 2018. Surface water quality therefore covered all seasonal periods in the study area (dry and wet seasons). The data was entered and analysed using Microsoft Excel 2010, SPSS (Version 21) and Stata 13 MP (StataCorp, College Station, TX, USA).

This chapter presents the results of the study. The results are presented using descriptive statistics of surface water quality, Pearson correlation, Principal Component Analysis (PCA), and Ordinary Least Square regression (OLS).

**Descriptive Statistics of Surface Water Quality**

The descriptive statistics of surface water quality is presented in three orders, thus descriptive statistics for the dry season surface water samples, wet season and a combination of both wet and dry season data. This gives the opportunity to understand the nuances in the water quality data with respect to variation in season and across streams and rivers.

**Dry Season Samples of Surface Water (Rivers and Streams)**

Table 4 gives the descriptive statistics of the dry season samples. From the table, the mean pH value of surface water was 6.815 with minimum and maximum values of 5.940 and 7.890 at locations S06D1 and S03D2, respectively. Conductivity of surface waters ranged from 38µS/cm at S10D1 to as high as 443µS/cm at S13D2. The mean conductivity value was found to be 142.289µS/cm. A mean alkalinity level of sampled surface water bodies was found to be 114.333 mg/L. The minimum and maximum Alkalinity readings were found at S10D1 and S13D1 with respective values of 19 mg/l and 246 mg/L.

Turbidity of surface waters during the dry season was variable. The minimum reading was found to be 9.8 NTU at location S09D1 and location S03D2 recorded the maximum value of 753 NTU. The standard deviation was found to be 261.725. Total dissolved solids ranged from 25 mg/L at three locations (S05D1, S09D1, S15D1) to 270 mg/L at S03D2 with a mean reading of 87.133 mg/L. TSS reading of surface water during the dry season sampling was highly elevated. The minimum TSS value (1 mg/L) was found at S04D1 and

S09D1 while S03D2 recorded the maximum value of 625 mg/L. The mean value and standard deviation was found to be 155.9 mg/L and 212.973, respectively.

The maximum and minimum dissolved Oxygen (DO) reading was 0.040 mg/L and 0.260 mg/L at S15D1 and S05D2, respectively during the dry season. The mean DO concentration was found to be 0.140 mg/L. The BOD concentration was variable among the surface waters sampled. The minimum concentration of 13.2 mg/L was found at location S10D1 and the maximum (64.9 mg/L) was found at location S04D2. Total hardness concentration was measured. Three locations S05D1, S10D2, S15D1 and S15D2 recorded the least values of 8 mg/L while the maximum concentration of 503 mg/L was found at location S03D2. The mean total hardness concentration was found as 91.944 mg/L.

The colour of the sampled waters was generally elevated in some of the locations. True colour ranged from 1 TCU at eighteen locations S05D1, S15D1, S15D2, S10D2, S10D1, S05D2, S14D1, S04D1, S09D1, S14D2, S09D2, S04D2, S04D1, S14D1, S14D2, S09D1, S09D2, S04D2) to 2003 TCU at S03D2. Also, minimum and maximum levels of apparent colour were found at S09D1 and S07D1 of concentrations 48 TCU and 9902 TCU, respectively. The mean concentrations of the water samples for true and apparent colour were 238.011 and 2183.778 TCU with standard deviations 506.493 and 2895.929, respectively.

S14D1 recorded the minimum chloride concentration of 1.9 mg/L and the maximum levels (21.2 mg/L) recorded at locations S02D2 and S12D2. S14D1 and S04D1 recorded the minimum nitrate levels of 0.7 mg/L and the maximum

concentration (6.02 mg/L) levels recorded at S15D2 and S05D2. The mean concentration of chloride and nitrate were found to be 10.093 mg/L and 2.524 mg/L, respectively.

The observed sulphate values ranged from 0.010 mg/L (S15D1, S05D1, S10D1, S10D2, S15D2, and S05D2) to 181 mg/L (S03D1, S13D1). The measured sodium levels were variable ranging from a low of 1.3 mg/L (S03D1, S13D1) to 79.5 mg/L (S03D1, S13D1). The mean sulphate and sodium concentration was found to 43.540 mg/L and 14.571 mg/L respectively.

The measured calcium concentration ranged from 0.01 mg/L (S08D1, S13D1, S03D1, S08D2, S13D2, and S03D2) and 40 mg/L (S08D2, S03D2, S14D2, S09D2, S04D2). The mean and standard deviation values were found to be 20.545 mg/L and 10.657, respectively. The concentrations of mercury, cadmium and lead measured at all locations were found to be below the detection limits of the instruments used (0.002 mg/L, 0.002 mg/L and 0.005 mg/L, respectively).

Magnesium concentration ranged from a minimum of 0.01 mg/L at forty-eight locations to a maximum of 13 mg/L at S14D2, S04D2. The mean concentration is 2.472 mg/L. The mean potassium concentration of sampled waters is 6.619 mg/L. The minimum concentration of 1.8 mg/L is found at location S07D1 while the maximum concentration of 18 mg/L is found at S05D2. Total phosphate concentration ranged from 0.1 mg/L (S06D2, S14D1) to 2.710 mg/L at S03D2. The measured phosphate values had a mean value of 0.477 mg/L.

All sampled locations recorded the presence of total coliform. The maximum total coliform count of 1999 cfu/100ml was obtained at S14D1 with the minimum of 1 cfu/100ml recorded at 17 locations- S05D1, S15D1, S05D1, S15D2, S10D2, S15D1, S05D1, S08D1, S03D1, S12D1, S07D1, S02D1, S12D1, S02D1, S12D1, S07D1, S02D1. The mean total coliform count was 183.578 cfu/100ml.

Faecal coliform was not recorded in all samples. The maximum faecal coliform load of 83 cfu/100ml was recorded at S01D2 whilst the minimum load of 0 cfu/100ml occurred at S15D1, S07D1, S12D1, S15D1, S13D1, S14D1, and S11D1. The mean load of faecal coliform was found to 9.411 cfu/100ml.

Iron concentration ranged between 0.02 mg/L (S13D1, S08D1, S03D1, S14D1, S04D1, S11D1, and S01D1) and 1.88 mg/L (S03D2). The mean and standard deviation were found to be 0.431 mg/L and 0.422, respectively. The lowest measurable level of Arsenic (0.001 mg/L) was obtained at eighteen different locations (S13D1, S08D1, S03D1, S03D2, S13D2, S08D2, S04D1, S14D1, S09D1, S14D1, S04D1, S09D1, S09D2, S09D2, S14D2, S14D2, S04D2, S04D2) with the highest of 0.2 mg/L occurring at S12D1, S07D1, S02D1, S07D2, S12D2, S02D2.

Thirty six locations - S04D1, S14D1, S09D1, S14D1, S04D1, S09D1, S09D2, S09D2, S14D2, S14D2, S04D2, S04D2, S15D1, S05D1, S10D1, S10D2, S15D2, S05D2, S15D1, S05D1, S10D1, S10D2, S05D2, S15D2, S15D1, S05D1, S10D1, S15D2, S10D2, S05D2, S14D1, S04D1, S09D1, S09D2, S14D2, S04D2 -

recorded the minimum levels of manganese of 0.001 mg/L. The highest levels of 0.016 mg/L were obtained at S11D1, S01D1, S06D1, S06D2, S11D2, and S01D2.

The highest zinc concentration of 0.6 mg/L measured was at locations S09D2, S04D2, S06D2, and S01D2. The minimum concentration and mean levels of zinc was 0.01 mg/L and 0.18 mg/L, respectively. The maximum nickel level of 2.3 mg/L was recorded at S03D2 with the lowest of 0.01 mg/L being recorded at 29 locations (S10D1, S15D1, S05D1, S05D1, S10D1, S11D1, S15D1, S01D1, S06D1, S11D2, S01D1, S11D2, S06D2, S01D2, S13D1, S03D1, S08D1, S08D2, S13D2, S11D1, S06D1, S06D2, S01D2, S15D2, S10D2, S05D2, S15D2, S10D2, and S05D2).

The minimum and maximum levels of chromium were 0.03 mg/L and 3.8 mg/L at locations S01D1, S11D1 and S01D2, S11D2, respectively. The highest concentration of copper of 4.23 mg/L was measured at S14D2 and S04D2 whilst the lowest concentration of 0.36 mg/L was measured at S03D1 and S13D1. The respective mean levels of chromium, copper, manganese, and arsenic were 0.937 mg/L, 1.977 mg/L, 0.005 mg/L and 0.024 mg/L.

The distribution of all the parameters analysed to evaluate surface water quality during the dry season were right skewed (skewness value greater than zero) except biological oxygen demand (Table 4), implying that most values of respective variables are concentrated on left of the mean, with extreme values to the right.

Table 4*: Descriptive Statistics of Dry Season Sampling*

| Parameter | Mean | Std. Deviation | Skewness | Kurtosis | Minimum | Maximum |
|---|---|---|---|---|---|---|
| pH | 6.82 | 0.51 | 0.07 | -0.77 | 5.94 | 7.89 |
| Cond. (µS/cm) | 142.29 | 95.85 | 1.90 | 3.92 | 38.00 | 443.00 |
| Alk. (mg/L) | 114.33 | 70.30 | 0.37 | -1.21 | 19.00 | 246.00 |
| Turb. (NTU) | 209.35 | 261.73 | 1.27 | -0.10 | 9.80 | 753.00 |
| TDS (mg/L) | 87.13 | 58.22 | 1.90 | 3.90 | 25.00 | 270.00 |
| TSS (mg/L) | 155.90 | 212.97 | 1.42 | 0.30 | 1.00 | 625.00 |
| DO (mg/L) | 0.14 | 0.05 | 0.01 | 0.50 | 0.04 | 0.26 |
| BOD (mg/L) | 47.58 | 13.34 | -0.90 | 0.33 | 13.20 | 64.90 |
| TH (mg/L) | 91.94 | 116.87 | 2.87 | 7.71 | 8.00 | 503.00 |
| TrC(mg/l Pt.co) | 238.01 | 506.49 | 2.88 | 7.53 | 1.00 | 2003.00 |
| ApC(mg/l Pt.co) | 2183.78 | 2895.93 | 1.65 | 1.56 | 48.00 | 9902.00 |
| Cl (mg/L) | 10.09 | 3.98 | 0.71 | 1.04 | 1.90 | 21.20 |
| Nitrate (mg/L) | 2.52 | 1.36 | 0.55 | -0.54 | 0.70 | 6.02 |
| Sulphate (mg/L) | 43.54 | 47.57 | 1.45 | 1.56 | 0.01 | 181.00 |
| Na (mg/L) | 14.57 | 17.25 | 3.27 | 9.65 | 1.30 | 79.50 |
| Ca (mg/L) | 20.55 | 10.66 | 0.14 | -0.60 | 0.01 | 40.00 |
| Mg (mg/L) | 2.47 | 3.64 | 1.43 | 0.92 | 0.01 | 13.00 |
| K (mg/L) | 6.62 | 4.06 | 1.19 | 0.44 | 1.80 | 18.00 |
| T. Phos. (mg/L) | 0.48 | 0.52 | 3.01 | 9.80 | 0.10 | 2.71 |
| T.Col.(cfu/100 ml) | 184 | 364.87 | 3.35 | 12.94 | 1.00 | 1999.00 |
| F.Col.(cfu/100 ml) | 9 | 21.47 | 2.67 | 5.93 | 0.00 | 83.00 |
| As (mg/L) | 0.02 | 0.05 | 3.35 | 9.89 | 0.00 | 0.20 |
| Fe (mg/L) | 0.43 | 0.42 | 1.63 | 2.72 | 0.02 | 1.88 |
| Mn (mg/L) | 0.01 | 0.01 | 0.93 | -0.53 | 0.00 | 0.02 |
| Cu (mg/L) | 1.98 | 1.19 | 0.18 | -1.30 | 0.36 | 4.23 |
| Cr (mg/L) | 0.94 | 0.82 | 1.48 | 2.85 | 0.03 | 3.80 |
| Ni (mg/L) | 0.26 | 0.45 | 2.88 | 9.00 | 0.01 | 2.30 |
| Zn (mg/L) | 0.18 | 0.18 | 1.04 | -0.20 | 0.01 | 0.60 |
| Hg (mg/L) | 0.00 | 0.00 | . | . | 0.00 | 0.00 |
| Pb (mg/L) | 0.01 | 0.00 | . | . | 0.01 | 0.01 |
| Cd (mg/L) | 0.00 | 0.00 | . | . | 0.00 | 0.00 |

Ten of the parameters (conductivity, total dissolved solids, total hardness, true colour, sodium, total phosphate, Total Coliform, Faecal Coliform, arsenic, nickel) were leptokurtic and hence had kurtosis values greater than three (Table 4). This therefore implies that, the distribution of such parameters are sharper than a normal distribution, hence, the values are concentrated around the mean and have thicker tails. This also reveals a high probability for extreme values in such parameters. The rest of the parameters (eighteen parameters) however, had a platykurtic distribution (thus, kurtosis values less than three), meaning that, the values are widely spread around the mean and the distributions are flatter than a normal distribution with a wider peak. This therefore signifies a less probability of extreme values compared to a normal distribution.

**Wet Season Sampling Output**

Table 5 gives the detailed descriptive statistics of the wet season samples of surface waters in the study area. The mean pH value recorded during the wet season is below that recorded during the dry season (difference of 0.465 pH units) (Table 5). The minimum and maximum values of 4.450 and 7 were measured at location S02W1 and S02W2, S12W2, respectively. The mean conductivity levels measured during the wet season is 94.433 µS/cm which is approximate 47.856 µS/cm below the value recorded during the dry season (142.289 µS/cm). The minimum and maximum alkalinity values of 10 mg/L and 78 mg/L were recorded at S05W1, S15W2 and S04W2, S14W2 respectively. The mean concentration level was 37.267 mg/L.

The mean turbidity levels of surface water samples during the dry season were over three times lower than that recorded during the wet season sampling. The mean concentration with respect to TDS, TSS, BOD and total hardness in surface water samples were higher in the dry season as compared to the wet season. However, the elements, dissolved oxygen, true colour, magnesium, calcium, total phosphate, faecal coliform, had higher means in the wet season than in the dry season.

The conductivity readings ranged from 24µS/cm at S03W1 and S13W1 to as high as 296 µS/cm at S04W2 and S09W2. The mean conductivity value was found to be 94.433 µS/cm. The mean wet season alkalinity level was found to be 37.267 mg/L with minimum (10 mg/L) and maximum (78 mg/L) readings found at S15W1, S05W1 and S14W2, S04W2, respectively.

Turbidity levels of surface waters during the wet season were variable. The minimum reading was found to be 4.0 NTU at locations S0W1, S06W1 while locations S12W2 and S02W2 recorded the maximum value of 82 NTU. The mean readings was found to be 41.122 mg/L. Total dissolved solids ranged from 16 mg/L at two locations (S13W1, S03W1) to 170 mg/L at S06W2 and S01W1 with a mean reading of 68.825 mg/L. TSS reading of surface water during the wet season sampling was highly elevated just as observed in the dry season. The minimum TSS value (3 mg/L) was found at S01W1, S11W1 and S14W1 while S010W1 and S05W1 recorded the maximum value of 147 mg/L. The mean value and standard deviation was found to be 43.722 mg/L and 35.862, respectively.

The maximum (8.75 mg/L) and minimum (3.36 mg/L) dissolved oxygen reading was recorded at SS14W2, S04W2 and S14W1, S04W1, respectively during the wet season. The mean DO concentration was found to be 7.059 mg/L. The minimum BOD concentration of 2.66 mg/L was found at locations S08W1 and S03W1 while the maximum (7.3 mg/L) was found at locations S08W2 and S03W2. Four locations S01W1, S11W1, S02W1 and S07W1 recorded the least values of total hardness concentration of 22 mg/L while the maximum concentration of 110 mg/L was found at locations S14W2 and S04W2. The mean total hardness concentration was found as 52.378 mg/L.

The colour levels of the sampled waters were generally elevated in almost all locations. True colour ranged from 44 TCU at locations S01W1 and S06W1 to 483 TCU (S01W2 and S11W2). Also, minimum (147 TCU) and maximum (2167 TCU) levels of apparent colour were found at (S04W1, S09W1) and (S07W2, S02W2), respectively. The mean concentrations of the water samples for true and apparent colour were 272.311 and 807.144 TCU with standard deviations 138.387 and 499.304 respectively.

The minimum chloride concentration of 2.551 mg/L was recorded at S03W1 and S08W1 while the maximum concentration (7.233 mg/L) was recorded at location S02W2. S03W1 and S13W1 recorded the minimum nitrate levels of 0.277 mg/L and the maximum levels (4.786 mg/L) recorded at S10W2 and S05W2. The mean concentrations of chloride and nitrate were found to be 4.872 mg/L and 2.572 mg/L, respectively.

The observed sulphate levels ranged from 0.398 mg/L (S06W1, S06W1) to 7.966 mg/L (S06W2, S01W2). The measured sodium levels were variable ranging from a low of 4.035 mg/L (S01W1, S11W1) to 12.567 mg/L (S04W2, S09W2). The mean sulphate and sodium concentration was found as 4.179 mg/L and 9.195 mg/L, respectively.

The measured calcium concentration ranged from 120.24 mg/L at S10W2 to 312.45 mg/L (S11W2). The mean and standard deviation values were found to be 212.231 mg/L and 47.623 respectively. The concentrations of mercury and cadmium measured at all locations were found to be below the detection limits of the instruments used (0.002 mg/L and 0.002 mg/L, respectively).

Magnesium concentration ranged from a minimum of 2.634 mg/L at S04W1 and S09W1 to a maximum of 11.897 mg/L at S12W2, S02W2. The mean concentration level is 7.677 mg/L. The mean potassium concentration of sampled waters during the wet season was 3.679 mg/L with minimum concentration of 0.678 mg/L found at locations S04W1 and S14W1while the maximum concentration of 6.987 mg/L is found at S04W2 and S14W2. Total phosphate concentration ranged from 0.732 mg/L (S05W1, S10W1) to 7.654 mg/L at S12W1. The measured total phosphate values had a mean value of 2.601 mg/L.

All sampled locations recorded the presence of total coliform. The maximum total coliform count of 130 cfu/100ml was obtained at S03W2 and S13W2 with the minimum of 13 cfu/100ml recorded at locations S04W1, S09W1. The mean total coliform count was 62.267 cfu/100ml.

Faecal coliform was equally recorded in all samples unlike as observed in the dry season. The maximum faecal coliform load of 74 cfu/100ml was recorded at S01W2 and S11W2 whilst the minimum load of 9 cfu/100ml occurred at S04W1 and S14W1. The mean load of faecal coliform was found to 31 cfu/100ml.

Iron concentration ranged between 0.214 mg/L (S01W1, S06W1) and 4.987 mg/L (S04W2 and S09W2). The mean and standard deviation were found to be 2.049 mg/L and 1.239 respectively. The lowest measurable level of Arsenic (0.049 mg/L) was obtained at four different locations (S02W1, S05W1, S10W1, S12W2) with the highest of 0.367 mg/L occurring at S06W1.

Two sampled locations recorded the minimum levels of manganese (S04D1, S14D1) of 0.211 mg/L and the highest levels of 0. 992 mg/L was obtained at S14W2, S04W2.

The highest zinc concentration of 0.123 mg/L was measured at locations S01W1, S06W1 and S11W1. The minimum concentration (S05W1, S10W1 and S15W1) and mean levels of zinc was 0.019 mg/L and 0.062 mg/L, respectively. The maximum nickel level of 0 .018mg/L was recorded at S03W1, S08W1 and S13W1 with lowest of 0.002 mg/L.

The minimum and maximum levels of chromium were 0.002 mg/L and 0.238 mg/L respectively. The highest concentration of copper (0.051 mg/L) was measured at S14W1, S04W1 and S09W1 whilst the lowest concentration was found to be 0.02 mg/L. The respective mean levels of chromium, copper,

manganese, and arsenic were 0.013 mg/L, 0.009 mg/L, 0.445 mg/L and 0.145 mg/L.

In relation to the wet season samples, nine of the water quality indicators (pH, dissolved oxygen, biological oxygen demand, true colour, nitrate, sulphate, sodium, magnesium, potassium) are left skewed and thus, the measured skewness values are less than zero (Table 4), indicating that, most values of the respective parameters are concentrated on the right of the mean, and with extreme values to the left.

Twenty of the water quality parameter had skewness values above zero, hence, are of right skewed distribution, implying most values of such parameters are concentrated on the left of the mean, with extreme values to the right.

With the exception of five parameters (conductivity, copper, chromium, nickel and lead), all other parameters had a platykurtic distribution. These parameters are therefore flatter than a normal distribution, with the values wider spread around the mean. The five parameters which are leptokurtic also signify that, their distributions are sharper than a normal distribution, with values concentrated around the mean and ticker tails. This equally, reveals extreme values for such parameters.

Table 5: *Descriptive Statistics for Wet Season Sampling*

| Parameter | Mean | Std. Deviation | Skewness | Kurtosis | Minimum | Maximum |
|---|---|---|---|---|---|---|
| pH (pH unit) | 6.35 | 0.54 | -1.21 | 1.37 | 4.45 | 7.00 |
| Cond. (µS/cm) | 94.43 | 48.02 | 2.58 | 8.51 | 24.00 | 296.00 |
| Alk. (mg/L) | 37.27 | 15.40 | 0.89 | 0.57 | 10.00 | 78.00 |
| Turb. (NTU) | 41.12 | 20.80 | 0.07 | -0.73 | 4.00 | 82.00 |
| TDS (mg/L) | 68.83 | 37.49 | 1.58 | 1.87 | 16.00 | 170.00 |
| TSS (mg/L) | 43.72 | 35.86 | 1.07 | 0.55 | 3.00 | 147.00 |
| DO (mg/L) | 7.06 | 1.14 | -1.01 | 1.84 | 3.36 | 8.75 |
| BOD (mg/L) | 5.23 | 1.11 | -0.24 | -0.32 | 2.66 | 7.30 |
| TH (mg/L) | 52.38 | 19.67 | 0.71 | 0.85 | 22.00 | 110.00 |
| TrC(mg/l Pt.co) | 272.31 | 138.39 | -0.42 | -1.20 | 44.00 | 483.00 |
| ApC(mg/l Pt.co) | 807.14 | 499.30 | 0.81 | 0.24 | 147.00 | 2167.00 |
| Cl (mg/L) | 4.87 | 1.26 | 0.12 | -0.73 | 2.55 | 7.23 |
| Nitrate (mg/L) | 2.57 | 1.11 | -0.24 | -0.55 | 0.28 | 4.79 |
| Sulphate (mg/L) | 4.18 | 1.65 | -0.05 | 0.07 | 0.40 | 7.97 |
| Na (mg/L) | 9.20 | 2.14 | -0.40 | -0.43 | 4.04 | 12.57 |
| Ca (mg/L) | 212.23 | 47.62 | 0.36 | -0.72 | 120.24 | 312.45 |
| Mg (mg/L) | 7.68 | 2.37 | -0.18 | -0.46 | 2.63 | 11.90 |
| K (mg/L) | 3.68 | 1.49 | -0.09 | 0.09 | 0.68 | 6.99 |
| T. Phos. (mg/L) | 2.60 | 1.39 | 0.80 | 0.64 | 0.73 | 7.65 |
| T.Col.(cfu/100 ml) | 62 | 29.61 | 0.34 | -0.10 | 13.00 | 130.00 |
| F.Col.(cfu/100 ml) | 31 | 13.60 | 0.85 | 1.32 | 9.00 | 74.00 |
| As (mg/L) | 0.15 | 0.08 | 1.07 | 0.05 | 0.05 | 0.37 |
| Fe (mg/L) | 2.05 | 1.24 | 0.88 | 0.18 | 0.21 | 4.99 |
| Mn (mg/L) | 0.45 | 0.21 | 1.07 | 0.28 | 0.21 | 0.99 |
| Cu (mg/L) | 0.01 | 0.01 | 2.18 | 4.95 | 0.00 | 0.05 |
| Cr (mg/L) | 0.01 | 0.04 | 4.54 | 20.52 | 0.00 | 0.24 |
| Ni (mg/L) | 0.00 | 0.00 | 2.18 | 3.80 | 0.00 | 0.02 |
| Zn (mg/L) | 0.06 | 0.03 | 0.41 | -0.40 | 0.02 | 0.12 |
| Hg (mg/L) | 0.00 | 0.00 | . | . | 0.00 | 0.00 |
| Pb (mg/L) | 0.10 | 0.23 | 2.58 | 5.57 | 0.00 | 0.95 |
| Cd (mg/L) | 0.00 | 0.00 | . | . | 0.00 | 0.00 |

**Descriptive Statistics for all Samples and Environmental Variables**

Table 6 gives detailed descriptive statistics of all samples during the study. From the Table, all measured parameters are right skewed except pH. However, the distribution of data was variable. Fourteen of the parameters had a platykurtic distribution while fifteen had a leptokurtic distribution. The parameters with platykurtic distribution (pH, alkalinity, dissolved oxygen, biological oxygen demand, chloride, nitrate, calcium, magnesium, total phosphate, faecal coliform, arsenic, iron, copper, manganese) inform that, those parameters have distributions flatter than a normal distribution, with values spread around the mean. Nonetheless, (conductivity, turbidity, total dissolved solids, total hardness, true colour, apparent colour, sulphate, sodium, potassium, total coliform, chromium, lead, nickel, and zinc) which showed a leptokurtic distribution, indicate that, the water quality indicators are sharper than a normal distribution, with high probability for extreme values.

The mean pH value for all water samples was 6.582. The minimum and maximum values of 4.450 and 7.890 were measured at S02W1 and S03D2 respectively. The minimum and maximum conductivity values of 24µS/cm and 443µS/cm were measured at (S03W1, S13W1) and S13D2, respectively. The mean values of conductivity, alkalinity, turbidity, TDS, and TSS levels were 118.361µS/cm, 75.8 mg/L, 125.238 NTU, 77.979 mg/L and 99.811 mg/L respectively. Mercury, cadmium, lead and arsenic concentration, had approximately similar mean values for all samples (ranging between 0.002 mg/L and 0.084 mg/L).

Sampling location S14W2, S14W1, S14D1 and S14D2 are the most elevated sample points at 210.342m and location S04W1, S04W2, S04D1 and S04D2 had the minimum elevation of 164.200m. More than 65% of the surface water bodies recorded a proportion of forest cover as 0% representing the minimum proportion while the maximum proportion of 22.45% was recorded at locations S02W1, S02W2, S02D1 and S02D2. With respect to Built-up in the study area, the minimum proportion of 8.84% was found at locations S02W1 S02W2 S02D1 S02D2 and a maximum proportion of 68.880% at S10W1, S10W2, S10D1 and S10D2. Locations S10W1, S10W2, S10D1 and S10D2 recorded the maximum proportion (83.110%) of cultivated land area.

Similarly, S09W1, S09W2, S09D1 and S09D2 recorded the minimum (0.269%) cultivated land areas in the study area. S10W1, S10W2, S10D1, and S10D2, had the least NDVI of 0.238. The sampling location with the maximum NDVI (0.332) was found at locations S02W1, S02W2, S02D1 and S02D2. The proportions of forest cover, built-up, cultivated land and NDVI were determined at a maximum buffer of 300m around sampling points. However, the total portions of forest cover, built-up and cultivated land in the whole study area was approximately 11.044% 16.231% and 70.058% respectively.

Table 6: *Descriptive Statistics of All Season Sampling and Environmental Variables*

| Parameter | Mean | Std. Deviation | Skewness | Kurtosis | Minimum | Maximum |
|---|---|---|---|---|---|---|
| pH | 6.582 | 0.572 | -0.517 | 1.064 | 4.450 | 7.890 |
| Cond. (µS/cm) | 118.361 | 79.308 | 2.426 | 7.111 | 24.000 | 443.000 |
| Alk. (mg/L) | 75.800 | 63.783 | 1.304 | 0.459 | 10.000 | 246.000 |
| Turb. (NTU) | 125.238 | 203.443 | 2.357 | 4.060 | 4.000 | 753.000 |
| TDS (mg/L) | 77.979 | 49.682 | 2.057 | 5.150 | 16.000 | 270.000 |
| TSS (mg/L) | 99.811 | 162.342 | 2.453 | 4.687 | 1.000 | 625.000 |
| DO (mg/L) | 3.600 | 3.561 | 0.134 | -1.866 | 0.040 | 8.750 |
| BOD (mg/L) | 26.401 | 23.238 | 0.366 | -1.616 | 2.660 | 64.900 |
| TH (mg/L) | 72.161 | 85.888 | 4.181 | 18.430 | 8.000 | 503.000 |
| TrC (mg/L Pt.co) | 255.161 | 370.633 | 3.482 | 14.125 | 1.000 | 2003.000 |
| ApC (mg/L Pt.co) | 1495.461 | 2184.070 | 2.711 | 6.877 | 48.000 | 9902.000 |
| $Cl^-$ (mg/L) | 7.482 | 3.940 | 1.279 | 1.724 | 1.900 | 21.200 |
| Nitrate (mg/L) | 2.548 | 1.237 | 0.257 | -0.501 | 0.280 | 6.020 |
| Sulphate (mg/L) | 23.859 | 38.935 | 2.435 | 5.868 | 0.010 | 181.000 |
| Na (mg/L) | 11.883 | 12.553 | 4.778 | 22.764 | 1.300 | 79.500 |
| Ca (mg/L) | 116.388 | 102.085 | 0.311 | -1.499 | 0.010 | 312.450 |
| Mg (mg/L) | 5.074 | 4.025 | 0.043 | -1.340 | 0.010 | 13.000 |
| K (mg/L) | 5.149 | 3.388 | 1.813 | 3.291 | 0.680 | 18.000 |
| T. Phos. (mg/L) | 1.539 | 1.494 | 1.184 | 0.954 | 0.100 | 7.650 |
| T. Col. (cfu/100ml) | 122.922 | 265.192 | 4.939 | 28.899 | 1.000 | 1999.000 |
| F.Col. (cfu/100ml) | 20.272 | 20.949 | 1.035 | 0.660 | 0.000 | 83.000 |
| As (mg/L) | 0.084 | 0.091 | 1.196 | 0.635 | 0.001 | 0.367 |
| Fe (mg/L) | 1.240 | 1.229 | 1.370 | 1.444 | 0.020 | 4.987 |
| Mn (mg/L) | 0.225 | 0.266 | 1.051 | 0.305 | 0.001 | 0.992 |
| Cu (mg/L) | 0.993 | 1.296 | 1.038 | -0.364 | 0.002 | 4.230 |
| Cr (mg/L) | 0.475 | 0.741 | 2.128 | 5.353 | 0.002 | 3.800 |
| Pb (mg/L) | 0.053 | 0.172 | 3.985 | 15.379 | 0.002 | 0.945 |
| Ni (mg/L) | 0.131 | 0.345 | 4.203 | 20.114 | 0.002 | 2.300 |
| Zn (mg/L) | 0.121 | 0.139 | 2.062 | 3.359 | 0.010 | 0.600 |
| Hg (mg/L) | 0.002 | 0.000 | . | . | 0.002 | 0.002 |
| Cd (mg/L) | 0.002 | 0.000 | . | . | 0.002 | 0.002 |
| Elevation (m) | 189.075 | 14.697 | -0.052 | -1.377 | 164.200 | 210.342 |
| Forest cover | 1.140 | 3.650 | 4.770 | 23.906 | 0.000 | 22.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| (%) | | | | | | |
| Built-up (%) | 30.179 | 16.752 | 0.624 | -0.174 | 0.000 | 68.880 |
| Cultivated land (%) | 44.150 | 19.673 | -0.585 | 0.016 | 0.000 | 83.110 |
| NDVI | 0.298 | 0.027 | -1.385 | 1.478 | 0.210 | 0.330 |

The variability of the concentrations of the water quality parameters in the sampled surface water bodies can be seen as box and whisker plots in the figures 3, 4, 5, 6, 7 and 8. The top and bottom edges of the box indicate the 75th and 25th percentiles, respectively. The horizontal lines inside each box show the median for that parameter. The horizontal lines which in most cases lie beyond the boxes represent the maximum and minimum values. The whiskers extend to the most extreme data points that are not considered outliers, and the outliers are plotted individually using the '•' symbol.

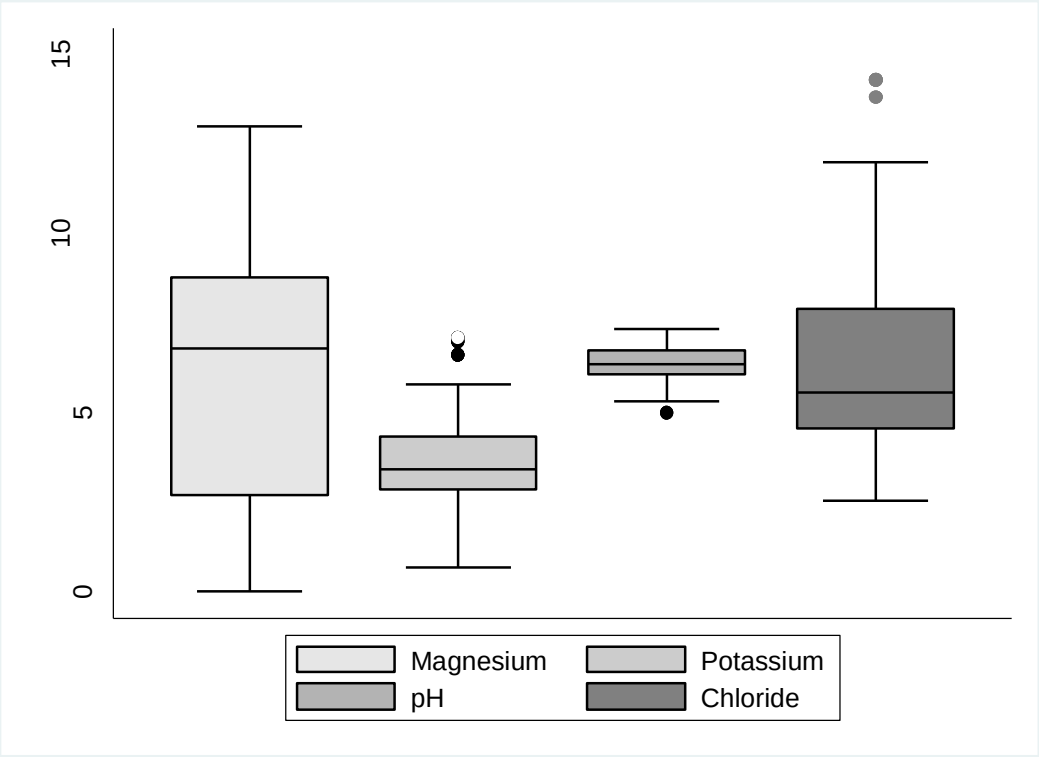


*Figure 4*: Box and Whisker plot of water quality indicators (Mg, K, pH, Cl)

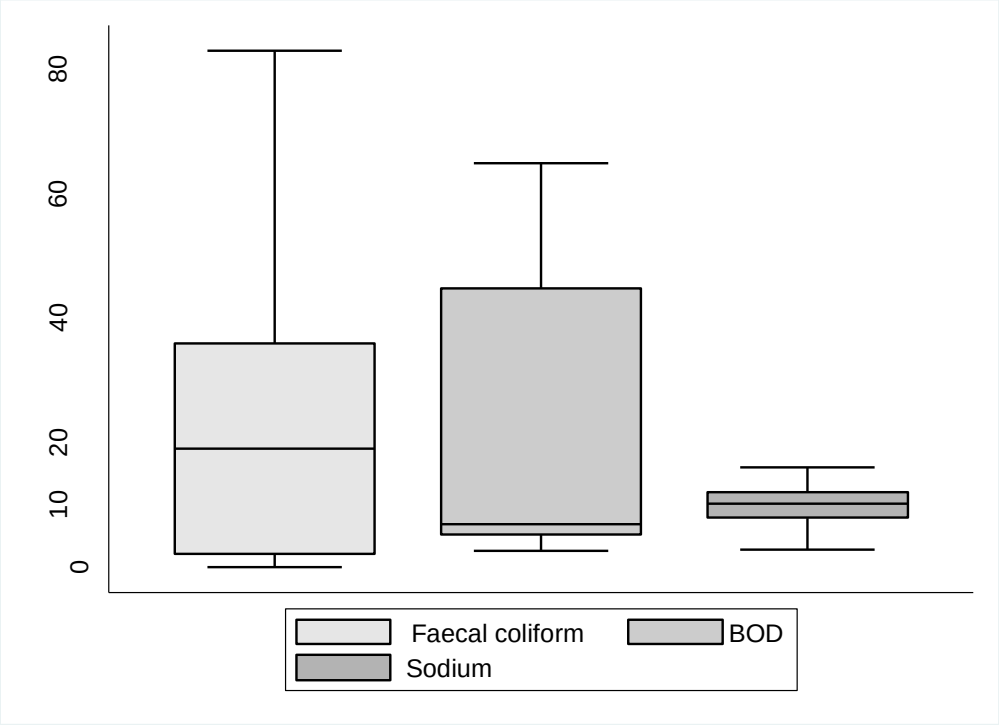


*Figure 5*: Box and Whisker plot of water quality indicators (Faecal coliform, BOD, Na)

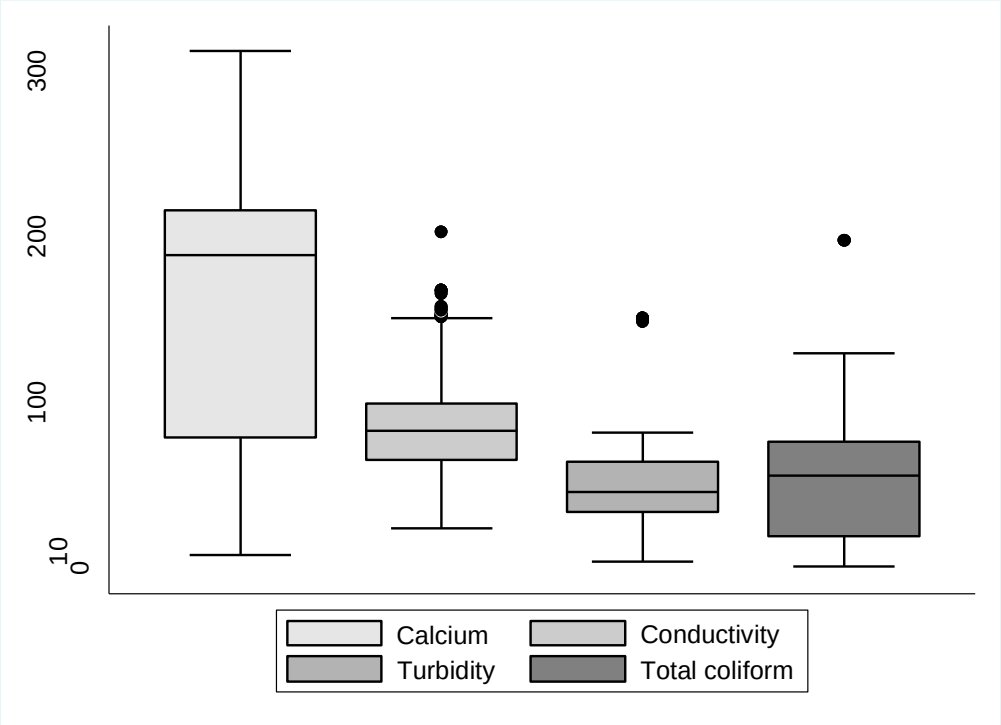


*Figure 6*: Box and whisker plots of water quality indicators (Ca, conductivity, turbidity, total coliform)

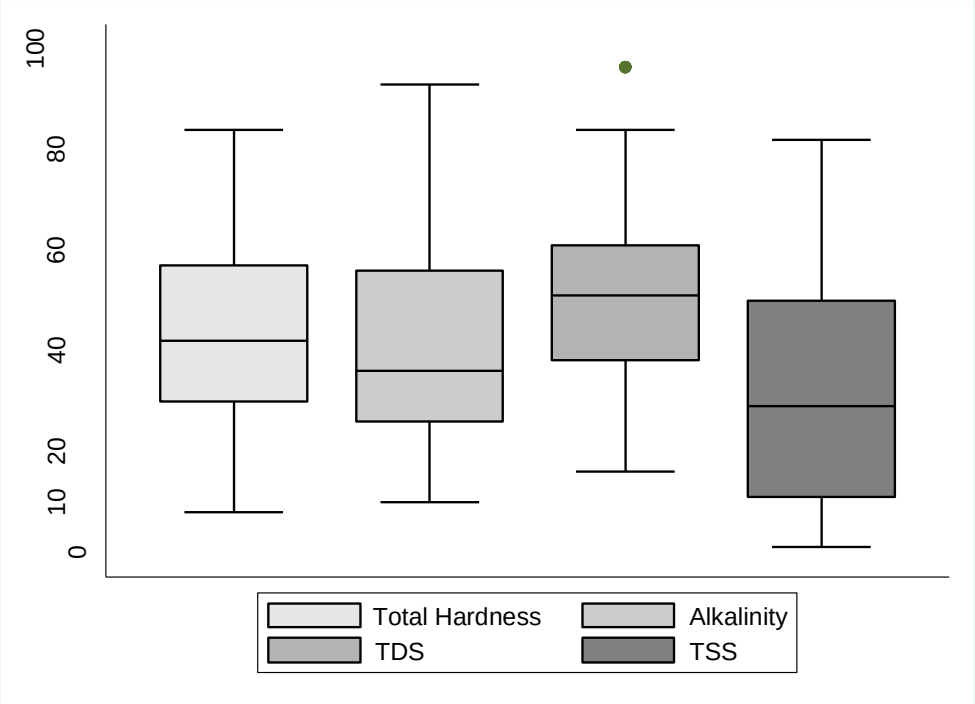


*Figure 7*: Box and whisker plots of water quality indicators (total hardness, alkalinity, TDS, TSS)

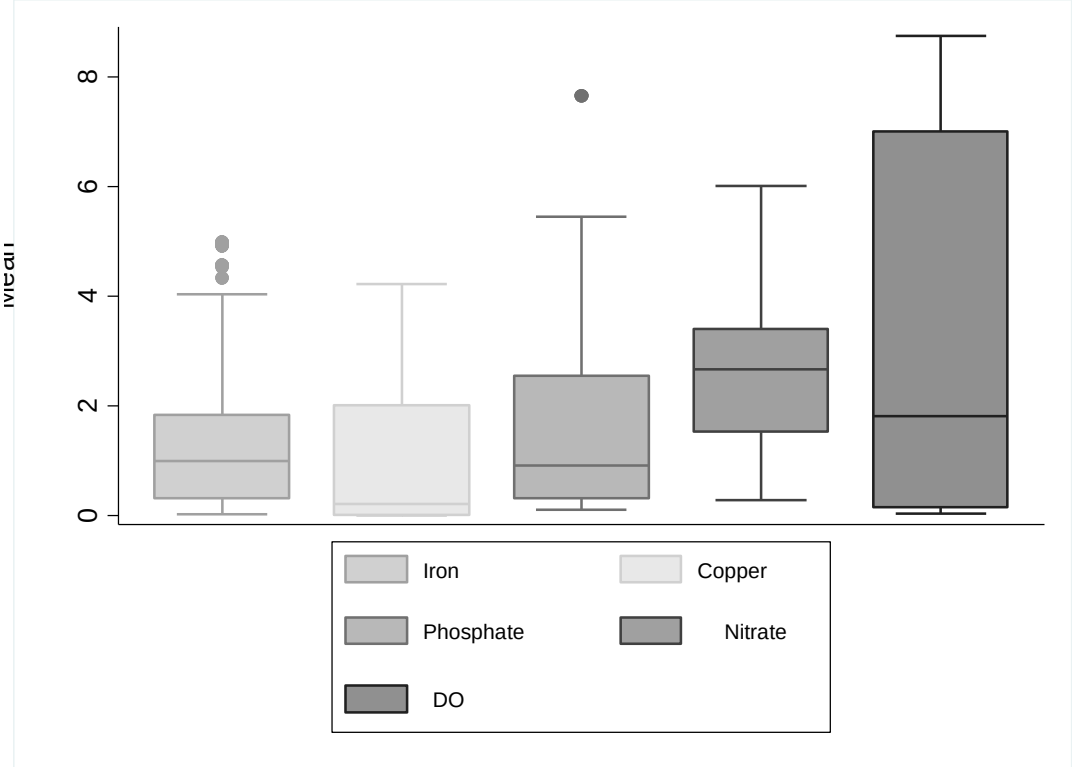


*Figure 8*: Box and whisker plots of water quality indicators (Fe, Cu, $SO_4^{-2}$, $NO_2$, DO)

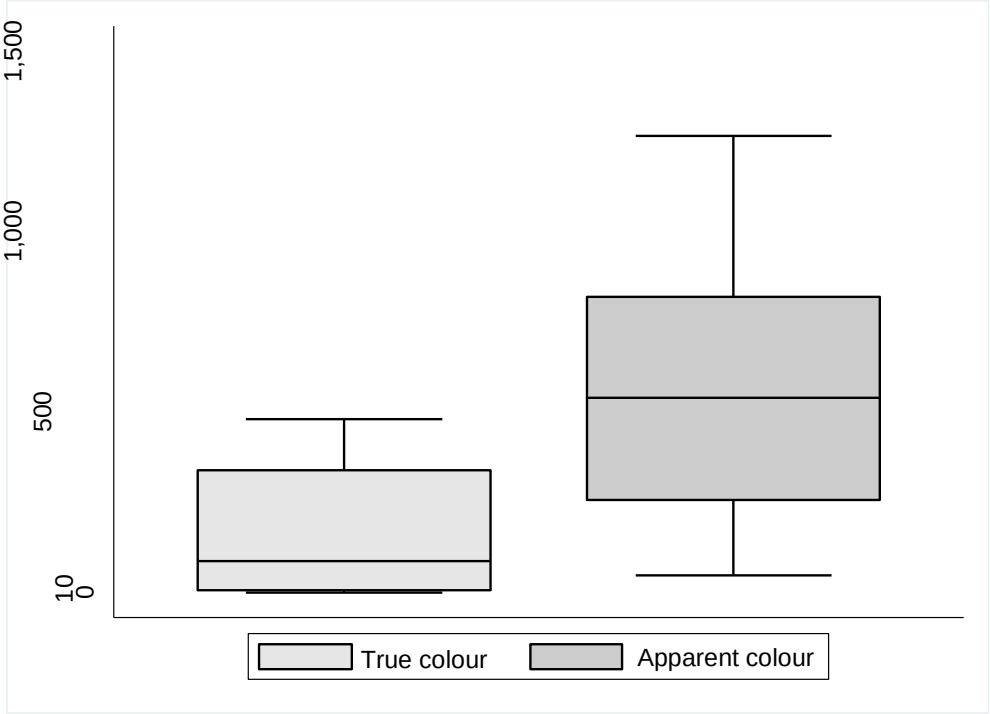


*Figure 9*: Box and whisker plots of water quality indicators (true colour, apparent colour)

**Pearson's Product Moment Correlation**

Surface water quality parameters were subjected to a Pearson correlation analysis to study the association, strength (effect size) and statistical significance between the independent surface water indicators.

The calculation of a correlation coefficient, *r* helps inform the strength of association between two random variables (Armah et al., 2012). The correlation coefficient *r* ranges between -1 and 1, where a value closer to 1 signifies a strong positive correlation between x and y, both values increase or decrease together. A value closer to -1 means a strong negative association and thus, the value of *y*

decreases as *x* increases. A coefficient, *r* closer to zero means the poorer the interrelationship. For effect size between variables, a correlation value of 0.1 means a weak association, 0.3 means a medium association and 0.5 means a high or strong association between the two variables.

Pearson correlation coefficients among selected surface water parameters revealed varied effect sizes from weak to strong, as well as significant associations (Table 7). The sources and pathways of species in surface water bodies could be traced through the inter-parameter relationships. Strong statistically significant correlations (0.5 and above) are in bold face from Table 6.

From Table 7, pH shows a strongly positive correlation with conductivity, alkalinity and TDS, hence, an increase in the surface water pH will cause an increase in the levels of the three parameters. Conductivity also showed a strong positive correlation with alkalinity, turbidity, and sodium, with coefficient, *r* above 0.7. Alkalinity showed significant correlations between several indicators including turbidity, TDS, TSS, BOD, total hardness, apparent colour, chloride, sulphate, Na, and calcium. Whereas all the parameters had a significantly (*r*= 0.611, 0.672, 0.545, 0.637, 0.531, 0.540, 0.627, 0.697, 0.515, respectively) large positive correlation (*r* above 0.5), DO and calcium revealed a significant negative correlation with alkalinity.

TSS, total hardness, true and apparent colour, sulphate and nickel, all showed significantly strong positive correlations with turbidity. TDS also exhibited a strong positive correlation with sodium. There existed a strong

positive association between TSS and total hardness, true and apparent colour, sulphate and nickel. A significantly strong negative association was observed between DO and four parameters (BOD, chloride, copper, chromium) implying that an increase in DO levels in surface waters in the study areas cause a decrease in BOD, copper, chromium and chloride levels of the waters. Nonetheless, a significantly strong positive association was observed between DO and calcium, magnesium, total phosphate, arsenic, iron and manganese ($r$= 0.956, 0.696, 0.689, 0.658, 0.635, 0.840, respectively).

BOD correlated strongly with chloride, sulphate, copper, and chromium positively while a strongly negative correlation is observed with calcium and magnesium, total phosphate, arsenic, iron, and manganese. True and apparent colour, sulpate and nickel revealed a strong positive correlation with total hardness. True colour also revealed a strong positive correlation with apparent colour, sulphate and nickel. A strong positive relation was observed between apparent colour and sulphate and nickel (coefficient, $r$ above 0.5). Whereas a strong negative correlation was observed between chloride and two parameters (calcium and manganese), a strong positive association was revealed between chloride and sulphate, copper, chromium and nickel.

Sulphate correlated negatively with calcium and positively with nickel. However, all showed strong correlations with sulphate. Calcium correlated strongly with magnesium, total phosphate, faecal coliform, arsenic, iron, manganese, copper and chromium. Similarly, total phosphate indicated strong associations with arsenic, iron, manganese and copper. Magnesium correlated

strongly with manganese and copper. A strong correlation is equally observed between arsenic and manganese, as well as between iron and manganese. Manganese revealed a strong negative correlation with copper and chromium. Copper correlated strongly with chromium.

Table 7: *Correlation Coefficients Matrix*

| | pH | Cond. | Alk. | Turb | TDS | TSS | DO | BOD | TH | TrC | ApC | Cl- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | **0.614** | **0.691** | 0.447 | **0.626** | 0.416 | -0.350 | 0.419 | 0.395 | 0.265 | 0.404 | 0.448 |
| Cond. | | 1 | **0.741** | 0.198 | **0.902** | 0.163 | -0.264 | 0.385 | 0.260 | 0.151 | 0.145 | 0.332 |
| Alk. | | | 1 | **0.611** | **0.672** | **0.545** | **-0.583** | **0.637** | **0.531** | 0.333 | **0.540** | **0.627** |
| Turb. | | | | 1 | 0.140 | **0.986** | -0.396 | 0.365 | **0.719** | **0.647** | **0.949** | 0.496 |
| TDS | | | | | 1 | 0.095 | -0.171 | 0.275 | 0.197 | 0.101 | 0.079 | 0.287 |
| TSS | | | | | | 1 | -0.319 | 0.304 | **0.726** | **0.687** | **0.961** | 0.410 |
| DO | | | | | | | 1 | **-0.889** | -0.212 | 0.066 | -0.288 | **-0.648** |
| BOD | | | | | | | | 1 | 0.309 | 0.043 | 0.259 | **0.534** |
| TH | | | | | | | | | 1 | **0.867** | **0.648** | 0.381 |
| TrC. | | | | | | | | | | 1 | **0.607** | 0.064 |
| ApC | | | | | | | | | | | 1 | 0.448 |
| Cl- | | | | | | | | | | | | 1 |

Table 7, continued.

| | NO3 | SO4 | Na | Ca2+ | Mg+ | K | PO4 | T. coli. | F. coli. | As | Iron | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 0.076 | 0.475 | 0.463 | -0.331 | 0.025 | 0.193 | -0.044 | -0.035 | -0.401 | -0.039 | -0.113 | -0.220 |
| Cond. | 0.032 | 0.313 | **0.797** | -0.244 | -0.059 | 0.199 | -0.106 | -0.104 | -0.333 | -0.162 | -0.200 | -0.142 |
| Alk. | -0.042 | **0.697** | **0.515** | **-0.570** | -0.228 | 0.128 | -0.307 | -0.064 | -0.484 | -0.298 | -0.365 | -0.470 |
| Turb. | -0.124 | **0.876** | 0.099 | -0.424 | -0.047 | 0.030 | -0.123 | -0.188 | -0.370 | -0.085 | -0.148 | -0.331 |
| TDS | 0.083 | 0.243 | **0.725** | -0.179 | -0.060 | 0.138 | -0.020 | -0.141 | -0.300 | 0.056 | -0.131 | -0.056 |
| TSS | -0.155 | **0.838** | 0.075 | -0.351 | 0.021 | 0.034 | -0.085 | -0.196 | -0.354 | -0.046 | -0.109 | -0.261 |
| DO | 0.014 | -0.491 | -0.197 | **0.956** | **0.696** | -0.386 | **0.689** | -0.222 | 0.499 | **0.658** | **0.635** | **0.840** |
| BOD | 0.095 | **0.505** | 0.274 | **-0.854** | **-0.618** | 0.402 | **-0.628** | 0.257 | -0.499 | **-0.658** | **-0.581** | **-0.760** |
| TH | -0.061 | **0.862** | 0.062 | -0.243 | 0.194 | 0.099 | 0.080 | -0.118 | -0.254 | -0.143 | 0.033 | -0.151 |
| TrC | -0.080 | **0.685** | 0.106 | 0.016 | 0.389 | -0.068 | 0.256 | -0.168 | -0.072 | 0.026 | 0.204 | -0.002 |
| ApC | -0.175 | **0.764** | 0.094 | -0.317 | 0.053 | -0.030 | -0.068 | -0.196 | -0.309 | 0.049 | -0.101 | -0.236 |
| Cl- | 0.121 | **0.584** | 0.179 | **-0.662** | -0.261 | 0.232 | -0.341 | -0.137 | -0.312 | -0.325 | -0.381 | **-0.555** |
| NO3 | 1 | -0.069 | 0.132 | 0.026 | -0.009 | 0.257 | 0.125 | -0.077 | 0.007 | -0.115 | 0.142 | -0.050 |
| SO4 | | 1 | 0.159 | **-0.517** | -0.104 | 0.114 | -0.173 | -0.047 | -0.430 | -0.275 | -0.176 | -0.412 |
| Na | | | 1 | -0.173 | -0.063 | 0.170 | -0.150 | -0.094 | -0.198 | -0.160 | -0.143 | -0.152 |
| Ca2+ | | | | 1 | **0.675** | -0.411 | **0.627** | -0.182 | **0.520** | **0.613** | **0.570** | **0.837** |
| Mg+ | | | | | 1 | -0.298 | 0.491 | -0.236 | 0.217 | 0.435 | 0.470 | **0.522** |
| K | | | | | | 1 | -0.304 | -0.177 | -0.433 | -0.322 | -0.249 | -0.320 |
| PO4 | | | | | | | 1 | -0.193 | 0.407 | **0.599** | **0.623** | **0.631** |
| T. Col | | | | | | | | 1 | 0.091 | -0.225 | -0.214 | -0.204 |
| F. Col | | | | | | | | | 1 | 0.326 | 0.284 | 0.456 |
| As | | | | | | | | | | 1 | 0.430 | **0.673** |
| Iron | | | | | | | | | | | 1 | **0.652** |
| Mn | | | | | | | | | | | | 1 |

| | Cu | Cr | Pb | Ni | Zn |
|---|---|---|---|---|---|
| pH | 0.258 | 0.198 | -0.055 | 0.398 | 0.350 |
| Cond. | 0.146 | 0.143 | -0.098 | 0.203 | 0.113 |
| Alk. | 0.399 | 0.323 | -0.127 | 0.453 | 0.369 |
| Turb. | 0.322 | 0.273 | -0.128 | **0.679** | 0.153 |
| TDS | 0.059 | 0.070 | 0.116 | 0.157 | 0.088 |
| TSS | 0.273 | 0.245 | -0.152 | **0.663** | 0.118 |
| DO | **-0.741** | **-0.606** | 0.198 | -0.360 | -0.411 |
| BOD | **0.737** | **0.570** | -0.261 | 0.396 | 0.307 |
| TH | 0.128 | 0.242 | -0.082 | **0.856** | -0.060 |
| TrC | -0.072 | 0.097 | -0.118 | **0.709** | -0.175 |
| ApC | 0.264 | 0.234 | -0.143 | **0.569** | 0.136 |
| Cl- | **0.621** | **0.600** | -0.139 | **0.513** | 0.321 |
| NO3 | 0.331 | 0.251 | 0.198 | 0.053 | -0.004 |
| SO4 | 0.368 | 0.334 | -0.156 | **0.810** | 0.162 |
| Na | 0.097 | 0.095 | -0.057 | 0.047 | -0.021 |
| Ca2+ | **-0.712** | **-0.595** | 0.277 | -0.382 | -0.379 |
| Mg+ | **-0.518** | -0.381 | -0.024 | 0.117 | -0.160 |
| K | 0.311 | 0.264 | -0.232 | 0.139 | 0.100 |
| PO4 | **-0.536** | -0.408 | 0.272 | -0.063 | -0.342 |
| T. Col. | 0.188 | 0.182 | -0.103 | -0.062 | -0.057 |
| F. Col. | -0.382 | -0.132 | 0.349 | -0.321 | -0.334 |
| Ar | -0.490 | -0.437 | 0.312 | -0.250 | -0.191 |
| Iron | -0.481 | -0.378 | 0.155 | -0.074 | -0.295 |
| Mn | **-0.629** | **-0.520** | 0.434 | -0.302 | -0.332 |
| Cu | 1 | **0.833** | -0.212 | 0.323 | 0.416 |
| Cr | | 1 | -0.180 | 0.381 | 0.173 |
| Pb | | | 1 | -0.105 | -0.069 |
| Ni | | | | 1 | 0.033 |
| Zn | | | | | 1 |

## Multivariate Analysis

### Principal Component Analysis (PCA)

The data were subjected or screened for their appropriateness for a principal component analysis and interpretation through correlation, Kaiser-Meyer-Olkin (KMO) and Bartlett's test and anti-image matrices.

After the first iteration, two parameters (cadmium and mercury) were removed from the analysis, as there was no variability among the observations. Principal component analysis requires that there must be correlations greater than 0.30 between the variables included in the analysis. The correlation matrix (Table 7) showed that most of the variables had correlations greater than 0.30, hence satisfying this rule.

The second execution of the data, the overall Kaiser-Meyer-Olkin Measure of Sampling Adequacy (MSA) for the set of variables included in the analysis was 0.714. This value exceeds the minimum requirement of 0.50 for overall MSA, signifying the suitability of the dataset for PCA and interpretation. Additionally, PCA analysis requires that the MSA be greater than 0.50 for each individual variables as well as the set of variables. Almost all of the individual variables included in the analysis (except nitrate, total coliform, lead and zinc) was greater than 0.50 (Appendix C), supporting their retention in the analysis.

Table 8: *KMO and Bartlett's Test*

| KMO and Bartlett's Test | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | 0.714 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 7290.542 |
| | df | 406 |
| | Sig. | **0.000** |

The probability associated with the Bartlett test is <0.001. This probability association therefore rejects the null hypothesis of the Bartlett's test which assumes that the correlation matrix is an identity matrix (there is no scope for dimensionality reduction). The significance level in the Bartlett's test ($p<0.001$) hence indicates that there are significant associations among the parameters. The data satisfies the requirement that the probability associated with Bartlett's Test of Sphericity be less than the level of significance. PCA was carried out using Varimax rotation with Kaiser Normalization.

Displayed in Table 9 are the initial Eigenvalues (total, percentage of variance, and cumulative percentage), extracted Eigenvalues (total, percentage of variance, and cumulative percentage), and the rotation sums of square loadings (total, percentage of variance, and cumulative percentage), of the components. Figure 10 is the equivalent scree plot showing the Eigenvalues sorted from large to small as a function of the principal components number. The scree plot of components Eigenvalues reveals that six components had Eigenvalues greater than one and hence account for the most variations in the dataset.

From Table 9, six principal components had Eigenvalues greater than 1 and thereby are extracted by PCA as significant components for interpretation and further analysis. Components with Eigenvalues less than one were considered insignificant and therefore omitted from further analysis. These components account for most of the variations in the data. Table 9 informs that nearly 78.172% of total variance in the surface water quality is explained by the first six principal components with variable loadings spread over the PCs.

Table 9: *Total Variance in the Data Explained By the Main Components*

| Total Variance Explained | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 10.243 | 35.320 | 35.320 | 10.243 | 35.320 | 35.320 | 7.460 | 25.725 | 25.725 |
| 2 | 5.101 | 17.590 | 52.909 | 5.101 | 17.590 | 52.909 | 6.476 | 22.332 | 48.057 |
| 3 | 2.957 | 10.195 | 63.105 | 2.957 | 10.195 | 63.105 | 3.767 | 12.988 | 61.046 |
| 4 | 1.622 | 5.593 | 68.697 | 1.622 | 5.593 | 68.697 | 1.710 | 5.895 | 66.941 |
| 5 | 1.400 | 4.829 | 73.526 | 1.400 | 4.829 | 73.526 | 1.682 | 5.801 | 72.742 |
| 6 | 1.347 | 4.646 | 78.172 | 1.347 | 4.646 | 78.172 | 1.575 | 5.430 | 78.172 |
| 7 | 0.974 | 3.359 | 81.531 | | | | | | |
| 8 | 0.832 | 2.870 | 84.401 | | | | | | |
| 9 | 0.719 | 2.478 | 86.878 | | | | | | |
| 10 | 0.620 | 2.138 | 89.017 | | | | | | |
| 11 | 0.541 | 1.865 | 90.882 | | | | | | |
| 12 | 0.454 | 1.565 | 92.447 | | | | | | |
| 13 | 0.436 | 1.503 | 93.950 | | | | | | |
| 14 | 0.360 | 1.242 | 95.192 | | | | | | |
| 15 | 0.266 | 0.917 | 96.109 | | | | | | |
| 16 | 0.229 | 0.789 | 96.898 | | | | | | |
| 17 | 0.220 | 0.757 | 97.655 | | | | | | |
| 18 | 0.169 | 0.582 | 98.237 | | | | | | |
| 19 | 0.136 | 0.469 | 98.706 | | | | | | |
| 20 | 0.120 | 0.414 | 99.120 | | | | | | |
| 21 | 0.056 | 0.192 | 99.312 | | | | | | |
| 22 | 0.054 | 0.187 | 99.500 | | | | | | |
| 23 | 0.040 | 0.139 | 99.638 | | | | | | |
| 24 | 0.037 | 0.128 | 99.766 | | | | | | |

Table 9, continued.

| Total Variance Explained | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 25 | 0.026 | 0.09 | 99.856 | | | | | | |
| 26 | 0.015 | 0.053 | 99.91 | | | | | | |
| 27 | 0.015 | 0.051 | 99.96 | | | | | | |
| 28 | 0.009 | 0.03 | 99.99 | | | | | | |
| 29 | 0.003 | 0.01 | 100 | | | | | | |

Extraction Method: Principal Component Analysis.

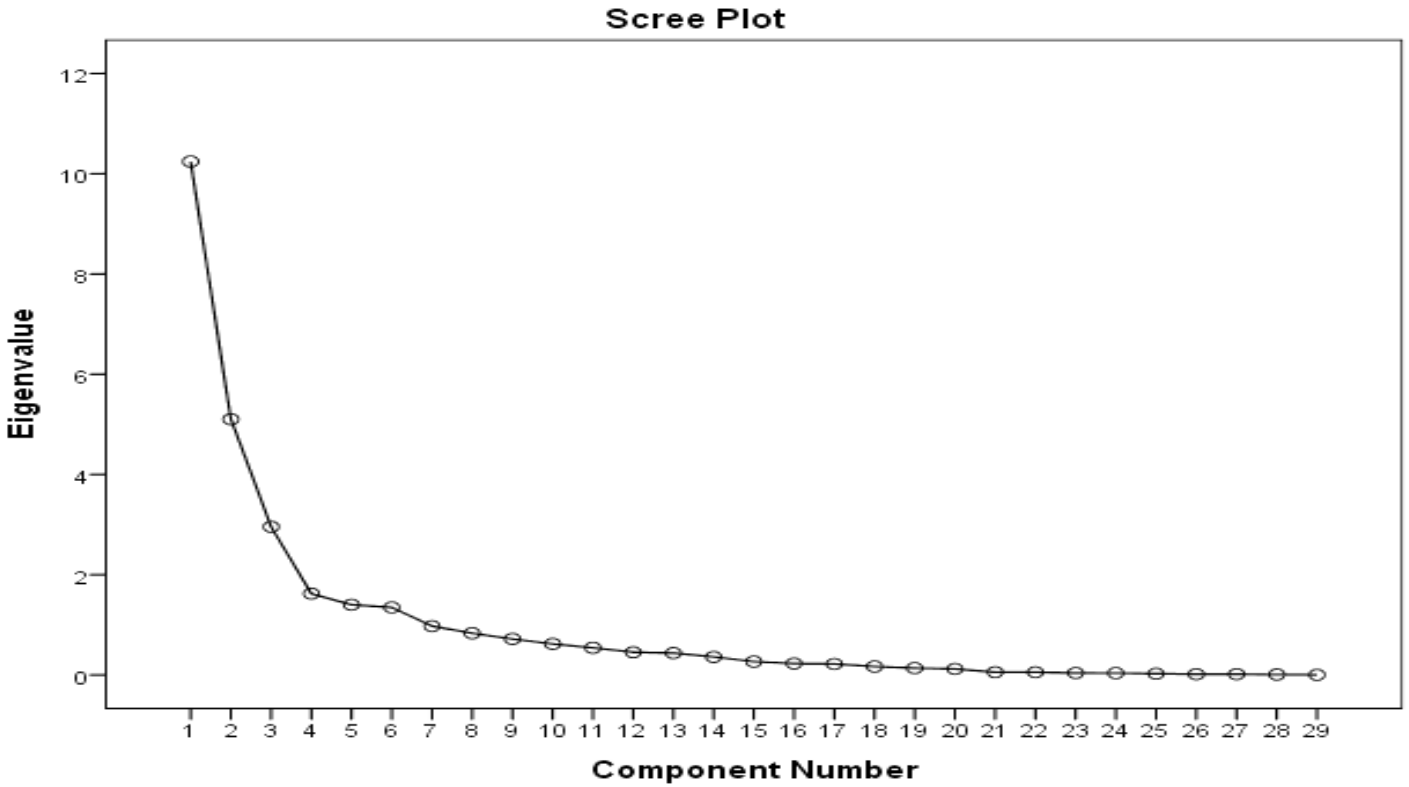


*Figure 10*: Scree plot of Eigenvalues fixed from large to small as a function of the principal component number.

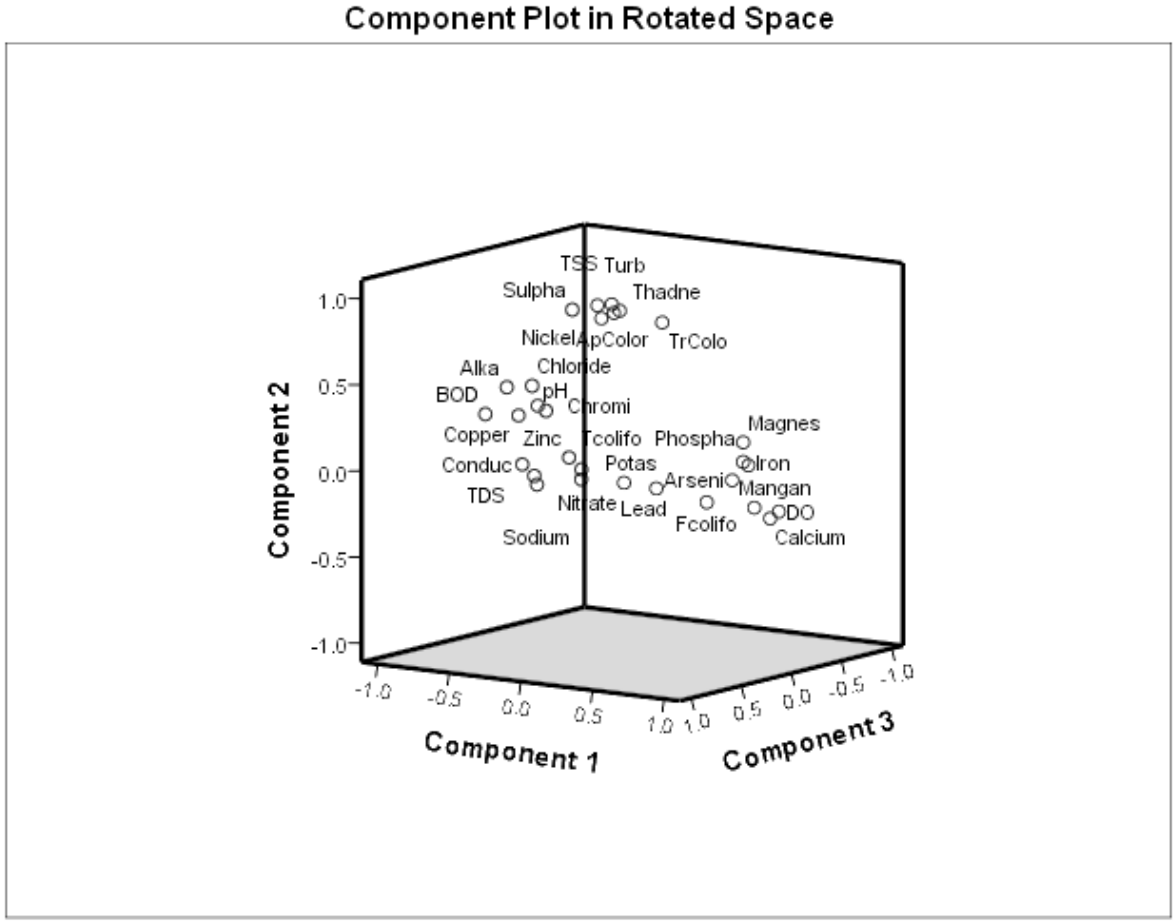


*Figure 11*: Loading plot of the variables from surface water data.

Figure 11, gives the relation between the variables in space; from which the six components can be contrasted.

The rotated component matrix (Table 10) reveals the factor loadings between the observed variables and the principal components.

The first principal component (PC1) had a strong positive loading on DO (0.916), calcium (0.870), manganese (0.822), magnesium (0.762), phosphate (0.759), and iron (0.727), arsenic (0.680) and a negative loading on BOD (-0.831) and copper (-0.791), explaining 25.725% of the total variance. PC2 loaded strongly on turbidity (0.905), TSS (0.913), total hardness (0.905), true colour (0.854), apparent colour (0.864), sulphate (0.887), and nickel (0.834) and explains an additional 22.332% of the total variance. Conductivity (0.945), TDS (0.948), and sodium (0.849), were strongly loaded on by PC3 and pH (0.657) showed a moderate loading and account for an additional 12.988% of the variance. PC4 accounted for an additional 5.895% of the variance and revealed a strong positive loading on lead (0.709) and a moderate negative loading on potassium (-0.617). Nitrate (0.871), was strongly loaded on by component five and the sixth component loaded moderately on total coliform (-0.590), and zinc (0.651).

Table 10: *Rotated Component Matrix of Surface Water Quality Parameters*

| | Component | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| pH | -0.142 | 0.381 | 0.657 | 0.022 | 0.071 | 0.256 |
| Cond. | -0.106 | 0.115 | 0.945 | -0.099 | 0.011 | -0.004 |
| Alk. | -0.407 | 0.493 | 0.669 | 0.005 | -0.086 | 0.184 |
| Turb. | -0.188 | 0.905 | 0.079 | 0.013 | -0.106 | 0.233 |
| TDS | -0.02 | 0.058 | 0.948 | 0.063 | 0.051 | 0.082 |
| TSS | -0.115 | 0.913 | 0.04 | -0.027 | -0.126 | 0.214 |
| DO | 0.916 | -0.214 | -0.154 | 0.109 | -0.027 | -0.108 |
| BOD | -0.831 | 0.238 | 0.278 | -0.178 | 0.097 | -0.045 |
| TH | 0.019 | 0.905 | 0.153 | -0.109 | 0.098 | -0.164 |
| TrC | 0.271 | 0.854 | 0.088 | -0.119 | 0.021 | -0.253 |
| ApC | -0.101 | 0.864 | 0.039 | 0.047 | -0.164 | 0.278 |
| $Cl^-$ | -0.546 | 0.423 | 0.219 | 0.063 | 0.261 | 0.291 |
| Nitrate | -0.01 | -0.108 | 0.069 | 0.05 | 0.871 | 0.014 |
| Sulphate | -0.284 | 0.887 | 0.192 | -0.067 | -0.006 | 0.028 |
| Na | -0.071 | -0.012 | 0.849 | -0.109 | 0.049 | -0.094 |
| Ca | 0.87 | -0.256 | -0.133 | 0.17 | -0.034 | -0.118 |
| Mg | 0.762 | 0.192 | -0.017 | -0.078 | -0.004 | -0.046 |
| K | -0.263 | -0.048 | 0.131 | -0.617 | 0.422 | 0.191 |
| T. Phos. | 0.759 | 0.078 | -0.021 | 0.267 | 0.167 | -0.097 |
| T. Col. | -0.417 | -0.152 | -0.087 | 0.205 | -0.214 | -0.59 |
| F. Col. | 0.335 | -0.235 | -0.263 | 0.553 | 0.046 | -0.361 |
| As | 0.68 | -0.038 | -0.025 | 0.385 | -0.128 | 0.256 |
| Fe | 0.727 | 0.04 | -0.12 | 0.063 | 0.211 | -0.075 |
| Mn | 0.822 | -0.185 | -0.043 | 0.297 | 0.004 | -0.017 |
| Cu | -0.791 | 0.195 | 0.004 | 0.016 | 0.39 | 0.146 |
| Cr | -0.661 | 0.263 | -0.001 | 0.082 | 0.446 | -0.1 |
| Pb | 0.206 | -0.121 | 0.055 | 0.709 | 0.203 | 0.101 |
| Ni | -0.155 | 0.834 | 0.085 | -0.113 | 0.228 | -0.122 |
| Zn | -0.393 | 0 | 0.068 | 0.035 | -0.065 | 0.651 |

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

**Non-Parametric Test of Association between Water Quality Index (WQI) and Season, River and Stream Clusters**

From Table 11, the quality of the surface water bodies systematically varies with season (dry and wet seasons). The null hypothesis of no difference in the surface water quality across season of sampling surface waters was rejected. Nonetheless, the quality of the surface water bodies does not systematically vary across the study river and stream clusters, hence the null hypothesis was failed to be rejected.

Table 11: *Non-parametric test of Association between surface water quality and Seasonal Variation and River Clusters*

Hypothesis Test Summary

| | Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|---|
| 1 | The quality of surface water is the same during the dry and wet season. | Independent-Samples t- test | **0.000** | Reject the null hypothesis. |
| 2 | The quality of surface water is the same across the river clusters. | Independent-Samples Kruskal-Wallis Test | 0.956 | Fail to reject the null hypothesis. |

Asymptotic significances are displayed. The significance level is 0.05.

**Ordinary Least Square Regression (OLS)**

Ordinary least square regression was operationalized to assess the effect of environmental factors on surface water quality in the study area. Water quality index was used as the dependent variable.

**Generation of Water Quality Index (WQI)**

In the assessment of environmental factors on surface water quality, a water quality index was generated using surface water quality data from the laboratory analysis of surface water samples.

Water quality index of the surface water samples was generated using eleven (11) of the studied water quality parameters (Table 12) based on theoretical relevance. The average inter item covariance was 848.3761 with scale reliability coefficient of 0.7421 between the variables indicating that the index satisfied the condition of reliability. The WQI was calculated using the equation;

$WQI = [\Sigma (qi.wi)/\Sigma wi]$…….(1) (Armah, et al., 2012)

Where *wi* is the unit weight, and $q_i$ is the water quality rating

Twenty seven water quality variables were employed in the generation of the water quality index. These variables are presented in Table 12. The average inter item covariance was 848.3761 with scale reliability coefficient of 0.7421 between the variables.

Table 12: *Selected Water Quality Parameters for WQI*

| Water quality variables | | | |
|---|---|---|---|
| pH | Conductivity | Alkalinity | Turbidity |
| TDS | TSS | BOD | Nitrate |
| Sulphate | Sodium | Magnesium | |

According to Armah et al. (2012), for a given water quality indicator, the more harmful it is, the lower its standard, and the unit weight ($W_I$) for the ith parameter ($P_I$) is assumed to be inversely proportional to its recommended guideline standard $S_i$ (i=1, 2, 3....n); where n is the number of parameters (11 in this study, i.e. pH, TDS, sulphate, conductivity TSS sodium alkalinity BOD magnesium turbidity and nitrate).

Except pH, unit weights for nitrate sulphate, turbidity, electrical conductivity, TDS, TSS, sodium, alkalinity, BOD and magnesium were calculated as the inverse of their guideline values (Best Applicable International Standards for surface water): 1/50, 1/250, 1/75, 1/1500, 1/1000, 1/50, 1/250, 1/150, 1/20, and 1/30 respectively.

Equation 2 shows the relationship between unit weights and the water quality standards

$wi = k/Si = 1/Si$.....(2) (Armah et al., 2012)

Where *wi* is the unit weight, S*i* is the water quality standard and k is the constant of proportionality which is equal to unity.

$qi$ =100(V$i$/S$i$) .....(3)

For pH, the quality rating $q$pH can be calculated from equation 4

$q$pH = 100[(VpH~ 7.0)/1.5].....(4)

Where $V$pH is the observed value of pH and the symbol "~" is essentially the algebraic difference between $V$pH and 7.0.

The higher the WQI the more polluted the surface water body. WQI < 100 implies that the water from the surface water is clean and fit for human consumption. Conversely, WQI > 100 implies that the water from the surface water body is polluted and deem unfit for human consumption without treatment (severely contaminated). Generally, WQI < 50 implies that it is fit for human consumption; WQI < 80 implies that is moderately contaminated; and 80< WQI < 100 implies that is excessively contaminated (Armah et al., 2012)

The correlation among predictor variables and WQI (Table 13) showed a strong negative correlation between WQI and season. Elevation equally correlated strongly with the River groups. Built-up showed a strong negative correlation between cultivated area and NDVI. Cultivated area correlated strongly with NDVI ($r$ = 0.878).

Due to multicollinearity between NDVI and other independent variables, it was excluded from the regression model. Table 14 shows the coefficient, robust standard errors, Beta and probability values associated with water quality index and predictor variables.

Table 13: *Correlation of Dependent Variable and Environmental Factors.*

| Variables | WQI | Elevation | Season | Forest | Built-up | Cultivated area | NDVI | River Group |
|---|---|---|---|---|---|---|---|---|
| WQI | 1.000 | | | | | | | |
| Elevation | -0.030 | 1.000 | | | | | | |
| Season | **-0.906** | 0.000 | 1.000 | | | | | |
| Forest | 0.059 | -0.161 | 0.000 | 1.000 | | | | |
| Built-up | -0.014 | 0.108 | 0.000 | -0.438 | 1.000 | | | |
| Cultivated area | 0.016 | 0.014 | 0.000 | 0.390 | **-0.953** | 1.000 | | |
| NDVI | 0.036 | -0.169 | 0.000 | 0.317 | **-0.906** | **0.878** | 1.000 | |
| River Group | -0.006 | **0.794** | 0.000 | -0.294 | 0.181 | -0.076 | -0.245 | 1.000 |

The R-squared value obtained for the model is 0.833 ($p<0.001$) signifying that about 83.3 % of the variance in the dependent variable, WQI, is accounted for by the environmental variables in the regression model. The independent variables therefore have a high predictive power. The standard error of the regression (Root MSE) is 0.410. From the model output (Table 14), change in season (dry to wet) is significantly associated with a change in the WQI ($p<0.001$). Similarly, change in elevation, forest, and location of surface water (river group) were significantly associated with a change in the WQI ($p<0.001$). The beta coefficient of the independent variables revealed intriguing results. Season of sampling had the greatest influence on WQI and hence, predicted the

dependent variable (WQI) most. The significant environmental variable that predicted WQI the least was buffer around the sampling points. The magnitude of environmental variables in increasing order of predicting WQI in the study area was as follows: Buffer < Cultivated area < Built-up < Forest < River location (River group) < Elevation < Season.

Season and Elevation were inversely related to WQI. This suggests that WQI was lower at higher altitudes and during the wet season. On the contrary, forest, buffer, built-up, cultivated land and River group were directly proportional to WQI. From the model output, the quality of the surface water bodies' decreases with increasing elevation. Hence, water bodies with higher elevation are of better quality as compared with those with lower elevation.

Similarly, the quality of the surface water bodies decreases in the wet season as compared to the dry season by approximately ninety percent (90%) ($p<0.001$, SE=0.036). Also, the results indicate that increase in forest cover gives a better WQI ($p<0.001$ SE=0.005). The surface water bodies found in the southern zone had better quality as compared to those in the Northern zone ($p<0.001$, SE=0.070).

Table 14: *Linear Regression Model Showing the Relationship between WQI and Environmental Variables*

| WQI | Coef. | Robust SE | P>t | Beta |
|---|---|---|---|---|
| Season (Ref. Dry season) | | | | |
| Wet season | -151.042 | 10.856 | **0.000** | -0.503 |
| Elevation | -2.817 | 0.572 | **0.000** | -0.276 |
| Forest | 8.748 | 1.701 | **0.000** | 0.213 |
| Scale (Ref. 100m) | | | | |
| 200m | 6.613 | 13.433 | 0.623 | 0.021 |
| 300m | 8.953 | 13.405 | 0.504 | 0.028 |
| Builtup | 1.519 | 1.229 | 0.217 | 0.169 |
| Cultivated area | 1.142 | 1.007 | 0.257 | 0.150 |
| River Cluster (Ref. Adofokrom/Amenam) | | | | |
| Nyafoman/Noyem | 32.471 | 15.431 | **0.036** | 0.102 |
| Akoase | 95.298 | 19.375 | **0.000** | 0.299 |

# CHAPTER FIVE

# DISCUSSION

This chapter discusses the results of the study which sought to assess surface water quality in the Birim North District of Ghana using spatial modeling. The study assessed two biological, twenty-three chemical and six physical indicators and their possible sources that account for variation in the quality of surface waters (rivers and streams) around the study area. The study also assessed the quality of river and stream clusters across the study area, and determined the influence of seasonal variation on rivers and streams quality in surface water-environment relationships. Furthermore, the study investigated the spatial scale(s) that best predict river and stream quality and modelled the relationship between water quality and environmental variables to find out the order and most important variable(s) that largely predicts surface water quality.

## Temporal Variation of Surface Water Quality Variables

Temporal disparities (seasonal variation) were observed in most of the water quality parameters in rivers and streams in the study area. For instance, pH, BOD, chloride, alkalinity, turbidity, TDS, TSS, electrical conductivity, sulphate, potassium, apparent colour, total coliform, copper, chromium, nickel, zinc had higher mean concentrations during the dry season while DO, total phosphate, faecal coliform, true colour, nitrate, calcium, magnesium, manganese, arsenic, iron, and lead had higher concentrations during the wet season. Mercury and cadmium showed no variation in the mean concentration of water samples with respect to season of sampling.

Pollutants with higher concentrations during the dry season and low concentrations during the wet season are thought to originate from point sources whose supply is constant and also as a result of dilution effect during the wet season on some water quality indicators while higher concentration of pollutants during the wet season and a low concentration during the dry season are seen to be influenced by non-point sources that are mobilized by high run-off during the wet seasons (Xia et al., 2002).

The mean pH value recorded during the wet season was 0.465 lower as compared to that recorded during the dry season. The low mean pH experienced during the wet season could be ascribed to the decomposition of organic materials, such as plant parts, resulting in the release of humic and fluvic acids into the water column as most of the surface waters traverse vegetated areas. Also, the stagnation of most of the sampled locations during the dry season especially S06D1 could have resulted in the depletion of the dissolved oxygen levels creating anaerobic conditions which could result in the release of hydrogen ions into the water column. The absence of flow could have resulted in low replenishment of the dissolved oxygen from atmospheric sources as there was no turbulence.

The mean electrical conductivity levels during the wet season were lower than the values recorded during the dry season. The low electrical conductivity is an indication of low levels of dissolved ions, especially sulphates, in the water bodies during the wet season. This could be as a result of dilution in the water

bodies by fresh water during the wet season. This influences TDS among other factors in surface waters, hence lower electrical conductivity as compared to the dry season. The measured mean alkalinity levels were higher in the dry season compared to the wet season. Generally, low alkalinity levels observed in surface waters could be due to very low levels of carbonate, bicarbonate and hydroxide-containing materials in the geologic formations of the area (Dladla, 2012; Haggarty, 2012). Nonetheless, alkalinity is important for aquatic life because it buffers against rapid pH changes. Higher alkalinity levels in surface waters will buffer acid rain and other acid wastes and prevent pH changes that are harmful to aquatic life (Armah, 2014). The low alkalinity levels during the wet season indicate that surface water bodies within the study area are poorly buffered during this period. The concentration of calcium and magnesium were low reflecting the low alkalinity and hence low buffering.

The mean turbidity level of surface water samples during the dry season was approximately three times higher than that recorded during the wet season sampling. Bathing, laundry and washing of tricycles and galamsey activities were done close to some river banks by people who live close to the rivers. These activities increase the turbidity of the water and are frequent because of water scarcity during the dry season. Dried hand dug wells limit the use of water to cooking and drinking only (Ogbozige & Alfa, 2018). Additionally, despite the absence of run-off during the dry season, domestic effluents still find their way into the surrounding rivers through drainage, which renders the water turbid.

The high turbidity values for surface water can mostly be attributed to the impact of artisanal gold mining activities (galamsey). The study area is inundated with farming and small scale gold mining activities and these could be a major cause of the high turbidity observed. The study area is equally very dusty due to the untarred surface of the road network, hence, as it rains, run-off from farming and small scale gold mining activities as well as the dusty road network are carried into the water bodies. These activities result in the dispersion of sediment within the water column which increases the amount of suspended particulates. This finding supports the work of Obiri et al. (2010), Armah et al. (2012) and Armah et al. (2011) who found higher turbidity levels in their respective studies on surface and groundwater quality and attributed the high levels to the effect of extensive small-scale mining activity which tends to muddy the waters in the study areas and the need to reduce the risk connected with humans drinking such water.

The mean concentration with respect to TDS, TSS, BOD, apparent colour and total hardness in surface water samples were higher in the dry season compared to the wet season. As discussed earlier, the road network of the study area is dusty coupled with small scale gold mining activities, and excessive atmospheric input of dust particles during the dry season will result in the deposition of large volumes of dust on land and in surface waters if the energy required to sustain the particles airborne dissipates.

Also, during the dry season, there is high abstraction of water from the streams and rivers to meet the large demanding needs as well as high evaporation rate of water molecule from the streams and rivers surface due to solar heating and low humidity. This leads to a decrease in the depth of the surface water bodies. Shallow depth and large surface area of water increase evaporation rate of the surface waters, resulting in increasing TDS content (Ogbozige & Alfa, 2018).

Dissolved and particulate materials in water can result in discoluoration. Apparent colour is caused by coloured particulates and the refraction and reflection of light on suspended particulates. Highly coloured water has significant effects on aquatic plants and algal growth. The higher BOD levels during the dry season are indicative of some extent of biodegradable organics pollution in the various water bodies during that period compared to the wet season. The TSS acts as adsorption sites for chemical and biological agents and instances where a bulk of the TSS is provided for by suspended organic solids, they may be degraded biologically, usually resulting in objectionable by-products which increase the hardness of the surface water body. The dusty nature of the roads and extensive activities of small scale gold mining seem to be the causal factors of the high TDS, TSS, BOD, apparent colour and total hardness in the surface water samples during the dry season.

The mean concentrations of DO, true colour, magnesium, calcium, total phosphate, faecal coliform, were higher in the wet season than in the dry season. Colour of surface water affects refraction and reflection of light on suspended

particulates. Light is very critical for the growth of aquatic plants and coloured water can limit the penetration of light. Thus, a higher true colour level of a water body may not be able to 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 almost totally block light penetration as well as use up the dissolved oxygen in the water body, causing eutrophic conditions that can drastically reduce all life in the water body.

The mean chloride concentration measured during the dry season was greater compared to the wet season. The presence of rocks in some of the surface water bodies which might have leached out chloride ions in the process of weathering and connection with flowing water as rock-water interactions result in mineral dissolution (Williams et al., 1997), and desorption which increase chloride ions concentration in surface waters influence this phenomenon. The use of inorganic fertilizers to enhance soil fertility by farmers might be another reason for the general presence of chlorides in the surface water bodies as plants are only able to absorb a fraction of the salt in irrigation water, hence resulting in saline soil which gets leached out through interflow and end up in the surface water bodies. Again, the observed findings could also be as a result of dilution effects. High dilution effect in the wet season and low in the dry season can increase the ion levels in the dry season and reduce it in the wet season through dilution with fresh water.

The higher coliform counts during the wet season and in the study area at large are not surprising as surface waters are naturally prone to contamination by microorganisms and humans through sources such as direct and indirect sewage disposal into water bodies; storm run-offs which may include rain, polluted run-off from roads and agricultural lands and also excreta from wild animals. The highest loads of coliforms were recorded around areas of small scale gold mining activities and visual evidence of human defecation was abundant. Thus, the main source of the coliforms in the sampled locations can be attributed to human defecation.

Arsenic, iron, manganese recorded higher mean concentrations during the wet season. The higher concentration of these elements during the wet season may mainly be geogenic accelerated by galamsey activities as well as for the higher mean concentrations recorded for copper, chromium, nickel and zinc during the dry season.

**Levels of Contaminants and Possible Sources into Surface Water Bodies (Rivers and Streams) in the Study Area**

Pearson's product moment correlation coefficients among selected water quality indicators showed a number of strong associations. A varied degree of associations and effect sizes ensued from very strong associations and effect sizes to moderate effect sizes while a few had no relationship at the $P<0.05$ and $P<0.001$ levels.

pH correlated strongly with conductivity, alkalinity, TDS, turbidity, TDS. Also, TSS, BOD, DO, total hardness, apparent colour, chloride, sulphate, and calcium showed a strong correlation. Similarly, TSS, total hardness, true and apparent colours, sulphate and nickel, all showed a significantly strong positive correlation with turbidity. Additionally, DO, calcium, magnesium, total phosphate, arsenic, manganese and iron correlated among each other.

Several studies have reported similar correlation effects among water quality indicators across the globe in surface and ground water bodies (Adelana, 2015; Armah et al, 2012; Attua, Ayamga, & Pabi, 2014) in assessing the quality of such water bodies.

Armah (2012) researched on water quality index in the Tarkwa gold mining area in Ghana and reported that the Pearson correlation coefficients revealed a number of strong associations among selected water properties such as strong correlation between turbidity and sulphates, as well as strong associations between pH and EC, TDS and sulphates.

Study carried out by Bortoletto et.al. (2015) in Brazil on “water quality monitoring of the Pirapó River watershed, Paraná, Brazil” showed that the majority of the water quality variables exhibited moderate to strong associations.

Multivariate statistical (principal component) analysis suggests that the data in this study is a six-component system that explains approximately 78% of the total variance in the data. This informs the possible sources of contaminants in

the surface water bodies and the interdependent relationship between the surface water indicators. The linkages showed among the water quality properties point the sources of pollutants to several anthropogenic and natural sources.

The first principal component (PC1) had a strong positive loading on DO, calcium, manganese, magnesium, phosphate, and iron and a negative loading on BOD and copper. It equally loaded moderately on arsenic. This factor is interpreted as "Agriculture". These indicators arise from anthropogenic activities like farming and natural processes (geology of the area). The relation observed between BOD and DO loading on PC1 is inversely proportional; hence, an increase in DO of the surface water bodies will result in a corresponding decrease in the BOD. Calcium and magnesium (micro nutrients) and phosphate (macro nutrients) can be traced to agricultural activities. Several farm lands are located up-hill along the banks of the studied water bodies (largely cocoa farms) and as chemical fertilizers are used by farmers to boost harvest on farm products, run-off from such non-point sources introduces these pollutants into the surface water bodies. The process of weathering and or agricultural run-off augment the ion exchange and oxidation-reduction conditions which cumulatively induce the nutrient solubility (Bohlke et al., 2007; Seiler et al., 2003; Giri et al., 2019). This finding confirms other works by Giri et al. (2019), Huang et al. (2013) and Attua et al. (2014) in Leh‑Ladakh (India), South China and Akyem-Abuakwa (Ghana) respectively. These studies reported nutrient loading in their respective study areas and attributed that to agricultural run-off or atmospheric deposition.

Similarly, this finding supports the works of Hoff (2013) who carried out a study to establish the source and degree of pollution in the Kranji Reservoir in Singapore. The findings from the study, which indicated high levels for nutrients and bacterial concentration in the downstream, is as a result of an intensive cropping vegetable production operation around the reservoir. Nyakungu et al., (2013) examined the impacts of human activities along Manyame River and its tributaries (Mukuvisi, Marimba, Ruwa and Nyatsime rivers) in Zimbabwe and equally established that the contamination of the river and its tributaries are as a result of agricultural activities among other sources. The moderate loading of As on PC1 could come from small scale mining activities as As has been known to impair surface water quality in artisanal gold mining areas of Ghana (Armah et al., 2010; Attua et al., 2014). In this current study, calcium and magnesium were found to strongly load on PC1 and hence support similar findings brought to the fore by van der Grift et al. (2016) who carried out a study titled "High-frequency monitoring reveals nutrient sources and transport processes in an agriculture-dominated lowland water system".

PC2 loaded strongly on turbidity, TSS, total hardness, true colour, apparent colour, sulphate, and nickel. These parameters cumulatively can be termed as "Small scale gold mining" related. This component largely describes the physical indicators of surface water quality signifying non-point pollution from anthropogenic activities such as artisanal gold mining activities, soluble rock salts as well as transport of sediment into rivers and streams through surface run-off in the study area. This findings confirm the study by Ochieng et al. (2010) on

impacts of mining on water resources in South Africa and several others. The inference of the analysis was that the pumping of untreated acid mine drainage into Wonderfonteinspruit and Klip River had negatively impaired the water quality in these rivers and hence the main source of pollutants into the surface water bodies. Other studies which reported mining activities as source of pollutants into surface water resources include Caruso et al. (2012) who investigated surface water quality in Georgia and reported pollution incidence on rivers downstream as a result of the impacts of mining in the Caucasus Mountains in Georgia.

Bharti et al. (2017) found that increase in total hardness concentration in surface water is due to the presence of higher levels of calcium and magnesium entering the water of which the findings of this study confirm as observed and discussed in PC1.

Conductivity, TDS, and sodium loaded strongly on PC3. This component explains the presence and contribution of inorganic ions in the water bodies that is temperature dependent. This component could be as a result of chemical weathering from rock-phosphates such as limestone which contributes chemicals to the water pH and the subsequent impact on water acidity, facilitated by temperature (Varol & Sen 2009).

PC4 revealed a strong positive loading on lead and a moderate negative loading on potassium. This component explains soil of the study area. Potassium

deposits in surface water found in this study is largely through run-off from cultivated fields.

Nitrate was strongly loaded on by the fifth principal component. This component could be organic matter input. This describes organic matter decomposing to release Nitrogen and Carbon. Nitrates are reported as significant components of agricultural fertilizer and serves as a major contribution in water environments from diffuse sources of pollution as opposed to point sources of pollution (EEA, 2010), however, this is not the case in this current study because it didn't load on PC1 which is agriculturally-related through nutrients. Vitousek et al. (1997) asserted that the other forms of nitrogen entering surface waters are from atmospheric deposition, nitrogen fixation and terrestrial inputs.

The sixth component loaded moderately on total coliform and zinc. The total coliform recorded is from sources such as direct and indirect sewage disposal into water bodies; storm run-offs which may include rain, polluted run-off from roads and agricultural lands and also excreta from wild animals. Visual evidence of human defecation was abundant during the study period. Accordingly, the main source of the coliforms in the surface water bodies can be attributed to human defecation.

Again, the application of chemical fertilizers by farmers as well as burning of farm lands which produce ashes could also introduce zinc into the surface waters through run-off as some of these chemical fertilizers and ashes contain zinc (Niemi & Raateland, 2007).

These findings are similar to the works done by Attua et al. (2014) who researched into water quality analysis of rivers used as drinking sources in artisanal gold mining communities of the Akyem-Abuakwa area in the Eastern Region of Ghana. The researchers reported that the principal component analysis identified five PC with eigenvalues above one and explained over 80% of the variability in water quality. The study equally revealed that, small scale gold mining accounted for more than 26 percent of the variability, with arsenic and mercury as the primary contaminants in the area. Other sources of contamination found in the study included agricultural activities, domestic waste disposal and other natural influence while in this current study agriculture, mining, geology of the area (soluble rocks)/soil and sewage are the major sources of the pollutants.

**Surface Water Quality across Sample Locations (Rivers and Streams Clusters)**

The quality of the surface water bodies does not systematically vary across the study rivers clusters as found in this current study. Based on the clustering considered, the Akoase cluster is of better quality compared to the Adofokrom/Amenam, and Nyafoman/Noyem clusters. The difference in quality could be attributed to the differences in distances of the various land use types to the water bodies. As already established in literature, the closer the land use type to a surface water catchment, the greater their ability to impair the quality of the water (Varanka, 2016).

Again, as established in this study, forest cover around rivers and streams catchment helps give better quality to the water. The Akoase cluster in comparison to the other two clusters had a better forest cover around the sampled waters within the 300m buffer. This could probably account for the difference in quality. Also, there are more extensive anthropogenic activities ongoing in the Adofokrom/Amenam cluster such as galamsey activities around the banks of the rivers especially sampled locations S10D1, S10W1.

Allan (2004) in his study asserted that topography and landscape factors influence several processes in surface water catchments including physical properties, flow dynamics and the content of surface water over time. However, the topography of these rivers and streams (elevation, geologic formation of rivers and streams basin) statistically vary from each other while other rivers had rocky basins through which water flows. This gives credence to the fact that the chemistry of the natural waters is linked to the reaction of these waters with sediments or rocks through which they flow. This further explains the observed relation in the studied surface waters in cluster. Surface water bodies with higher elevations are not easily polluted by run-off.

**Seasonal Influence on Surface Water Quality**

Seasonal variation in surface water quality was assessed. Surface water quality was found to systematically vary with season (dry and wet seasons). The quality of the water was better in the dry season as compared to the wet season. It is extensively proven that seasonal variability in surface water quality is the result

of interactions between many processes caused by variations in climate (Araoye, 2009). During the dry season, run-off of contaminants into surface waters is less as compared to the wet season.

Run-off into surface water bodies is observed when infiltration is limited by low soil permeability or its saturation causing water to flow over the landscape surfaces increasing discharge in the receiving surface water bodies during the wet season (Winter 2001; Dosskey et al. 2010). As surface runoff cause soil erosion and the delivery of eroded sediments and contaminants into surface water ecosystems, it influences their quality (Bechmann, 2014). The degrees of surface runoff and discharge are dependent on the proportion of precipitation and evapotranspiration (Winter 2001), which the former is greater in the wet season than in the dry season and vice versa.

Additionally, the environmental parameters considered in evaluating the quality of surface water in the study area have greater influence in the wet season as compared to the dry season. The proportions of these environmental variables are different hence those known to influence surface water quality are greater during the dry season.

Pratt & Chang (2012) in their study on effects of land cover, topography, and built structure on seasonal water quality at multiple spatial scales asserted that most wet season water quality parameters are associated with urban land covers while most dry season water quality parameters are related to topographic features such as elevation and slope. This therefore suggests that, the proportions of urban

land cover and topographic features such as elevation and slope had a greater influence in the surface water quality as evidenced by the findings in this study.

This finding confirms the works of Carroll et al. (2013), and Gonzales-Inca et al. (2015) in their respective works in which both reported poor quality of surface water during the wet season and attributed it to increased nutrient input but contrary to the findings of Zhang et al. (2014) who reported that greater precipitation and discharge result in lower nutrient concentrations and pollution through dilution effect, thus, greater discharge has a greater capacity to dilute pollution from point sources. Additionally, during the dry season, minimal flow exists and hence less turbulence will lead to sedimentation of suspended particles (settling) which will reduce turbidity amongst other factors hence improving physical quality.

**Spatial Scales (Buffers) in Explaining Surface Water Quality**

No statistical significance was found between the designated buffers in assessing which buffer around surface water catchment predicts the water quality the most. Nonetheless, the three buffers (100m, 200m and 300m) considered in this study revealed that, the 300m buffer predicts the surface water quality most in the studied rivers and streams.

The quality of surface water resources differs spatially and temporally together with the processes affecting water quality (Miller et al., 2014). In this current study, the 300m buffer seems to control for several environmental

conditions and pollution sources around the surface water bodies hence the observed findings. These findings support several other works in literature which assert that the variation in different water quality indicators are explained the most by the characteristics of the entire catchment (Sliva & Williams 2001; Nielsen et al. 2012).

It is interesting to note that the study of Meynendonckx et al. (2006) on effects of watershed and riparian zone characteristics on nutrient concentrations in the River Scheldt Basin, Belgium, revealed that environmental conditions near the river were not critical factors in water quality modeling. Varanka (2016) also found that in scale studies, nutrients and water colour were best explained by the characteristics of the entire catchment.

This finding however, differs from the findings of Chang (2008), Moerke and Lamberti (2006), and Roberts and Prince (2010) who established that the areas closest to the river channel largely explain water quality. Chang (2008) submits that land cover and other topographic and soil factors at the riparian buffer scale better explain the variations in BOD, COD, SS, TP, and TN in the Han River basin, South Korea. Temperature and DO variations however, are better explained by landscape factors at the whole basin scale. Moerke and Lamberti (2006) also report similar outcomes for streams in Michigan, USA, where temperature variations were better explained by land cover at the whole watershed scale, and specific conductivity and turbidity better explained by urban or agricultural land covers at the riparian buffer scale.

The differences observed in these studies and the current study is that while this current study considers the quality of surface waters wholly with respect to the buffers, the others considered the influence of the buffers on specific elements. Again, Chang (2008) focused on one river in a study while the current study considered several rivers and streams for which environmental conditions and pollution sources are not constant. This difference in contextual attribute and surface waters could also account for the different findings among the studies.

**Relationship between Surface Water Quality and Environmental Variables**

As several environmental variables are known in literature to influence water quality, this study determined the most important factors that account for variation in surface water quality. The relationship between surface water quality and environmental and contextual variables (season, elevation, forest cover, built-up, cultivated area, rivers and streams cluster, and buffer) was assessed. These variables were found to have a high prediction power and account for 83.3 % of the variance in the dependent variable, WQI.

The linear regression model output showed that, change in season (dry to wet) is significantly associated with a change in the WQI. This factor was found to be the most essential variable in the modelled relationship between surface water quality and environmental variables to determine which of the variables most predict such a relationship. This means that seasonal variation which affects river and stream flow is key and should be considered in evaluating surface water

quality–environment relationships in the study area. This finding therefore suggests that the anthropogenic human activities (including all land use types) and natural factors and processes are highly dependent on season (dry and wet). This makes it the most important predictor in investigating surface water quality-environment relationships.

Elevation of the surface water ecosystems was the second most important variable that predicts the quality of the surface water bodies. The higher the elevation of the water body the better the quality and vice versa. This is so because; surface run-off usually flows down steep slopes into rivers and streams. These findings confirm the findings of You et al. (2019) who reported that within a watershed, mean elevation best predict pH.

The third most important variable that predicts the surface water quality was forest cover around the water catchments. The study found that, increase in forest cover increases the quality of the surface water and thus had the power to predict the surface water quality in the rivers and streams. Higher proportion of forest around a surface water catchment indicates less anthropogenic activities and hence less potential sources of pollution. Forest sustains water quality by reducing soil erosion as well as filtering other pollutants that could easily get into the water body (You et al., 2019).

Furthermore, densely growing vegetation in a forest can absorb and concentrate pollutants like nitrogen and phosphorus coupling with microbial

communities in surface litters, debris and organically enriched soil can help in efficient degradation of pollutants that impair surface water quality.

This finding supports similar works carried out across the globe including works in Denmark by Nielson et al. (2012) on watershed land use effects on lake water quality in Denmark and Ahearn et al. (2005) in California who researched on land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada. The findings are equally consistent with the study by Allan et al., (1997) who researched on the influence of catchment land use on stream integrity across multiple spatial scales at Michigan and reported that an increase in forested land cover resulted in dramatic declines in runoff and nutrient yields hence had influenced the quality of the stream water bodies.

In contrast to the findings in this study which reveals that forest had more explanatory power than cultivated areas, and built-up in the studied rivers and streams, earlier studies carried out to assess which land use types predict water quality most, farmland (Morrice et al., 2008) and built-up area (Chen & Lu, 2014), were found as the most land use variables that primarily determine and predict surface water quality. The disparity between those studies and the current study could be attributable to the intensity and closeness of the various land use types and environmental variables identified around the surface water bodies.

The last significant variable that predicts the quality of the water is the location of the water body (Rivers and Streams cluster). The rivers and streams cluster is purely contextual and informs the impact of anthropogenic and natural

factors and processes hence, in this study, the location attribute of the water bodies helps predict the quality. The anthropogenic and natural factors vary across the surface water bodies. The higher the intensity of this process the poorer the quality of the water.

# CHAPTER SIX

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was carried out to investigate the application of spatial statistical modelling to assess the effects of environmental factors on surface water quality in the Birim North District of Ghana.

The study was guided by the following research questions in order to achieve the set objectives:

1. Which water quality indicators account for the variability in surface water quality in the Birim North District?

2. What are the sources of the water quality indicators that explain the variation in surface water quality in the Birim North District?

3. Does the quality of surface water in the study area vary across river clusters?

4. What is the influence of seasonal variation on rivers and streams in predicting surface water quality-environmental relationships?

5. Which spatial scale(s) around study rivers and streams catchment predicts better the quality of surface water in surface water quality –environment relationships?

6. Which environmental variable(s) explain surface water (streams and rivers) quality better in surface water quality-environment relationships?

The cross-sectional study design was adopted in this study to evaluate surface water quality through field sampling of surface water bodies. This study design gives clear meaning of events and explains prevailing conditions of a given ecosystem on the basis of data gathered at a particular point in time.

In all, five hundred and forty (540) surface water samples were collected from fifteen surface water bodies (rivers and streams) in the Birim North District from January 2018 to December 2018.

Surface water quality was studied using thirty one (31) indicators classified into physical, chemical and biological parameters both in situ and ex situ. Sampling and analytical methods of surface water bodies followed the protocols developed by the American Public Health Association (APHA) (1998) and the Australian and New Zealand guidelines (2000) for fresh and marine water quality.

Landsat satellite images for 2019 of the study area were downloaded from the United States Geological Survey Earth Resources Observation and Science Data Centre (http://www.usgs.gov) and analysed to obtain land use and NDVI data. Environmental data comprising proportional total land covered by built-up, forest, cultivated land were explored at the 100m, 200m and 300m buffer around the surface water catchments. ENVI v. 15 image analysis software was used to generate the environmental data. The data were entered and analysed using

Microsoft Excel 2010, SPSS (Version 21) and Stata 13 MP (StataCorp, College Station, TX, USA).

The main analytical methods on the data obtained included descriptive, inferential and multivariate statistics. The results were presented using descriptive statistics of surface water quality, Pearson's product moment correlation, Principal Component Analysis (PCA), and Ordinary Least Square regression (OLS) in order to achieve the specific objectives stipulated in the study.

The inferential statistics was used for hypothesis testing in order to reject or fail to reject the null hypothesis as well as establish relationship between the measured variables. Independent t-test was adopted to evaluate whether seasonal variation influence surface water quality while Kruskal-Wallis test was adopted to evaluate whether the quality of surface waters systematically vary across the river and streams clusters.

The descriptive statistics of surface water quality is presented in three orders, thus descriptive statistics for the dry season surface water samples, wet season and a combination of both wet and dry seasons data. This gives the opportunity to understand the nuances in the water quality data with respect to variation in season and across streams and rivers. The descriptive statistics included mean, standard deviation, skewness, kurtosis, minimum and maximum values which together describe the distribution, measures of central tendency and dispersion.

**Summary of Findings**

Temporal disparities (seasonal variation) were observed in most of the water quality parameters in the rivers and streams. BOD, pH, chloride, alkalinity, turbidity, TDS, TSS, electrical conductivity, sulphate, potassium, apparent colour, total coliform, copper, chromium, nickel, zinc had higher mean concentrations measured during the dry season while DO, total phosphate, faecal coliform, true colour, nitrate, calcium, magnesium, manganese, arsenic, iron, and lead were higher during the wet season. Mercury and cadmium showed no variation in the mean concentration of water samples with respect to season of sampling.

Pearson's product moment correlation coefficients among selected water properties showed a number of strong associations at the $P<0.05$ and $P<0.001$ levels. pH correlated strongly with conductivity, alkalinity, TDS, turbidity, TDS. Also, TSS, BOD, DO, total hardness, apparent colour, chloride, sulphate, and calcium showed a strong correlation. Similarly, TSS, total hardness, true and apparent colours, sulphate and nickel, all showed significantly strong positive correlations with turbidity. Additionally, DO, calcium, magnesium, total phosphate, arsenic, manganese and iron correlated among each other.

Multivariate statistical (principal component) analysis suggests that the data is a six-component system that explains approximately 78% of the total variance in the data pointing the sources of pollutants to several anthropogenic and natural sources.

The indicators that largely define the quality of the studied rivers and streams in the study area are DO, calcium, manganese, magnesium, phosphate, iron, arsenic, copper and BOD as they account for the most variance (25.7%). The major sources of pollutants into surface water bodies include agriculture, mining, geology of the area (soluble rocks) /soil and sewage.

The quality of the surface water bodies does not systematically vary across the study river clusters as found in this current study. Based on the clustering considered, the Akoase cluster is of better quality compared to the Adofokrom/Amenam, and Nyafoman/Noyem clusters. Surface water quality was found to systematically vary with season (dry and wet seasons). The quality of the water was better during the dry season as compared to the wet season.

No statistical significance was found between the designated buffers in assessing which buffer around surface water catchment predicts the most of the water quality. Nonetheless, the three buffers (100m, 200m and 300m) considered in the study reveal that, the 300 m buffer predicts the surface water quality the most in the studied rivers and streams.

The independent variables (environmental variables) accounted for about 83.3 % of the variance in the dependent variable (WQI), in the regression model. From the model output, change in season (dry to wet) is significantly associated with a change in the WQI ($p<0.001$). Similarly, changes in elevation, forest, and location of surface water (river group) were significantly associated with a change in the WQI ($p<0.001$).

Season of sampling had the greatest influence on WQI and hence, predicted the dependent variable (WQI) most. The significant environmental variable that predicted WQI the least was buffer around the sampling points. The magnitude of environmental variables in increasing order of predicting WQI in the study area was: Buffer < Cultivated area < Built-up < Forest < River location (River group) < Elevation < Season.

**Conclusions**

Based on the results, six main conclusions are made according to the research questions. The main variables that define the quality of the studied rivers and streams were dissolved oxygen, calcium, manganese, magnesium, phosphate, iron, arsenic, copper and BOD. This answers the first research question of the study.

The quality of surface water ecosystems are influenced by several factors and processes, however this current study identified agriculture, mining, geology of the area (soluble rocks)/soil and sewage as the main factors affecting the quality of the surface water bodies in the study area which answers the second research question. These sources were made known through the principal component analysis of water quality data.

The implication of agriculture as a source of pollutants to surface water bodies suggest that despite the improvement made in agricultural farming methods (technology), it is imperative to develop more efficient technologies in

order to reduce leaching of nutrients and other pollutants into surface water bodies. Similarly, efficient technologies should be adopted by small scale gold miners to reduce the effects of their activities on the surface water bodies.

The study found that the quality of the surface water bodies does not systematically vary across the study rivers and streams clusters. Nonetheless the Akoase cluster is of better quality compared to the Adofokrom/Amenam, and Nyafoman/Noyem clusters. Surface water quality was found to systematically vary with season (dry and wet seasons).

Seasonal changes affect surface water quality. Surface water quality was found to systematically vary with season (dry and wet seasons). The quality of the surface water bodies was better during the dry season as compared to the wet season. This defines the fourth research question of the study.

Surface water quality was best explained when the environmental variables around the rivers and streams catchment were considered at 300m buffer. However, no statistical difference was observed between the different buffers, signifying that either of the buffers could be considered in surface water quality modeling.

The environmental variables were found to have great power in accounting for the variance in the dependent variable, WQI. From the model output it can be concluded that season, elevation, forest cover and location of river and stream should be considered in evaluating surface water quality in the study area. The magnitude of environmental variables in increasing order of

predicting WQI in the study area was: Buffer, Cultivated area, Built-up, Forest, River location (River group), Elevation, and Season.

Generally the results support the use of the statistical analysis adopted in the study and as first filter methods for assessing surface water quality–environment relationships across several areas. The results found in this study confirm that rivers and streams quality are interlinked with several processes and factors. The modeled relationships are in accordance with the results from other studies. Combining GIS data and water quality data as well as statistical methods give suitable modeling output for water quality determinants. The results posit that management interventions for surface water ecosystems should be targeted temporally and spatially to the key areas which is necessary from both practical and economic perspective.

**Recommendations**

Based on the results obtained, the following actions are made for:

a. Policy review
b. Further study

It is recommended that;

1. The WRC established by an Act of Parliament (Act 522 of 1996) as well as the National Community Water and Sanitation Program Policy should be enforced especially within the 300m buffer zones around surface water ecosystems to protect them from anthropogenic activities and help

rehabilitate and restore their quality in the study area and the country at large.

2. Management interventions for surface water ecosystems should be targeted temporally and spatially to the key areas which is necessary from both practical and economic perspective.
3. High spatial resolution satellite images (possibly drone images) should be adopted and analysed for spatial environmental data such that more land use type can be classified and their impact on surface water quality evaluated.
4. Future studies should be geared towards considering several areas (across the whole country) to investigate the spatio-temporal relationship between surface water quality-environment relationships.
5. Additionally, longitudinal study should be carried out that will account for several seasonal periods to evaluate the water quality-environment relationships in the studied rivers and streams.

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# LIST OF APPENDICES

## Appendix A: Sampling Locations

| ID | Location Name | Longitude | Latitude | Elevation |
|---|---|---|---|---|
| S1 | Asuoabena around Asempanaye | -1.036 | 6.459 | 200.226 |
| S2 | Asuoabena near pillar P18 | -1.018 | 6.451 | 179.322 |
| S3 | Tributary of River Pra after Apragya | -1.018 | 6.440 | 171.357 |
| S4 | River Nwin near Amenam | -1.005 | 6.419 | 164.201 |
| S5 | Pra River at Apragya | -1.016 | 6.435 | 173.127 |
| S6 | River Nwin near Nyamebekyere high tension line | -0.959 | 6.440 | 182.824 |
| S7 | Tributary of Nwin river at Dadekurom | -0.963 | 6.434 | 172.729 |
| S8 | Nsuten along main road | -0.941 | 6.438 | 185.891 |
| S9 | Nsuten near the exclusion zone | -0.936 | 6.445 | 185.679 |
| S10 | Aprokroma stream along the main road | -0.932 | 6.452 | 189.755 |
| S11 | Sakapea stream at Domeabra | -0.907 | 6.430 | 206.134 |
| S12 | Nsuten along Domeabra - Nyafoman road | -0.899 | 6.434 | 202.741 |
| S13 | Nyanoma along Domeabra - Nyafoman road | -0.897 | 6.441 | 207.055 |
| S14 | Nsuten near Odumase | -0.897 | 6.419 | 210.342 |
| S15 | Nsuten near Nsiasakuraa | -0.895 | 6.429 | 204.747 |

**Appendix B: Land use and NDVI Data**

| RIVER 1D | Buffer | Forest Cover (%) | Builtup Area(%) | Cultivated Area (%) | NDVI |
|---|---|---|---|---|---|
| S1 | 100m | 0.00 | 15.62 | 57.81 | 0.327 |
| S2 | 100m | 22.45 | 0.00 | 69.39 | 0.332 |
| S3 | 100m | 0.00 | 31.25 | 32.81 | 0.317 |
| S4 | 100m | 0.00 | 21.43 | 51.79 | 0.303 |
| S5 | 100m | 0.00 | 29.69 | 40.62 | 0.309 |
| S6 | 100m | 4.08 | 4.08 | 77.55 | 0.323 |
| S7 | 100m | 0.00 | 26.53 | 53.06 | 0.321 |
| S8 | 100m | 0.00 | 68.75 | 1.56 | 0.240 |
| S9 | 100m | 0.00 | 53.57 | 12.50 | 0.278 |
| S10 | 100m | 0.00 | 57.81 | 0.00 | 0.214 |
| S11 | 100m | 0.00 | 31.25 | 43.75 | 0.312 |
| S12 | 100m | 0.00 | 35.71 | 44.64 | 0.295 |
| S13 | 100m | 0.00 | 39.29 | 39.29 | 0.295 |
| S14 | 100m | 0.00 | 39.29 | 41.07 | 0.286 |
| S15 | 100m | 0.00 | 8.16 | 79.59 | 0.314 |
| S1 | 200m | 0.00 | 23.47 | 57.14 | 0.316 |
| S2 | 200m | 9.78 | 6.67 | 83.11 | 0.329 |
| S3 | 200m | 0.00 | 33.67 | 41.33 | 0.312 |
| S4 | 200m | 0.00 | 22.38 | 52.38 | 0.306 |
| S5 | 200m | 1.02 | 35.20 | 43.37 | 0.304 |
| S6 | 200m | 0.89 | 15.55 | 54.67 | 0.320 |
| S7 | 200m | 0.00 | 16.00 | 48.89 | 0.327 |
| S8 | 200m | 0.00 | 61.73 | 16.33 | 0.263 |
| S9 | 200m | 0.00 | 47.62 | 10.95 | 0.268 |
| S10 | 200m | 0.00 | 68.88 | 5.10 | 0.229 |
| S11 | 200m | 0.00 | 31.63 | 50.00 | 0.302 |

| | | | | | |
|---|---|---|---|---|---|
| S12 | 200m | 0.48 | 26.67 | 48.57 | 0.294 |
| S13 | 200m | 0.00 | 33.33 | 42.38 | 0.294 |
| S14 | 200m | 0.00 | 32.38 | 45.24 | 0.287 |
| S15 | 200m | 0.00 | 21.78 | 49.78 | 0.303 |
| S1 | 300m | 1.81 | 18.37 | 56.46 | 0.321 |
| S2 | 300m | 5.44 | 8.84 | 62.58 | 0.323 |
| S3 | 300m | 0.68 | 26.98 | 44.90 | 0.312 |
| S4 | 300m | 0.00 | 21.99 | 53.97 | 0.306 |
| S5 | 300m | 1.13 | 20.04 | 50.34 | 0.312 |
| S6 | 300m | 0.91 | 17.46 | 58.05 | 0.319 |
| S7 | 300m | 0.23 | 14.06 | 57.60 | 0.322 |
| S8 | 300m | 0.00 | 51.93 | 23.36 | 0.273 |
| S9 | 300m | 0.00 | 52.15 | 12.70 | 0.269 |
| S10 | 300m | 0.00 | 59.18 | 13.60 | 0.238 |
| S11 | 300m | 0.00 | 27.89 | 50.57 | 0.302 |
| S12 | 300m | 1.36 | 21.09 | 54.87 | 0.301 |
| S13 | 300m | 1.13 | 29.70 | 46.71 | 0.297 |
| S14 | 300m | 0.00 | 30.61 | 48.53 | 0.293 |
| S15 | 300m | 0.00 | 18.37 | 57.82 | 0.310 |

## Appendix C: Anti-image Correlation Matrix

| | pH | Cond | Alk | Turb | TDS | TSS | DO | BOD | TH | TrC | ApC | Cl | NO3 | SO4 | Na | Ca | Mg | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | **.750a** | | | | | | | | | | | | | | | | | |
| Cond | 0.211 | **.644a** | | | | | | | | | | | | | | | | |
| Alk. | -0.057 | -0.324 | **.800a** | | | | | | | | | | | | | | | |
| Turb. | -0.088 | -0.035 | -0.386 | **.745a** | | | | | | | | | | | | | | |
| TDS | -0.216 | -0.703 | -0.157 | 0.105 | **.559a** | | | | | | | | | | | | | |
| TSS | -0.133 | -0.016 | 0.358 | -0.812 | -0.192 | **.766a** | | | | | | | | | | | | |
| DO | 0.153 | 0.309 | -0.036 | 0.119 | -0.437 | -0.017 | **.825a** | | | | | | | | | | | |
| BOD | -0.362 | 0.024 | -0.221 | 0.028 | -0.111 | 0.144 | 0.253 | **.802a** | | | | | | | | | | |
| TH | 0.006 | -0.088 | -0.227 | 0.458 | 0.029 | -0.213 | 0.132 | -0.287 | **.710a** | | | | | | | | | |
| TrC | -0.022 | 0.190 | -0.295 | 0.035 | 0.044 | -0.132 | -0.143 | 0.210 | -0.504 | **.675a** | | | | | | | | |
| ApC | 0.255 | 0.035 | -0.153 | -0.042 | 0.320 | -0.507 | -0.150 | -0.251 | -0.235 | 0.140 | **.730a** | | | | | | | |
| Cl | -0.295 | 0.089 | -0.357 | 0.079 | -0.068 | 0.192 | 0.098 | 0.472 | -0.073 | 0.612 | -0.385 | **.658a** | | | | | | |
| NO3 | 0.056 | 0.142 | -0.106 | -0.123 | -0.031 | 0.042 | -0.289 | -0.124 | -0.026 | 0.147 | 0.142 | 0.005 | .295a | | | | | |
| SO4 | 0.194 | 0.061 | 0.223 | -0.598 | -0.030 | 0.236 | -0.134 | 0.016 | -0.648 | -0.076 | 0.327 | -0.429 | 0.043 | **.735a** | | | | |
| Na | -0.267 | -0.386 | 0.094 | 0.243 | -0.118 | 0.096 | 0.192 | 0.131 | 0.518 | -0.412 | -0.513 | 0.122 | -0.225 | -0.403 | **.551a** | | | |
| Ca | -0.299 | -0.283 | -0.100 | 0.091 | 0.334 | 0.000 | -0.550 | 0.184 | -0.028 | 0.154 | -0.064 | 0.299 | -0.110 | -0.135 | 0.070 | **.869a** | | |
| Mg | -0.175 | -0.191 | 0.280 | -0.186 | 0.125 | 0.149 | -0.229 | 0.122 | -0.293 | -0.245 | -0.043 | -0.357 | -0.160 | 0.475 | -0.096 | -0.156 | **.698a** | |
| K | -0.193 | -0.182 | 0.275 | 0.088 | 0.151 | -0.131 | 0.028 | -0.003 | -0.253 | 0.073 | 0.115 | -0.038 | -0.436 | 0.082 | -0.069 | 0.178 | 0.204 | **.659a** |

Appendix C continued

| | pH | Cond | Alk | Turb | TDS | TSS | DO | BOD | TH | TrC | ApC | Cl | NO3 | SO4 | Na | Ca | Mg | K | PO4 | Tcol | Fcol | As | Fe | Mn | Cu | Cr | Pb | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PO4 | -0.320 | -0.402 | 0.218 | -0.061 | 0.225 | 0.104 | -0.203 | 0.200 | -0.135 | -0.216 | -0.063 | -0.113 | -0.283 | 0.148 | 0.225 | 0.193 | 0.341 | 0.197 | **.798a** | | | | | | | | | | |
| Tcol | -0.374 | 0.012 | -0.223 | 0.341 | 0.019 | -0.049 | 0.151 | 0.188 | 0.168 | 0.314 | -0.288 | 0.642 | -0.045 | -0.568 | 0.238 | 0.220 | -0.304 | 0.225 | -0.071 | .258a | | | | | | | | | |
| Fcol | 0.189 | -0.191 | 0.267 | -0.240 | 0.303 | 0.059 | -0.195 | -0.397 | -0.009 | -0.333 | 0.267 | -0.540 | -0.022 | 0.309 | -0.201 | -0.139 | 0.256 | 0.218 | -0.007 | -0.405 | **.630a** | | | | | | | | |
| As | -0.095 | 0.399 | 0.130 | -0.173 | -0.644 | 0.356 | 0.126 | 0.193 | 0.069 | -0.119 | -0.494 | 0.095 | 0.123 | 0.018 | 0.226 | -0.091 | -0.018 | -0.188 | -0.218 | 0.014 | -0.203 | **.695a** | | | | | | | |
| Fe | -0.194 | 0.124 | 0.095 | -0.119 | -0.111 | 0.246 | 0.100 | 0.144 | 0.010 | -0.121 | -0.209 | 0.107 | -0.362 | -0.054 | 0.058 | 0.164 | 0.047 | 0.199 | -0.102 | 0.152 | 0.014 | 0.196 | **.791a** | | | | | | |
| Mn | -0.086 | -0.351 | -0.032 | 0.144 | 0.350 | -0.231 | -0.440 | 0.032 | -0.228 | 0.369 | 0.185 | 0.120 | 0.374 | 0.003 | -0.099 | 0.028 | 0.047 | -0.070 | 0.082 | 0.031 | -0.048 | -0.353 | -0.513 | **.783a** | | | | | |
| Cu | 0.219 | -0.120 | 0.164 | 0.001 | 0.202 | -0.102 | -0.022 | -0.567 | 0.227 | -0.135 | 0.128 | -0.312 | -0.398 | -0.042 | -0.062 | -0.108 | 0.094 | 0.202 | -0.022 | -0.165 | 0.454 | -0.237 | 0.080 | -0.176 | **.746a** | | | | |
| Cr | -0.105 | 0.041 | 0.060 | 0.040 | -0.230 | 0.015 | 0.147 | 0.388 | -0.140 | -0.249 | -0.112 | -0.152 | 0.032 | 0.234 | 0.149 | 0.007 | 0.174 | -0.085 | 0.200 | -0.128 | -0.323 | 0.223 | 0.007 | -0.046 | -0.702 | **.763a** | | | |
| Pb | 0.051 | 0.500 | 0.015 | -0.196 | -0.539 | 0.229 | 0.523 | 0.264 | -0.225 | 0.100 | -0.153 | 0.161 | -0.376 | 0.138 | -0.074 | -0.246 | 0.123 | 0.172 | -0.102 | 0.093 | -0.272 | 0.257 | 0.341 | -0.551 | -0.008 | 0.121 | **.350a** | | |
| Ni | 0.052 | -0.046 | 0.455 | -0.219 | -0.093 | 0.047 | 0.083 | -0.167 | -0.260 | -0.246 | 0.236 | -0.377 | -0.046 | 0.146 | -0.018 | -0.064 | -0.109 | 0.145 | 0.061 | -0.215 | 0.258 | 0.015 | 0.012 | -0.070 | 0.025 | 0.045 | -0.049 | **.851a** | |
| Zn | -0.386 | 0.007 | -0.465 | 0.399 | 0.048 | -0.157 | 0.178 | 0.346 | 0.342 | 0.092 | -0.196 | 0.424 | 0.054 | -0.489 | 0.386 | 0.215 | -0.403 | -0.078 | 0.006 | 0.498 | -0.336 | 0.047 | 0.033 | 0.022 | -0.410 | 0.181 | -0.090 | -0.160 | **.418a** |