A Baseline Assessment of Water Quality in the Gambia River and the Potential for Community-Based Monitoring in The Gambia, West Africa

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This thesis is dedicated to my loving pop, Henry Somerton.

February 3rd, 1932 - September 25th, 2007

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Abstract

As human populations continue to grow and land uses expand, the capacity to negatively impact our surface waters and watersheds throughout the world through contamination and human disturbances likewise increases. This potential for adverse effects on our world's water often results in reduced water quality. It is for this reason that water quality monitoring has become an important aspect of environmental science over the past several decades and is continuing to be an issue of community concern. Throughout the country of The Gambia, there is little information regarding the status of the countries groundwater and surface water quality. In an attempt to fill this information gap, this thesis undertook a baseline study of water quality on The Gambia River pertaining to human and ecosystem health. Furthermore, this thesis evaluated the capacity for community-based monitoring in The Gambia as a means of establishing whether local community members can engage themselves as citizen scientists, to determine if they can collect credible data.

Keywords. Citizen Science, Community-Based Monitoring, Ecosystem Health, Environment, Human Health, Surface Water, The Gambia, The Gambia River, Water Quality

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List of Abbreviations

CABIN	Canadian Aquatic Biomonitoring Network
CBM	Community Based Monitoring
CET	Certified Engineering Technologist
CCME	Canadian Council of Minister of the Environment
COND	Electrical Conductivity
DO	Dissolved Oxygen
GIS	Geographical Information Systems
IPCC	Intergovernmental Panel on Climate Change
MDG	Millennium Development Goal
NGO	Non-Governmental Organizations
NSE	Nova Scotia Environment
NSGA	Nova Scotia – Gambia Association
QA/QC	Quality Assurance Quality Control
RCCA	Reef Check California
SAL	Salinity
SPC	Specific Conductivity
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UN	United Nations
USGS	United States Geological Survey
WAM	West African Monsoon
WHO	World Health Organization
WQM	Water Quality Monitoring
YSI ProPlus	YSI Professional Plus

Chapter One

INTRODUCTION AND LITERATURE REVIEW

1.1 Research Content

Life thrives on water. It is a human right, not a privilege, and is essential for both human and ecosystem health. Water is a basic necessity for all living organisms; its quality is continuously under pressure as it is vital to the human body and ecosystem. Without access to clean water, humans place themselves at risk of contracting numerous diseases and parasites that can have serious chronic effects on health, or even threaten life (Botkin, Heathcote & Keller, 2006, pp.375-398). This concern is increasing in many countries around the world, especially in those that do not have access to suitable water quality. For the purposes of this study, the term ‘suitable water quality’ refers to surface waters which are deemed: (1) safe to consume, and/or (2) safe for recreational or agricultural purposes, taking into consideration several chemical, physical, and biological processes.

Clean, fresh water is critical for meeting basic human needs, from consumption and sanitation, to economic activity and agriculture purposes (Bartram & Balance, 1996; UNEP, 2010). Water is a “right” for all human life on earth, and also plays a crucial role in many ecosystems, especially aquatic ones (Moiseenko, 2008). Aquatic ecosystem health indicators, such as data sets which are the results of monitoring programs, are becoming increasingly important. Climate change, land alterations, and extreme weather events can have a significant effect on aquatic ecosystems, which can increase anthropogenic alteration and disturbances, therefore modifying delicate ecosystems.

The growing human population is causing a negative impact on surface waters and watersheds worldwide. Rivers are essential for many people and their use includes drinking water, recreation, religious ceremonies, and aesthetic enjoyment (Forslund *et al.*, 2009; Hunt, 2004, p.25). For example, many Gambians rely on water from the Gambia River to wash before attending Mosque or eating meals. Therefore, impacts on the Gambia River which negatively affect water quality and how water is used throughout the country are important. The impact of poor surface water quality is evident worldwide; however, humans need to continue to use available water for consumption and everyday use. A detailed understanding of the causes of poor water quality, how they affect humans, and what we can do to prevent and/or address poor water quality is important. It is therefore necessary to gain an understanding of the essential services that ecosystems provide, and try to identify the cause and effects of poor water quality. This can be achieved, in part, by water quality monitoring (i.e. assessing the physical, chemical, and biological characteristics of a water system that are pertinent to human health and ecosystem health) (Fukue, Mulligan & Sato, 2004).

The following sections will investigate the important links between human, ecosystem health and water quality, while providing an overview of water quality monitoring, especially in relation to citizen science and community-based monitoring.

1.2 Research Rationale

Although understanding the issues surrounding water quality has grown recently, there are substantial knowledge gaps in the literature relating to water quality and human and ecosystem health in The Gambia, as well as many other parts of the developed and under-developed world. Gaps also exist with respect to the scientific validity of water data collected by volunteers, and whether it is comparable to data collected by trained professionals.

1.2.1 Research Objectives

The main purpose of this research was to assess the current state of surface waters throughout the Gambia River, West Africa, especially with respect to human and ecosystem health. The data collected was used to evaluate the condition and function of the aquatic ecosystem examined, including spatial trends. This research, and the water quality data that was collected, also serve as a valuable baseline for future research, water quality monitoring efforts, and educational outreach in the Gambia.

Two objectives were developed to address this research.

1) To identify areas of good water quality.

2) To identify spatial variations of water quality.

The secondary purpose of this research was to examine whether citizen science data was comparable to data collected by a trained professional. This work will contribute to a better understanding of citizen science data collection. By allowing community members to engage in this form of science, we will also increase local and international knowledge of water quality issues as they relate to aquatic ecosystems.

Two main objectives were developed to address this research.

1) To determine whether volunteer-derived data sets are comparable to a professional's data set.
2) To identify common sources of error in water quality parameters collected by citizen scientists.

1.2.2 Thesis Questions and Hypothesis

The principal study of this thesis examined two main research questions:

1) What are the spatial variations in water quality in the Gambia River?
    a. I hypothesized that spatial variations in water quality are expected to emerge based on changes in land use/cover and natural and anthropogenic changes.
2) What factors have influenced the spatial variations in water quality in The Gambia River?
    a. I hypothesized that anthropogenic disturbances have altered the spatial distribution of water quality.

The secondary study examined two main research questions:

1) Are volunteer citizen scientists able to collect data that are considered comparable to data collected by a trained professional?
    a. I hypothesized that there would be no major differences between the data collected by volunteers and the data collected by the professional.

2) What conditions make it possible for volunteer citizen scientists to collect the most accurate data?
    a. I hypothesized that sources of error are most likely to prevent volunteer citizen scientists from collecting the most accurate data possible. These include: equipment stabilization times, probe placement and accurate data recording, without errors.

1.3 Water Quality and Human Health

In 1854, water quality was shown to have an impact on human health when Dr. John Snow discovered that a cholera outbreak in London was linked to a public well near the Thames River which was contaminated by sewage infiltration. This led to an increased recognition of the importance of water quality to human health (National Research Council (U.S.), 1977; Olajire & Imeokparia, 2002; Salzman, 2012, pp. 87-89). As a result of this growing awareness, water quality testing has become increasingly important over the past number of decades (Gibbs, 1972; Niemi, Devore, Detenbeck, Taylor & Lima, 1990; Sacomani & Silva, 2000).

Contaminated water containing pathogenic microorganisms, or various chemical contaminants, can cause many diseases in humans, particularly in developing countries. Such diseases can be contracted by ingesting affected food or water, or by coming into contact with contaminated water through bathing or washing. As stated by the World Health Organization (WHO), "Water, sanitation and hygiene have important impacts on both health and disease" (World Health Organization, 2014). Water related diseases are classified into four main categories including: waterborne (fecal-oral), water-washed, water-based, and water-related insect vector. Two of the most common categories related to poor water quality used for drinking, bathing, etc. are waterborne and water-based categories. Waterborne diseases occur when water transmits the disease (i.e. diarrhea, typhoid, cholera, dysentery and hepatitis A). Drinking water contaminated by human fecal matter is the main cause for waterborne diseases. Water-based diseases are caused by hosts (i.e. mosquitoes or Guinea worm) that live in water or require water for part of their life cycle (Gleick, 2012, pp.57-58).

1.3.1 Millennium Development Goals

Over the years, it has become obvious that our world has succumbed to poverty worldwide and this has had social, economic, political, and environmental consequences for human beings. Many initiatives have been put forward, particularly by the United Nations (UN), and they have established a set of targets with timelines for world development projects. Prior to the Millennium Summit in 2000, eight international development goals, known as the Millennium Development Goals (MDGs), were set to be achieved by the year 2015. These eight goals are further broken down into various subcategories which define specific aspects of each goal. The first seven goals are targeted towards poverty and hunger, education, gender equality and empowerment of women, child mortality, maternal health, combating diseases, and ensuring environmental sustainability. The eighth goal focuses on a global partnership for development.

Water is fundamental for human life and an essential resource to be protected. One of the UNs eight Millennium Development Goals of particular interest is 7c, which aims to “Halve by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation” (United Nations, 2011, p. 53). In Resolution 64/292, the UN stresses “the importance of equitable access to safe and clean drinking water and sanitation as an integral component of the realization of all human rights” and “recognizes the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights” (General Assembly, 2010).

1.4 Water Quality and Ecosystem Health

The focus on water quality is starting to shift from a principal focus on human health to a focus on both human and ecosystem health (Karr, 1992). “Most of the earth's surface is covered by water, and most of the human body is composed of water – two facts illustrating the critical linkages between water, health and ecosystems” (UNEP, 2010). As water resources around the world are being depleted, we are starting to see that water scarcity is leading to degraded ecosystems and contamination (UNEP, 2010). As of 1995, 88 percent of freshwater withdrawn from water bodies in Africa was used for agricultural purposes, seven percent for domestic uses and five percent for industry (Hunt, 2007). Places such as The Gambia are beginning to see the signs and feel the stresses of water exhaustion.

Since the 1800s, scientific research related to ecosystem health has been undertaken. Research connecting ecosystem problems related to water date back to the early 1900s when Swedish chemist, Savante Arrhenius, stated that carbon dioxide levels would increase in the future, and ultimately lead to an increase in global temperatures (Weart, 2011). Decades later, in the 1980s and 1990s, ice cores and computer-generated models supported Arrhenius’ assertion of increasing global temperatures, which is causing worldwide effects on our water resources. In the 1920s and 1930s, conservationist, Aldo Leopold, played a major role in increasing awareness of the environment, ecology, and forestry. In his book entitled *A Sand County Almanac*, Leopold commented that “land health is the capacity for self-renewal in the soils, waters, plants, and animals that collectively comprise the land.” (quoted in Meine & Knight, 2006, p.148).

In many developing countries, there is a lack of significant funding and expertise to implement and maintain water quality monitoring programs on their rivers and streams. On the African continent, 80 percent of all diseases are related to poor water quality and unsanitary conditions (Olajire & Imeokparia, 2002; Sharma, Jain & Trivedi, 2004). There is limited research and documentation on African water sources, despite the ongoing concern over water quality and the scarcity the continent is currently facing (Mwanza, 2005). In The Gambia, this is due to: lack of funding, available equipment, and resources (Personal communication, Conteh , December 2011). Most of the population within The Gambia get their drinking water from groundwater sources, but the Gambia River water still remains an important source for daily activities such as bathing, cooking, livestock watering, recreational activities, agricultural purposes, etc. (**Figures 1.0** to **Figure 1.3**).

In order for continued human and ecosystem existence, we must secure enough water to provide for our future needs. Water security is an increasing concern for countries and water resources worldwide. With a limited amount of freshwater available for human consumption, it is imperative to secure enough water for survival. Quite often the issue of water security is threatened due to lack of water quantity and poor water quality. UN Water, 2013, p.9 defines water security as:

> “The capacity of a population to safeguard sustainable access to adequate

> quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.”

This ever increasing concern over water security can be caused by both natural sources and man-made sources. However, provisions are necessary to ensure the sustainability of such a precious resource worldwide.

Figure 1.0. Laundry Being Washed in the Gambia River
Source: Photograph captured by author, Melissa Healey

Figure 1.1. Cattle Drinking and Defecating in the Gambia River
Source: Photograph captured by author, Melissa Healey

Figure 1.2. Children Preparing to Bath in the Gambia River
Source: Photograph captured by author, Melissa Healey

Figure 1.3. Rice Fields Along the Gambia River
Source: Photograph captured by author, Melissa Healey

1.5 Water Quality Monitoring

Water quality monitoring (WQM) is defined as an evaluation of trends in the physical, chemical, and biological characteristics of water. Water quality is influenced by multiple factors including climate, precipitation, underlying geology, ground water, surface water, anthropogenic activities, pollutants, and other natural and human processes (Ahuja, 2013). Monitoring water quality allows us to study ecosystem health and environmental trends, and also to obtain baseline data for future studies. Worldwide, there are various water quality parameters used to provide an overall understanding of an ecosystem's health, water status, and other important environmental issues. As discussed by Sene and Farquharson (1998), surface water quality monitoring is used to assess spatial and temporal variations in a region. Rivers and streams are complex systems which vary both temporally and spatially as they are always changing in their capacity and structure (Cushing & Allan, 2001). Therefore, it is important to understand the components of water quality to assess the characteristics of a river.

1.5.1 Design of a Water Monitoring Program

The design of monitoring programs can depend on many factors. For example, they can serve to assess water standards, the state of the environment, or water quality trends (Fukue *et al*., 2004). Parameters and programs should be modified and adopted to suit specific monitoring needs. The purpose of this study's monitoring program was to provide information on human and ecosystem health related to the water quality of the Gambia River. Although every parameter is important in relation to the health and status of a water body, it is not always feasible or necessary to explore each parameter as there are numerous options to be studied when assessing non-potable water. Some of the most important parameters include: physical parameters (e.g. water temperature, conductivity (COND), salinity (SAL) and total suspended solids (TSS)); chemical parameters (e.g. dissolved oxygen (DO) and pH) and; biological indicators (e.g. fecal coliform bacteria and benthic invertebrates) (Conrad & Sharpe, 2006). It is important to consider all three types of classifications when assessing a water body (Albaret, Ecoutin, Laurent & Simier 2006; Chang, 2008; Grobbelarr, Koning & Roos, 2000; Hondzo & Markfort, 2009; Sacomani & Silva, 2000). For example, chemical parameters are useful in providing a "snapshot" of the water quality, while biological parameters can provide an assessment of the environmental quality by integrating variables of water chemistry (Savan, Morgan & Gore, 2003). Recommended parameters which are simple and quick to measure include: pH, temperature, dissolved oxygen, salinity, turbidity and water level (Nicholson, Ryan & Hodgkins, 2002). Parameters such as dissolved oxygen, temperature, and pH are critical indicators of freshwater ecosystem health (PASCO, 2007).

In developing countries, such as The Gambia, physical and chemical parameters are the most accessible means of sampling water quality due to the low expenditure of field measurements (Davies *et al*., 2001). Hart *et al.* (2001) emphasized the importance of assessing river health by using water-quality probes in developing areas. Savan *et al.* (2003) notes the importance of chemical parameters by stating that they can be measured to determine the freshwater ecosystem health of a particular area of interest.

1.5.2 Selected Water Monitoring Parameters

Dissolved Oxygen (DO) (% Sat and mg/L) is one of the most important indicators of freshwater ecosystem health (PASCO, 2007; Wetzel, 2001). It provides important information regarding the biological and biochemical reactions that are taking place within the aquatic ecosystem (Hondzo & Markfort, 2009), and is essential for all aquatic life. A high DO reading indicates a healthy ecosystem which is capable of supporting various types of aquatic life, whereas a low DO reading can indicate possible pollution or a type of anthropogenic change.

Water Temperature (°C) provides an overall picture of the quality of a water body (PASCO, 2007). Temperature can relate to both pH and DO (temperature dependent) measurements and varies both spatially and temporally.

The pH is an important parameter in the chemical and biological systems of water bodies, reflecting underlying geology. A decrease in pH can influence the solubility of metals in water, such as aluminum, copper and lead, therefore increasing any water toxicity. For example, acid drainage has the potential to dissolve metals and toxins surrounding surface waters and ground water.

Electrical Conductivity (uS/cm) measures the ability of a water body to carry an electric current, which reflects the concentration of ions within the water body. Conductivity will vary with temperature; in rivers, it is affected by the geology of the surrounding area. It is an indication of the level of inorganic dissolved solids, such as chloride and sodium; a high reading could be an indication that there is runoff within the area. Specific conductivity (SPC) is often recorded as it has already been adjusted for temperature. When measuring conductivity directly, informed decisions can be made on the suitability of using the water source for irrigation or agricultural purposes (Fresenius, Quentin & Schneider, 1988, p. 20).

Total Dissolved Solids (mg/L) usually refers to any mineral metals, salts, anions, or cations, dissolved in water, and dissolved organic matter may also be included. High total dissolved solids (TDS) can cause aesthetic problems related to taste, odour, and appearance; for example, they can make the water hard and/or stain sinks and rocks. High levels of TDS may also indicate contamination from magnesium, sodium, potassium, chloride, sulphate and nitrate due to runoff from agricultural uses (Health Canada, 2009).

Salinity (ppt) refers to the dissolved salt content of the water body. It is a critical parameter in this study as the Gambia River is saline for a portion of its length. Salt levels can change in response to tidal conditions, precipitation, runoff events and daily temperature variations and fluctuations, influencing the growth of aquatic life and the plant species (Arendt *et al*., 2004).

Coliform Bacteria (Present/Absent) provides an indicator that pathogenic organisms of fecal origin may be present within a water body, in the soil, or on the surrounding vegetation. In Canada, the fecal coliform counts should not exceed 200 cells per 100 milliliters for safe swimming, and water containing any coliform levels are considered unsuitable potable water (i.e. for drinking purposes) (Botkin *et al*., 2006).

1.6 Water Quality Studies

There is a lack of information on The Gambia River’s water quality. However, various studies have been conducted on water quality pertaining to particular fish species or treatment processes. It was decided that a baseline study of the water quality as it pertains to human health would be beneficial and compliment the previous and on-going targeted studies on the Gambia River. Studies elsewhere that are similar to this thesis are presented below.

In a water quality assessment of the Osun River in southwest Nigeria, surface water samples were collected for: pH, temperature, electrical conductivity, total dissolved solids, and additional chemical and biological parameters for the purposes of determining the chemical composition and pollution levels in the river. Readings were taken in the main river and also in the tributaries that enter the river. The authors concluded that the selected parameters provided sufficient information and allowed for a suitable snapshot of the river’s water quality (Olajire & Imeokparia, 2002).

Abdul-Razak, Asiedu, Entsua-Mensah & deGraft-Johnson (2010) carried out a study on the Oti River in Ghana. The water quality of the river’s surface was analyzed as the local community relies on the river for both domestic and agricultural purposes. The study noted that the pollution of the river appeared minimal and usually resulted from the disposal of local fecal matter and garbage along the riverbanks. The study provided useful baseline information; however, it found that the water was not suitable for human consumption due to the presence of coliform at all sampling locations.

In a study by Healey, Moll & Diallo (1988), a water quality analysis was conducted on the Gambia River at four sampling sites, within each of the four hydrologic seasons within a year. Samples were taken for plankton and also physical-chemical parameters including: temperature pH, alkalinity, dissolved oxygen, total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate-nitrogen, silica, chlorophyll A, and phaeopigments. The study concluded that heterotrophy overshadowed autotrophy within the river system, and that the remaining parameters taken in the study were influenced by the annual flood and the mangrove presence in the estuarine portion of the river.

In a study by Albaret *et al*. (2006), a spatial and seasonal variability of fish assemblages was conducted within the Gambia River estuary. Fish assemblages were sampled, as well as selected environmental variables (i.e. water depth, transparency with a secchi disc, salinity, temperature and dissolved oxygen using a ysi handheld monitoring device). The study noted that dissolved oxygen and depth never had an effect on the estuary scale. However, bio-ecological categories did respond to changes in the seasons and distance from the ocean. The study used fish assemblage data and environmental data to conclude that The Gambia estuary is considered to be a reference ecosystem for future comparisons with tropical estuarine ecosystems due to balanced effects of marine and freshwater influences and the presence of all bio-ecological categories.

The Gambian Department of Water Resources has studied the Gambia River extensively and has collected an abundance of data over numerous years throughout the length of the river. This data included handheld parameters such as those conducted in this study, and also various lab analyses. Frequently, data collected by the Department of Water Resources does not get analyzed and remains unpublished. This data is critical to the understanding of the Gambia River and its surrounding ecosystems. However, the data provided contained many gaps, sometimes by years, making it less useful for the current study. However, this data is helpful when determining if the river has changed over time.

1.7 Citizen Science

As an alternative to government agencies or certified scientists collecting water quality monitoring data, volunteer citizen scientists can also collect data. Citizen science "is the process whereby citizens are involved in science as researchers" and it can also involve community-based monitoring (Conrad & Hilchey, 2010, p.2). Community-based monitoring (CBM) is "a process where concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to monitor, track and respond to issues of common community concern" (Whitelaw, Vaughan, Craig & Atkinson, 2003, p.410). Prior to science being considered a paid profession in the late 19th century, research was conducted by average citizens, which we now refer to as citizen scientists (Silvertown, 2009). Often, these volunteers provide a significant amount of their time and effort to collect data. However, there are still some questions as to whether the data they collect is considered reliable enough to be used by government agencies (Loperfido, Beyer, Just & Schnoor, 2010).

1.7.1 Rationale

Water quality is of great concern, especially in rural areas (Roa Garcia & Brown, 2009) such as those found within The Gambia, West Africa. The demand for water quality data and public information pertaining to water is rapidly increasing worldwide, as both humans and ecosystems need this valuable resource (Silva & Sacomani, 2000). Furthermore, the planet is facing imminent water shortages (Asano, 2009). To address these issues, water quality studies and monitoring projects are crucial for current and future research. Fortunately, new technologies, such as real time data collection probes, make monitoring for pollutants and other harmful factors much simpler and more accurate than in the past (Telci, Nam, Guan, & Aral, 2009).

Frequently, the public seeks a professional in government, academia or within a private consulting firm to conduct water monitoring programs. These groups are often referred to as ‘professionals’ due to their educational and scientific background. They often have a scientific university degree(s), or a specialized college diploma.

As stated by Bonney *et al.* (2009), public participation in science is not a new concept. As early as 1880, lighthouse keepers would record bird data, and the National Weather Service Cooperative Observer Program started in 1890. In the 1900s, the Audubon Society initiated a Christmas bird count where thousands of citizen scientist volunteers participated. The 20th century brought about public participation in water quality monitoring, and over the past two decades, new forms of data collection have involved more scientific equipment and protocols.

1.7.2 Benefits and Concerns

Citizen science monitoring has many advantages which have been documented and contribute to ecosystem monitoring worldwide (Conrad & Daoust, 2008). One obvious advantage is that the required data can usually be collected at a reduced cost compared with data generated by government organizations or private firms (Caselle *et al.*, 2011). Citizen science groups can fill spatial and temporal gaps in monitoring conducted by professional scientists in academia or in the government (Conrad & Sharpe, 2006).

Although volunteer-based monitoring has many advantages, the data collected by these programs have historically been considered unreliable (Breed, Stichter & Crone, 2012; Gillett *et al.*, 2011; Schmeller *et al.*, 2009). Therefore, there is suspicion regarding the value of data collected by the public compared with that collected by professional scientists (Caselle *et al.*, 2011). There is a need to study the ability of citizen scientists to collect data that is considered as reliable as data collected by a professional.

1.7.3 Credibility

Even though the literature on citizen science data collection discusses numerous studies and displays the advancement in community monitoring programs (Bonney *et al*., 2009), there is still some skepticism as to whether volunteers can collect data as credible as that collected by professionals. As noted by both Nali and Lorenzini (2007) and Au *et al*. (2000), environmental education can be taught through volunteer activities. Even students from local schools can become involved in community-based monitoring.

By reviewing the literature, it becomes evident that the methodology can be a potential source of error in volunteer-based water monitoring studies. Au *et al*. (2000), compared the data collected by students with no background in water quality who used simplified methodology, with data collected by a microbiologist. The students were provided with a brief environmental training and they then collected various chemical and physical parameters. The study concluded that the simplified methodologies can provide comparable data.

In another study (Caselle *et al*., 2011), the Reef Check California (RCCA) program in Southern California, a volunteer-based citizen group, monitored biological and physical parameters. However, when compared with the professional group, the volunteer-based groups sampling protocol included simplifications to make the process more accessible to them. The results showed some discrepancies between the data collected. First, there were differences in physical habitat variables, and how both of the programs selected their starting transect points, i.e., there were small-scale spatial and temporal differences between the two groups. Secondly, the identification of fish species showed discrepancies as this can be a difficult process. The last source of potential error involved the overall study design of the program. Although much of the data was comparable between the two groups, differences could have resulted in biases and errors in the methodologies, or the fact that the study used a post-hoc design and the data was not synoptically collected. The study concluded that in order for data from both groups to be used, procedural changes would have to be made as the collection protocol was too comprehensive for volunteer groups.

In a recent study conducted by Shelton (2013), a more in-depth study was conducted on the accuracy of citizen science water quality data when compared to the data collected by a trained professional. The study indicated that water temperature, pH, conductivity, and discharge, were among some of the potential water quality parameters which would be acceptable for citizen scientists. The study also concluded that monitoring dissolved oxygen would require further training on the correct use and handling of equipment and also on the detailed field sampling procedures. Shelton's study contained a strict methodology which included calibration and field training with sampling being conducted in-situ at the same time.

Chapter Two

STUDY AREA

2.1 Introduction

The African continent is comprised of countries with varying cultures, traditions landscapes, and wildlife. The Republic of The Gambia, also referred to as The Gambia, is a small West African country (the smallest on the continent), well-known as the "Smiling Coast of Africa" due to its geographical location and its notably friendly residents. The population of The Gambia has increased from 1.5 million people in 2006 (Gregg & Trillo, 2006, p.5) to an estimated 1.8 million in July 2013 (CIA World Factbook, 2014). Eighty percent of the population lives in rural settlements along the Gambia River (Ceesay, 1993).

The Gambia's official language is English, but numerous other traditional languages are still spoken, including Mandinka, Fula, Wolof and Jola. The vast majority of Gambians speak several languages, as well as English, which is learned through the educational system. French is commonly spoken along the border with Senegal as it is the official language of that country. Ninety-nine percent of the country's population is African and includes ethnic groups such as; (1) Mandinka: 42 percent; (2) Fula: 18 percent; (3) Wolof: 16 percent; (4) Jola: 10 percent; (5) Serahuli: 9 percent; and (6) other:

4 percent (Archer *et. al*, 2006). The country is predominantly Muslim (90 percent), but nine percent follow Christian beliefs or other indigenous beliefs (1 percent) (Janson, 2011). Islam traveled across the Sahara desert and arrived in West Africa in about 1900 and became a very powerful influence in the area, resulting in the majority of the West African population converting to this religion (Buah, 1977, p.31; Darboe, 2004). Today, practicing Muslims pursue Islam as their way of life. On Friday, the Muslim Sabbath, it is very common to see men and women dressed in traditional clothing as they go to the mosque for Friday prayer.

Due to its location and friendly nature of its citizens, The Gambia has become a popular tourist destination for many Europeans and travelers from around the globe. Tourists flock here to enjoy the beautiful unspoiled beaches and the relaxed atmosphere which the country offers. The country is a bird watcher’s paradise as it is home to over 600 species (Walley, 2006) but The Gambia lacks Africa’s large mammals, with the exception of the hippopotamus found in the upper regions of the river. The country is not heavily industrialized and there are no major sources of pollution.

2.2 Land Use

The Gambia is a country with a long history and it is the oldest British colonial territory located in West Africa (Higson, 1961). Impressive burial sites and stone circles (**Figure 2.0**) are found here. The Wassu Stone Circles date to AD 500-1000 which is an indication that the country has been inhabited for over one thousand years (Norton, 2006).

In the 1450s, the Portuguese and Italians used the Gambia River and Rio Grande estuaries as a way of exporting slaves from Senegal (Newitt, 2005, p.29). The Gambia River was a major gateway to the West African interior, as it provided a way to transport slaves from the continent's interior at James Island. Bathurst, now known as the capital city of Banjul, was founded by the British in 1816 as a trading post and, in 1821, the Banjul area was laid out with wide streets which followed a grid pattern. (Europa, 2010, p. 529; Hoepli, 1971, pp.131-132). The country was colonized by Europeans in the latter part of the 19th century and was recognized as a British crown colony in 1889 (Gailey, 1965). It became a separate state under international law from 1894 until it gained independence from Britain on February 18th, 1965 (Berlin, 2006; Commonwealth, 2012; Sallah, 1990). On July 22nd 1994, the current president, Yahya Jammeh, took power in a peaceful coup. President Jammeh has brought some stability to the country, being re-elected three times, most recently in November, 2011.

Figure 2.0. Wassu Stone Circles in Wassu, Central River Region, The Gambia
Source: Photograph captured by author, Melissa Healey

2.2.1 Economy

The Gambia is a low-income country which relies heavily on agriculture and tourism for its survival. Chartered flights enter the country from October to May (Ceesay, 1993) providing many jobs for local Gambians within hotels, restaurants and tour operations. Tourists purchase local food, drinks, and souvenirs which sustain many Gambians over the low tourist season. The primary economy consists of agriculture, fishing and livestock. The chief crops in the lowlands and middle regions of the country are rice in the rainy season and vegetables in the dry season. Groundnuts are the country's major cash crop in the upper regions of the country (Ceesay, 1993). Sorghum and millet are also grown during the rainy season (Ceesay, 1993; Jarrett, 1948).

2.3 Description of Study Area

The Gambia is an elongated, narrow country (**Figure 2.1**), approximately 48 kilometers at its widest point near the coast at Banjul and about 24 kilometers in width at its eastern end (Hughes, Hughes & Bernacsek, 1992; Sallah, 1992). The boundaries of the country are 480 kilometers in length, and the land has a total surface area of about 11,300 square kilometers making The Gambia the smallest, most densely populated country on the continent (Gregg & Trillo, 2006, p.5). The Gambia shares the watershed with Senegal and Guinea (**Figure 2.2**).

There are five main administrative divisions within The Gambia: (1) Central River Region; (2) Lower River Region; (3) North Bank Region; (4) Upper River Region; and (5) West Coast Region (**Figure 2.3**).

2.4 Climate

West African climates fluctuate from humid to semi-humid to arid. The Gambia is a Sahelian state with a sub-tropical climate. It is located halfway between the Tropic of Cancer and the Equator so there is intense sunlight year round and high temperatures for most of the year, with very little temperature fluctuation. The weather is influenced by the West African Monsoon (WAM) wind system which is driven by land-sea thermal differences and also by the release of heat into the atmosphere (Lau *et. al*., 2010). The sub-tropical climate of The Gambia consists of two seasons; rainy and dry. The rainy season typically extends from June to October (Albaret et al., 2006; Higson & Gatrell, 1961; Louca, Lindsay, Majambere & Lucas, 2009; Mikhailov & Isupova, 2007). During this season, humidity increases and rainfall is heaviest in July and August. Winds blown from Guinea to the south carry moist air and bring rain. During the rainy season, the country experiences severe flooding, mudslides, and landslides, making travel by road difficult in many areas. The night-time temperatures stay around 20 degrees Celsius while daytime temperatures are in the low 30s. The dry season is typically from November to May (Albaret *et al*., 2006; Higson & Gatrell, 1961) and the arid conditions cause the land to become extremely dry. Grasses and shrubs wither due to the hot dry Harmattan winds which blow from the Sahara Desert.

Climate change is not a new concept, as it has been in the media for the past few decades. It has a significant effect on ecosystems, modifies long term weather patterns, and water quality. The Intergovernmental Panel on Climate Change (IPCC) has declared that the African continent is one of the most susceptible places for climate change worldwide (Huq & Ayers, 2007). In The Gambia, climate change has already affected rainfall patterns. The rainy season is more unpredictable which can lead to a negative effect on water security, crops, and day to day life in general (Toulmin, 2009). Daily weather temperatures have been steadily increasing in The Gambia since 1965 (NAPA Government of The Gambia, 2007), which can affect crops and water security, and increase the distress associated with speculating when the next rains will occur. With increases in temperature, there is also concern for the health of Gambians; temperature increases could lead to a greater incidence of heat stroke, dehydration, and malaria.

Climate change can have a lasting negative impact on the Gambia River. As the temperatures increase, sea-level rise will force the Gambia River to rise, flooding the land and surrounding crops. This can have a severe impact on the country’s food security. Also, this rise in water could increase the spread of invasive species to new areas.

Figure 2.1. The Gambia Location Map

Source: Cartography by Will Flanagan, Saint Mary's University, February 2013. Data Sources: Map Titles by Stamen Design, Under CC by 3.0. Data by Openstreetmap, Under CC by SA

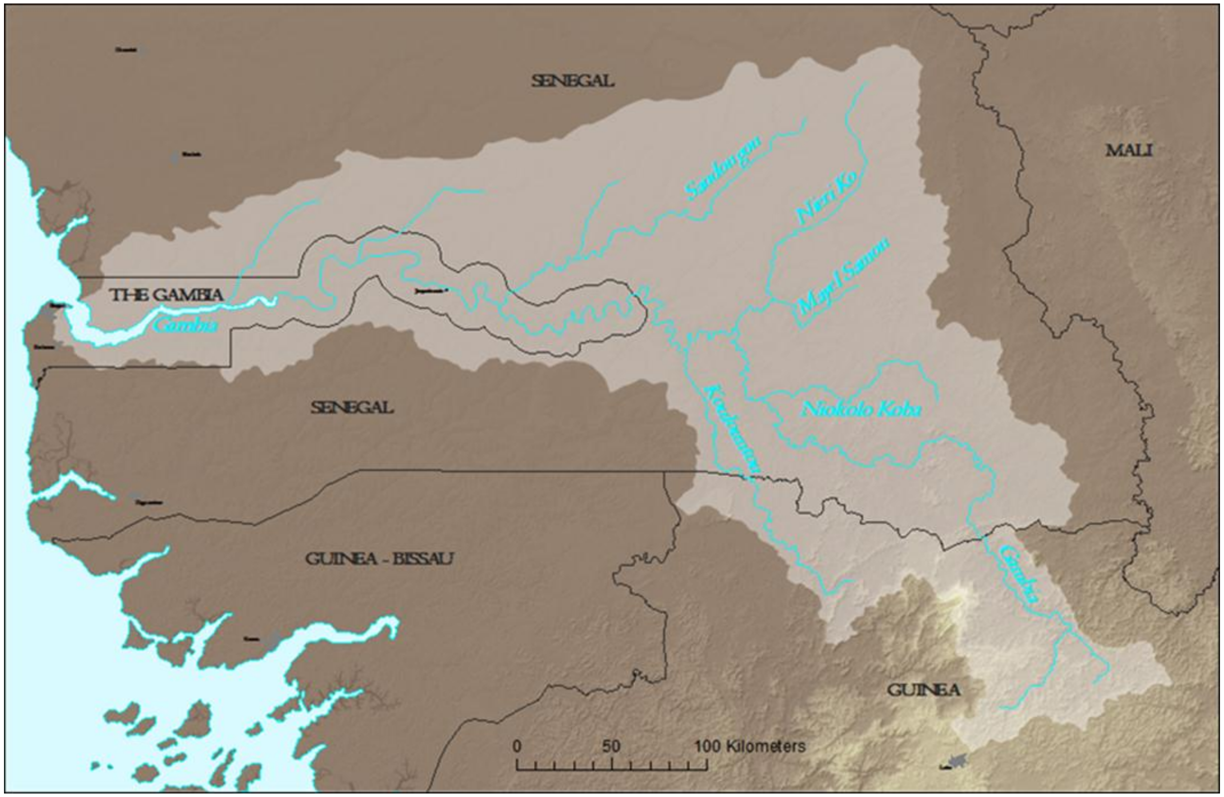

Figure 2.2. Watershed of the Gambia River

Source: Cartography by Greg Baker, Saint Mary's University, 2012. Data Sources: Shuttle Radar Topography Mission Level-1 Data, National Aeronautics and Space Administration, 2000; ESRI Data & Maps, Environmental Systems Research Institute/DeLorme, 2012

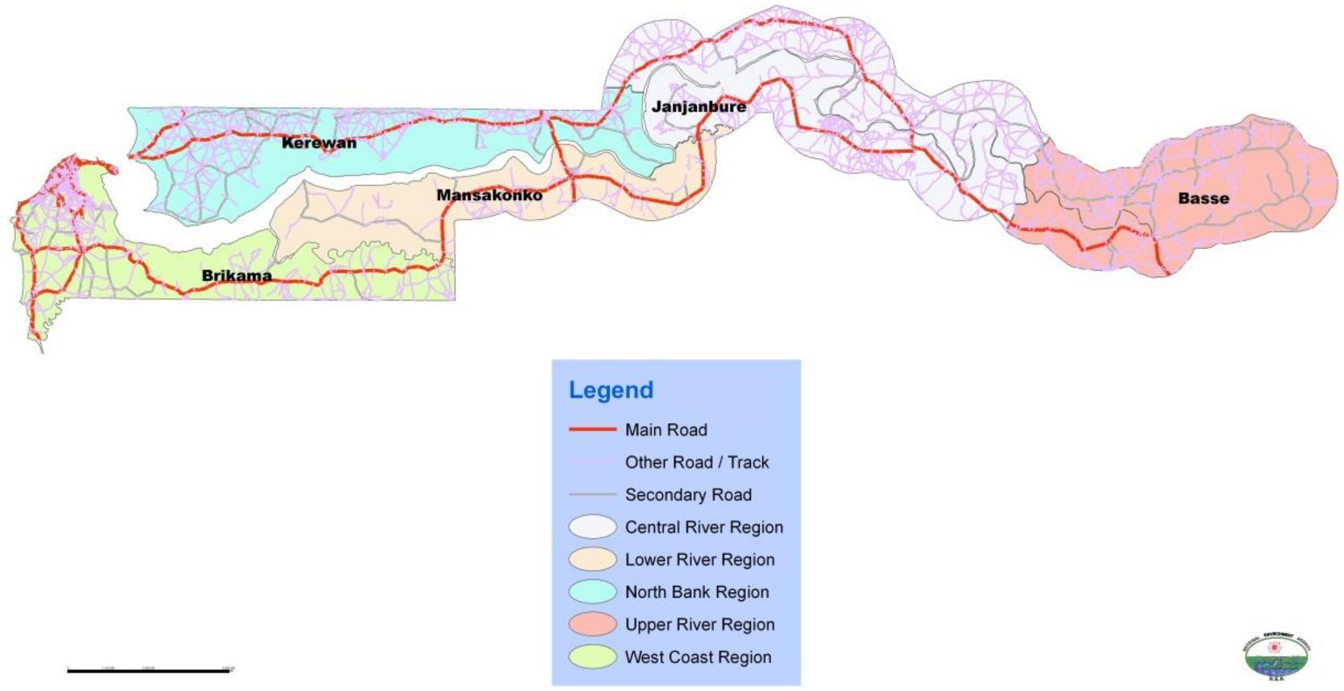

Figure 2.3. The Administrative Regions of The Gambia

Source: The Gamiba National Environment Agency. Modified by author, Melissa Healey

2.5 The Gambia River

Rivers and watersheds, as landscape features (Harvey & Clifford, 2009), are comprised of many components (Strobl & Robillard, 2008). The Gambia River, often referred to as the River Gambia, is a complex biological system and is important for the survival of the human population. Most of The Gambia's population is spread out along the river. It provides for the transport of goods and as a water resource. Often, water is collected from the river and is used for purposes which may contaminate the water before being returned to the river in an inferior condition (Bartram & Balance, 1996). Many Gambians use the Gambia River for daily activities that include drinking, irrigation, etc. Therefore, the quality of water is important (Gailey, 1965).

The geomorphology of The Gambia is dominated by the Gambia River, the country's most valuable natural resource. The river flows through the center of the country from East to West, emptying into the Atlantic Ocean (**Figure 2.2**). It also divides the country into the North bank and the South bank, and both Senegal and Guinea can be reached by travelling along the river (**Figure 2.3**).

The majority of The Gambia is less than 20 meters above sea level, and no point in the country is more than 60 meters above sea level. The Gambia River is one of the few remaining river systems in Africa which is free flowing and currently does not have dams or catchment areas within the limits of the country (**Figure 2.4**). Furthermore, the Gambia River has not yet been heavily damaged by human disturbance and industrial pollution (Lae *et al*., 2004; Albaret *et al*., 2006; Louca et *al*., 2009).

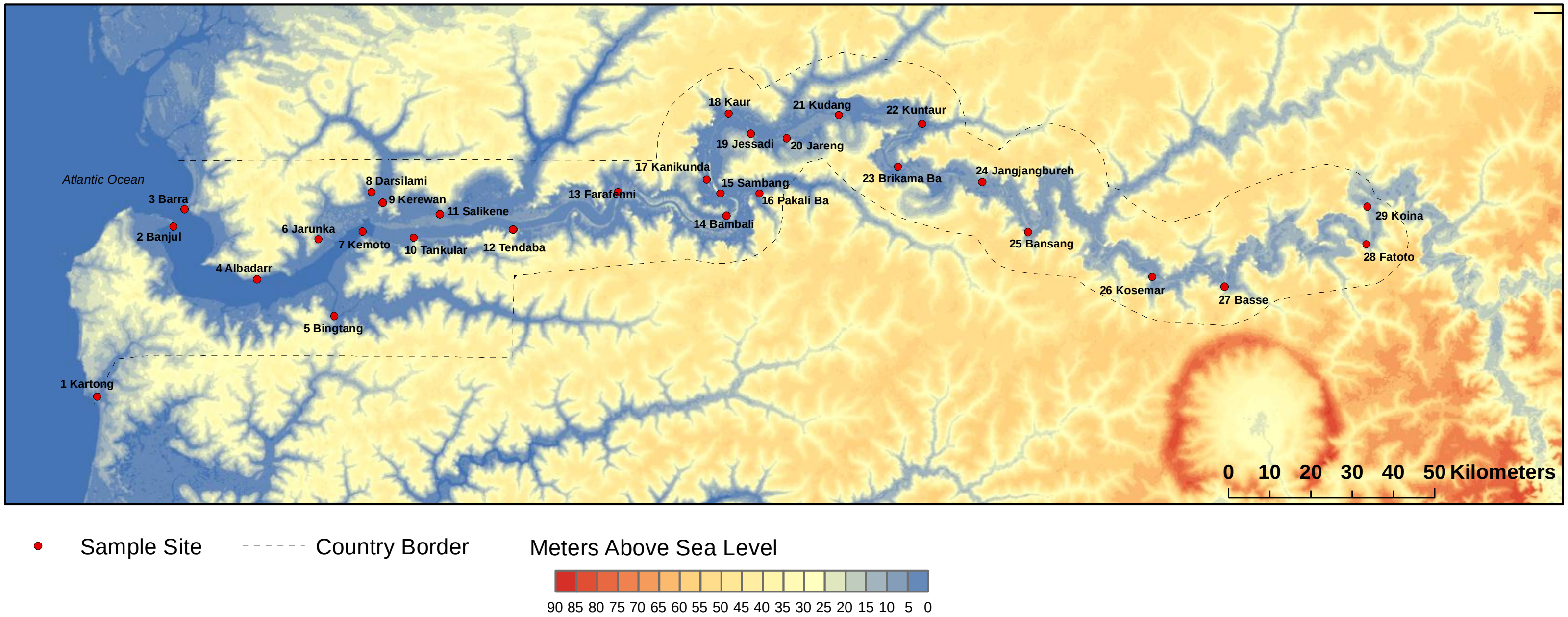

Figure 2.4. **Elevation Map of The Gambia**
Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Data Source: Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

2.6 Surficial Hydrology

Three separate rivers, the Niger, the Senegal and The Gambia initially flow north and then west (**Figure 2.2**). The Gambia River is 1,130 kilometers long and rises in rugged highlands beginning in the Fouta Dajallon plateau in northern Guinea. It flows through southeastern Senegal, westward through The Gambia, and eventually into the capital city of Banjul, where it empties into the Atlantic Ocean (Hudgens & Trillo, 2008, pp.263-320). The river basin covers approximately 77,054 km^2 (Albaret *et al*., 2006; Guillard *et a*l., 2004; Healey, Moll & Diallo, 1988). There is a one meter drop in the river over the last 500 kilometers of the river until it reaches the Atlantic Ocean (James, 1992). This section has adjacent floodplains that are flooded seasonally (Louca *et al*., 2009). The rainfall is greatest in August and a peak in the river discharge occurs in September after which it falls to almost zero by December (Albaret *et al*., 2004; Louca *et al*., 2009).

Climate change will not only affect rainfall patterns and temperature in The Gambia, but it will also severely affect sea-level rise and coastal erosion, crop yields, and the fishery (Dixon, Smith, & Guill, 2003). Sea-level rise increases of 1.0 meter (Dixon, Smith, & Guill, 2003) will result in a higher loss of land due to floods rather than erosion. According to Hug *et. al* (2007), climate change is projected to increase runoff in the catchment area of the Gambia River by 50%. This in turn will have a growing effect on the salt water intrusion in the river, by increasing runoff by 3% which would result in major alterations to the river's balance.

2.7 Geology

The Gambia's geology is composed of Cenozoic rocks made of alluvial, fluvial marine and coastal beach sediments (Schlüter & Trauth, 2006). The geological formations in The Gambia consist of the Essau formation (white, fine to medium, quartz sandstone), the Yumdum formation (sandy clay), the Sapu formation (brown ferrogenous quartz sandstone) and the Farafeni rock formation (grey symmict sandstone, silt, clay and cockle shell (Camara & Jobe, 2011).

The areas along the coast are comprised of mainly sedimentary rocks and are slightly thicker towards the West of the country (Camara & Jobe, 2011; Jallow, Barrow & Leatherman, 1996; Schlüter & Trauth, 2006). The Banjul spit formation and other areas along The Gambia River and its tributaries, are a Holocene feature comprised of marine/coastal sands, silts, clays/salts; they sometimes contain organic intercalations (Schlüter & Trauth, 2006.; Jallow *et. al.,* 1996). Thus, Banjul has been built on a landform consisting of erodible sedimentary materials. The beaches of the country consist of predominantly white, medium/fine pure quartz sand but some beaches consist of yellow cockle shell (Camara & Jobe, 2011).

2.8 The Gambia River Zones and Ecology

The lack of gradient in the lower reaches (**Figure 2.4**) results in the river being divided into two distinct zones: an estuarine and an upper river freshwater segment

(Jarrett, 1948). These two zones influence agriculture and play a major role in the ecosystems that are present (marshes, mudflats, mangroves and swamps).

The Gambia, inland from the river, consists of a Savanna, or grassland ecosystem (**Figure 2.5**). Areas along the coast consist of relatively flat sandstone cliffs and sand dunes. The estuary consists of grassy banks in the wet season (Higson & Gatrell, 1961). Further away from the river (approximately 3 or 4 kilometers), the land is elevated and dry which creates ideal conditions for building villages.

2.8.1 Saltwater Estuarine Zone

Upstream from the mouth of the river, at the Atlantic Ocean, saltwater intrusion has a major effect on the surrounding landscape. The river is tidal and brackish water can penetrate up to 200-250 kilometers from the river mouth in the dry season, but not as far in the rainy season when the river receives an influx of freshwater (Albaret *et al*., 2004; Healey *et. al*, 1988; Louca *et al*., 2009; Webb, 1992). The point at which these two zones meet is referred to as a salt front. Clay soils support tidal communities of thick mangrove swamps along the river and its tributaries (**Figure 2.6** and **Figure 2.7**). These tributaries are referred to as bolongs locally and drain into the lower portion of the river basin (Albaret *et al*., 2006; Giglioli & Thornton, 1965). The *Rhizophera racemosa* mangroves reach 4.5 meters in height and behind these mangroves are shorter *Avicenna africana* trees which reach 2 to 2.5 meters (Webb, 1992). During the rains, these mangroves are flooded with diluted salt water, as are adjacent lands which are unsuitable for agriculture during this period of the year.

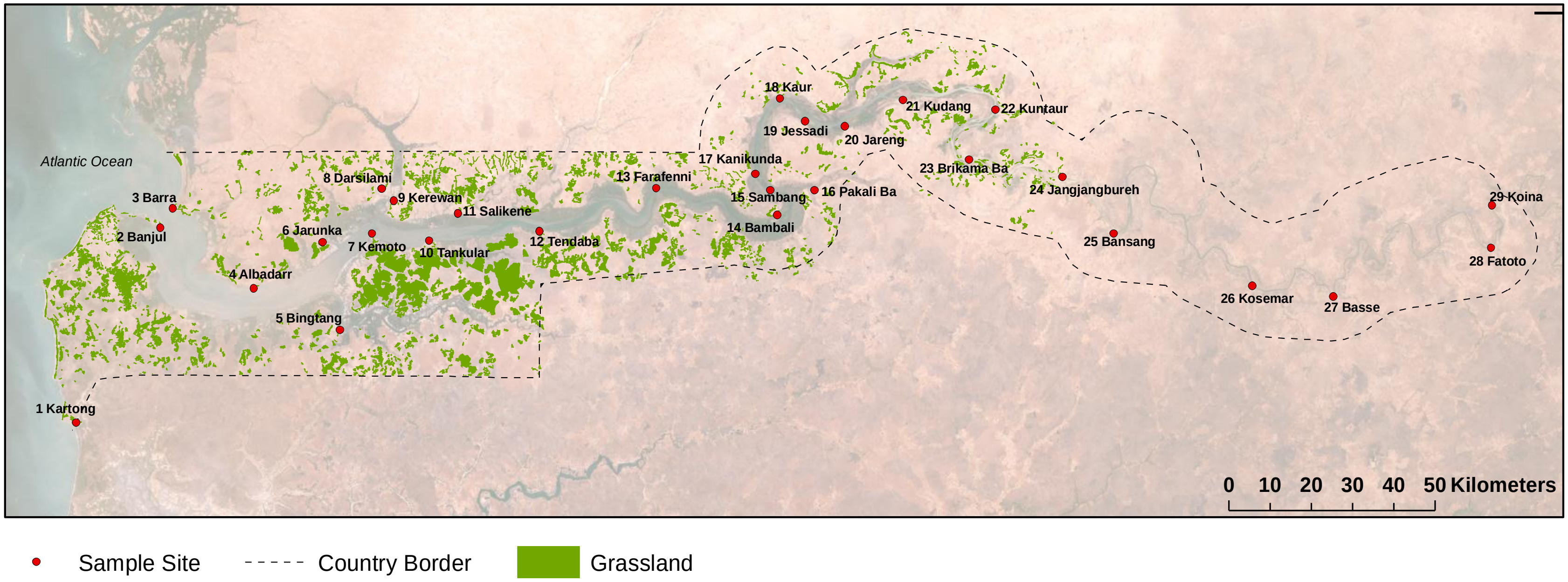

Figure 2.5. Grassland Area of The Gambia
Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Data Source: Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey, Land Data Provided by The National Environment Agency, The Gambia

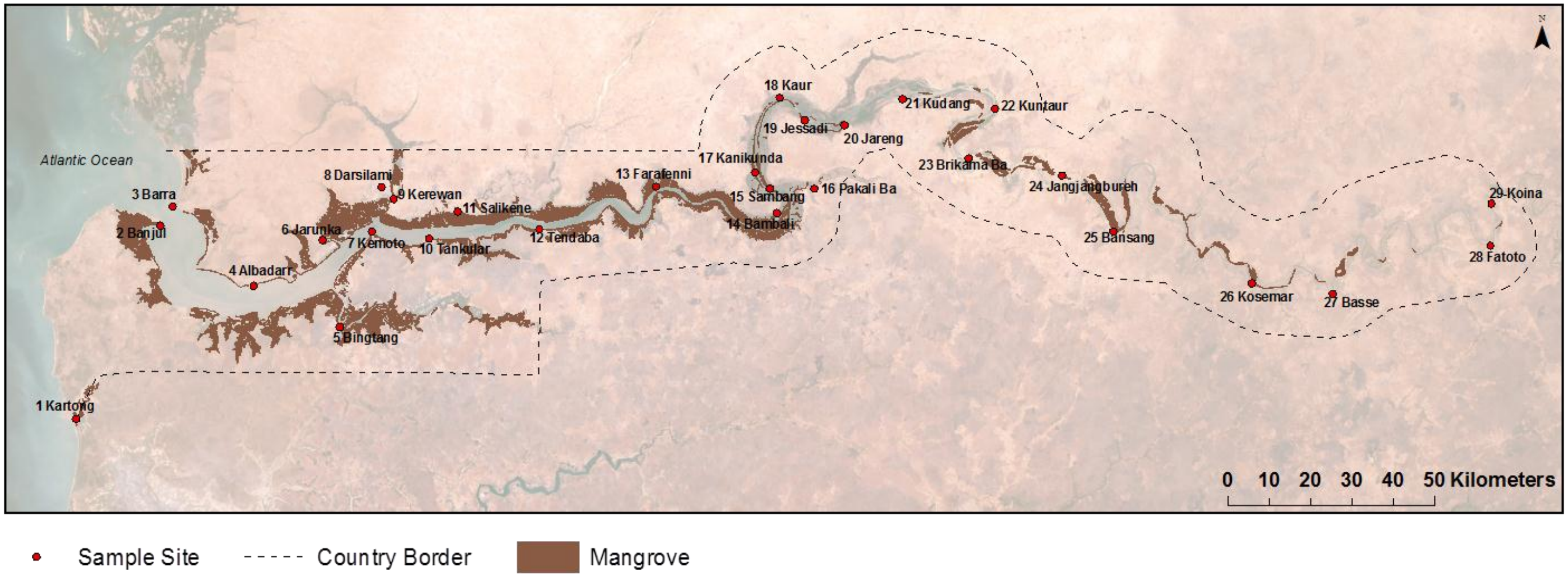

Figure 2.6. **Mangrove Area of The Gambia**

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Data Source:Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey, Land Data Provided by The National Environment Agency, The Gambia

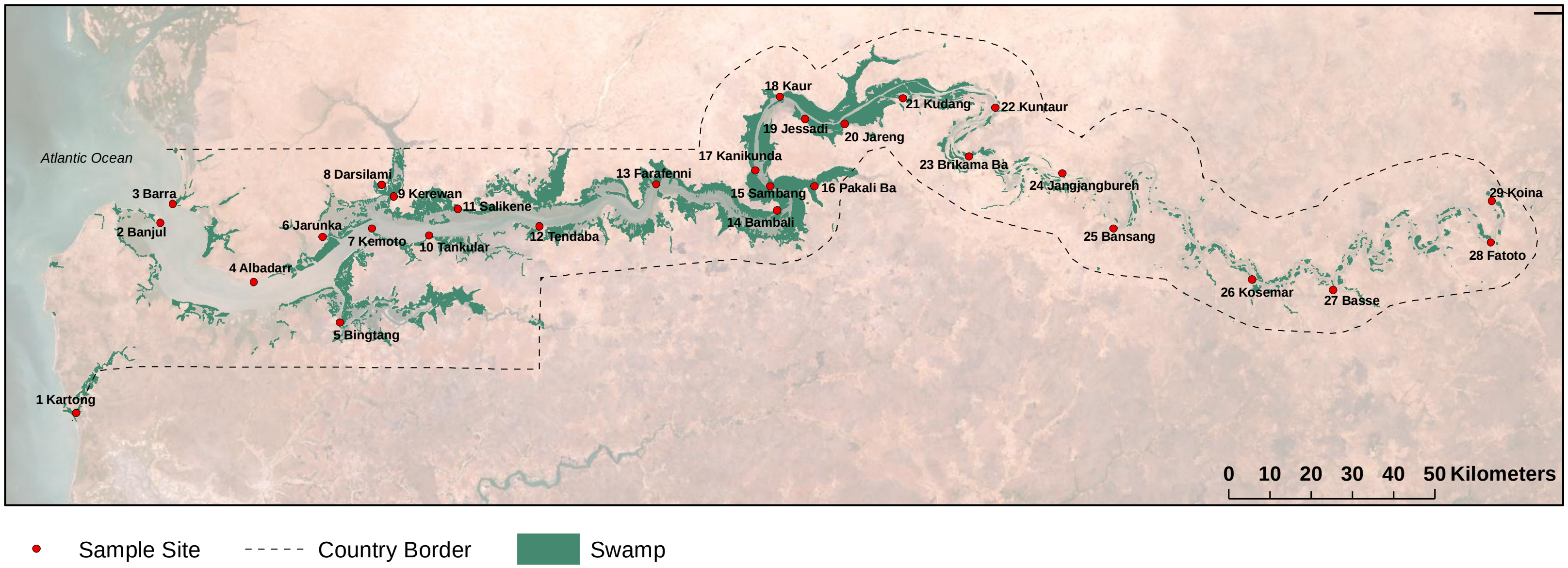

Figure 2.7. **Swamp Area of The Gambia**

Source:Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Data Source:Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey, Land Data Provided by The National Environment Agency, The Gambia

2.8.2 Freshwater Environment Zone

In the upriver freshwater zone, thick mangroves are replaced by marshy flatlands that extend up to 290 kilometers inland. Riverbanks become more distinct but high waters are still present in the rainy season (Webb, 1992). In this zone, the land is flooded with freshwater in the rainy season and the river consists of freshwater year round. The soils and land are more fertile and allow for the production of a wide range of agricultural crops including several varieties of rice, the country's dietary staple (Jarrett *et al.*, 1948). The area referred to as Banto Faros is the main area for rice production in the country (**Figure 2.8**).

2.8.3 Water Quality

There are two primary sources of water within the Gambia: surface water and groundwater. Surface water includes lakes, rivers, oceans or streams; in The Gambia it comes from the Gambia River and its surrounding tributaries. Due to the salinization and contamination of surface waters, groundwater and bottled water have become the primary sources of drinking water in The Gambia. Groundwater is water which is extracted from underneath the earth's surface or bore holes.

Although the water quality in the Gambia is of concern, Gambians are within the top 10 percent of Africans having sufficient access to safe drinking water (Mwanza, 2003). However, the water quality varies significantly within the different regions. For example, the eastern portion of The Gambia contains the best quality of water in the country for irrigation. This region has abundant freshwater with very little, if any, salt

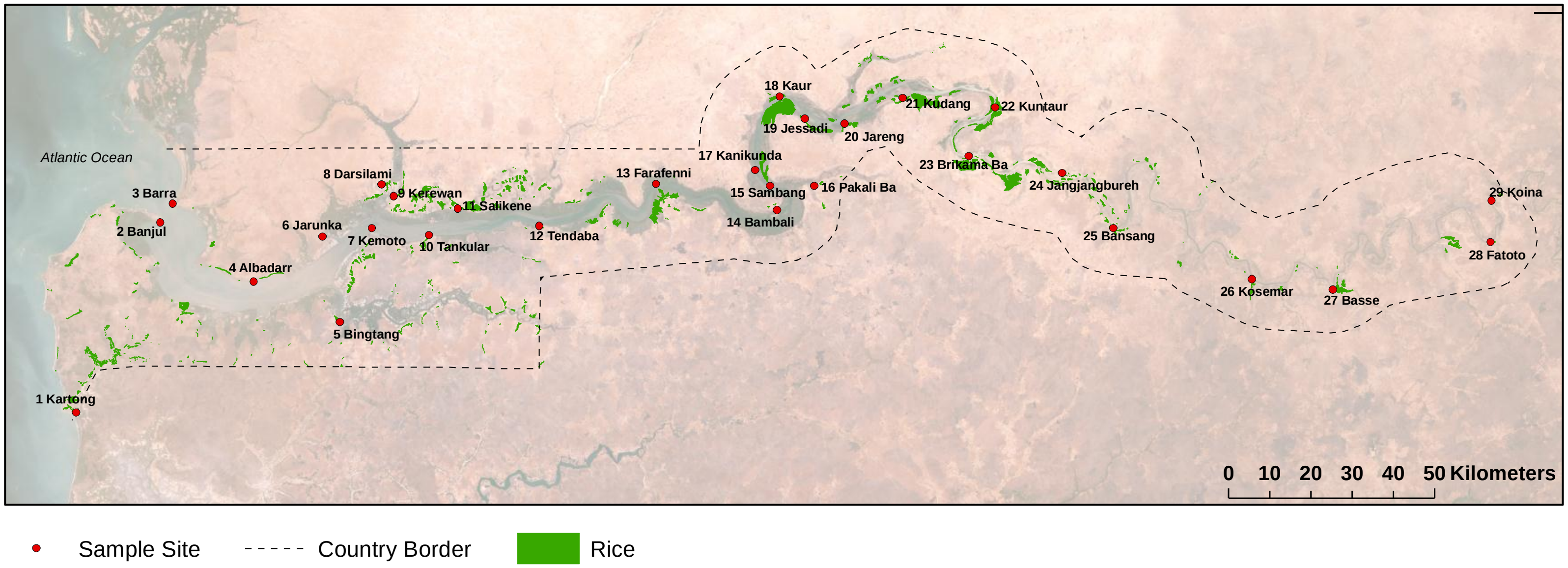

Figure 2.8. **Rice Area of The Gambia**

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Data Source:Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey, Land Data Provided by The National Environment Agency, The Gambia content (NAPA, 2007), making the water useful for crop irrigation. It is not suitable for drinking purposes due to the presence of coliform bacteria in the water.

2.9 Human Impact

The Gambia River is an important source of communication within the country, being used as a transportation route. Humans have had an impact on the riverbank. Many of the mangrove swamps have been cut for rice cultivation, largely in the upriver areas. Due to increased land clearing for agriculture, erosion and siltation are becoming more evident.

Desertification, when dry lands become increasingly arid, is a recent problem in The Gambia (Cheesay, 1993). Lands are being overgrazed, used for agriculture, or building. The Gambia now has desert shrub communities and very little natural grasslands remain. Desertification has a major negative effect on surrounding ecosystems, limiting the production of crops, water transport, wood, and other important ecosystem services.

3.0 Summary

The Gambia is a unique African country which resides as a small landmass in West Africa. The Gambia River is the dominant feature which runs the entire length of the country and provides food, transport, irrigation, and a way of life. It is important to study and understand this delicate, yet vital, attribute.

Chapter Three

RESEARCH DESIGN AND METHODS

3.1 Water Quality Characterization

The world over, water is a human right (WHO, 2003). All persons should have access to clean, potable water to allow for a sustainable, healthy life. Without such access, we run the risk of contracting water borne diseases, food contamination and insufficient ecosystem health.

Water quality can vary greatly over a short distance or time frame due to changes in the physical, chemical, and biological characteristics of the water. For this reason, it is important to obtain a diverse, extensive range of sampling locations within a particular water body in order to allow for an overall snapshot of the water quality in a particular area of interest. Identifying and understanding water quality conditions are essential for ensuring human and ecosystem health, while recognizing the importance of water quality can help prevent many future water concerns and harmful diseases.

With water quality becoming such an important topic in recent years, more volunteers are becoming involved in local water quality studies when concerns arise within their community. However, the data collected are often considered unreliable by professionals and professional institutions due to the lack of credentials citizen scientists hold. Volunteers are critical to any aspect of research, as they often work for free and have extra time to become involved in a particular project. It is important that volunteer data not be discredited, and that volunteers are not discouraged.

In order to conduct a baseline study of water quality on the Gambia River, a field study was conducted over a 17 day period, from December 6th 2011 to December 22nd 2011, within the boundaries of The Gambia. A smaller, secondary study also took place during this time, to examine and compare the accuracy of data collection between volunteers and professionals at three chosen locations throughout the study area.

3.2 Preliminary Evaluation

Prior to data collection in December 2011, a one week investigative trip to The Gambia was carried out from July 23rd 2011 to August 2nd 2011 to plan the study design and identify potential sampling locations with the use of local topographic maps and discussions with the Gambian Water Resources Agency staff. These locations were delineated using the ArcGIS mapping program. During this time, a meeting with the head of The National Water Quality Monitoring and Control Laboratory in Banjul, took place. An employee for the Ministry of Fisheries and Water Resource, assisted in identifying the 29 sampling locations which were used in this study (**Figure 3.0** and **Table 3.0)**. In order to encompass both the saltwater and freshwater environments, and the breadth of the entire country, it was decided that the study area for this thesis would extend approximately 424 kilometers from Kartong (13.07356;-16.7433) up-country to Koina (13.48922;-13.8897) near the Senegalese border. The study area included sites located within each of the five regions and two municipalities, and took place along both the North and South banks of the river during the dry season, due to time restraints and travel limitations.

A meeting was arranged with a senior staff member at the National Environment Agency office in Kanifing, where Geographical Information System (GIS) data were obtained on mangroves, rice, swamps, roads, grasslands and forests in order to create a better understanding of the ecosystems and surroundings of the Gambia River.

In order to accommodate both the main water quality study and the secondary citizen science study, a sampling itinerary was created in consultation with the Nova Scotia - Gambian Association. This itinerary included a field work schedule to facilitate the most feasible times for sampling (**Appendix A, Figure 1**). It also included the dates and locations of a water training program which was being conducted by Nova Scotia-Gambia Association (NSGA) Peer Health Educators. It was decided that I, the professional holding certification, would use the data collected by the peer health educators during this education session as citizen science data for the secondary study (**Figure 3.1** and **Table 3.1**).

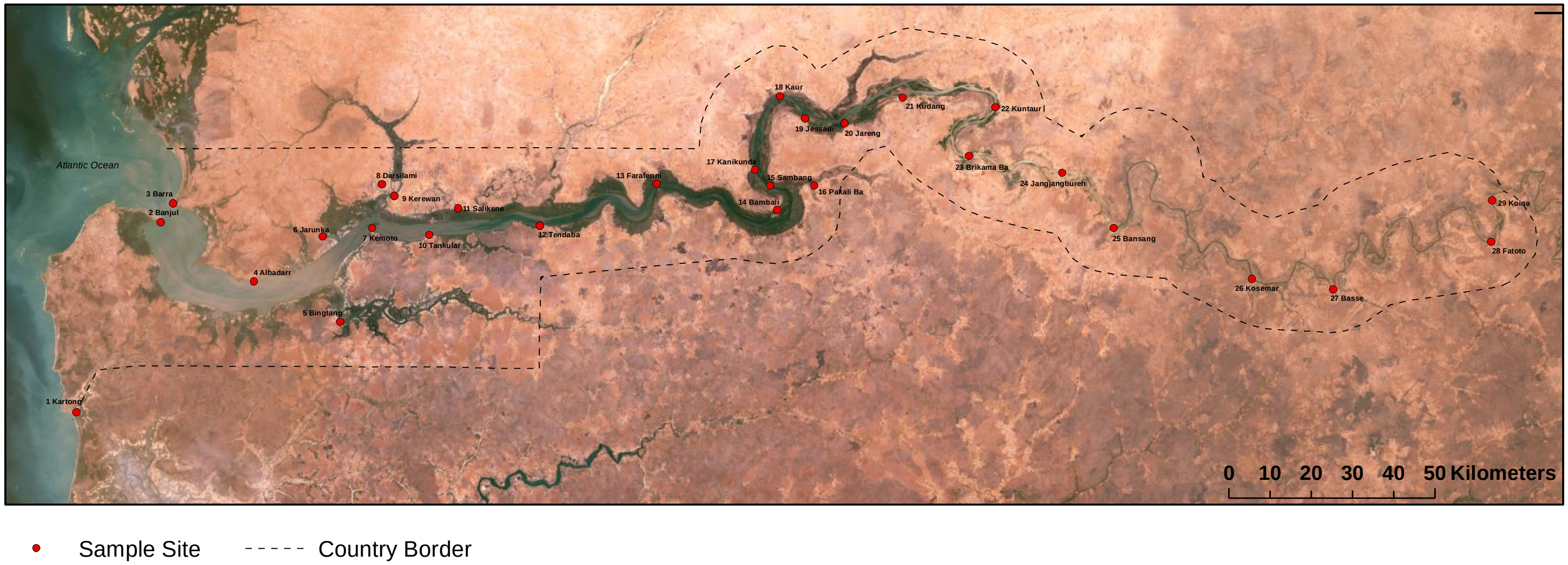

Figure 3.0. Surface Water Quality Sample Sites

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary’s University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

Table 3.0. Water Quality Sampling Locations with Corresponding GPS coordinates

Site Code	Name	Location	Latitude	Longitude
1	Kartong	South Bank	13.0736	-16.7433
2	Banjul	South Bank	13.4464	-16.5724
3	Barra	North Bank	13.4838	-16.5479
4	Albadarr	North Bank	13.3307	-16.3843
5	Bintang	South Bank	13.2508	-16.211
6	Jurunka	North Bank	13.4181	-16.2459
7	Kemoto	South Bank	13.435	-16.1464
8	Darsilami	North Bank	13.5206	-16.1273
9	Kerewan	North Bank	13.4978	-16.1024
10	Tankular	South Bank	13.4207	-16.0316
11	Salikene	North Bank	13.4736	-15.9735
12	Tendaba	South Bank	13.44	-15.8093
13	Farafenni	North Bank	13.5208	-15.5735
14	Bambali	North Bank	13.4705	-15.3305
15	Sambang	North Bank	13.5175	-15.3441
16	Pakali Ba	South Bank	13.5246	-15.2455
17	Kanikunda	North Bank	13.5484	-15.3742
18	Kaur	North Bank	13.6926	-15.3243
19	Jessadi	South Bank	13.6493	-15.2744
20	Jareng	South Bank	13.6396	-15.1939
21	Kudang	South Bank	13.6894	-15.0772
22	Kuntaur	North Bank	13.671	-14.891
23	Brikamaba	North Bank	13.5762	-14.9437
24	Jangjangbureh	North Bank	13.5429	-14.7556
25	Bansang	South Bank	13.4346	-14.6524
26	Kosemar	South Bank	13.3358	-14.3734
27	Basse	South Bank	13.3153	-14.2109
28	Fatoto	South Bank	13.4072	-13.8921
29	Koina	North Bank	13.4892	-13.8897

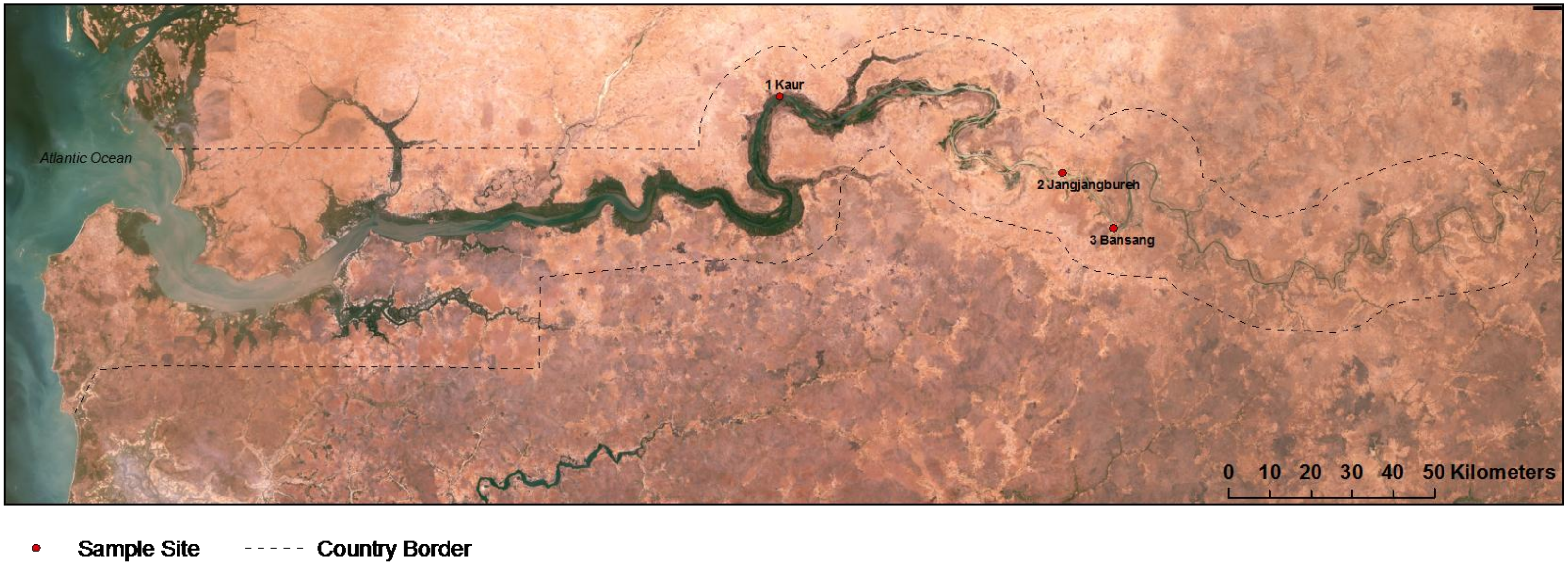

Figure 3.1. Citizen Science Sampling Sites
Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

Table 3.1. Citizen Science Sampling Locations with Corresponding GPS coordinates

Site Code	Name	Location	Latitude	Longitude
1	Kaur	North Bank	13.6926	-15.3243
2	Jangjangbureh	North Bank	13.5429	-14.7556
3	Bansang	South Bank	13.4346	-14.6524

3.3 Secondary Evaluation: Main Study Procedures and Protocols

Research involved collecting surface water quality data at 29 various locations along the Gambia River in order to identify baseline data associated with human and ecosystem health. Sampling was conducted from the coast to the Senegalese border to provide an indication of the entire river's water quality within the country's boundaries.

Field procedures were based on water quality data collection techniques designed by the Canadian Council of Minister of the Environment (CCME) and the Canadian Aquatic Biomonitoring Network (CABIN). The calibration procedure used in this study was adapted from YSI and the (CCME) guidelines.

3.3.1 Study Design

Upon arrival at each location, a suitable sampling point was chosen based on accessibility and safety for the sampling procedure. Once chosen, this location was labeled as "B" with visual markers (sticks, rocks, etc.) and was the first sample in the transect. Site "A" was then measured 15 meters to the left (downstream) of site "B" using a conventional metric measuring tape. Site "C" was located 15 meters to the right (upstream) of site “B”. See **Figures 3.2** and **3.3** for a visual representation.

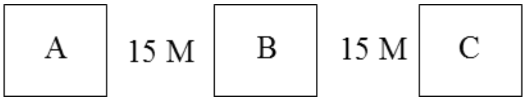

Figure 3.2. Transect Layout

A B C

Figure 3.3. Tendaba Transect

3.3.2 Site Description

Upon arrival at each location, photos were taken and GPS coordinates were recorded using a Garmin Oregon 550 unit. Field site notes and descriptions were recorded in a preassembled field sheet, noting the date, time, location weather conditions, air temperature, humidity, canopy cover, land use, etc. (**Appendix A, Figure 2**). A solar wireless weather station was placed out of direct sunlight and was left for 10-15 minutes to adjust before commencing measurements. At the end of each day, photos and site descriptions were transferred from a field notebook to a computer and hard drive for back up purposes.

3.3.3 Water Quality Field Measurements

Various parameters that can have an effect on the water quality of a river were measured. The parameters that were utilized in this thesis were: water temperature (°C), dissolved oxygen (%/mg/L), pH, conductivity (uS/cm), specific conductivity (uS/cm), total dissolved solids (mg/L), and salinity (ppt) (**Table 3.2**).

Two in-situ real time water quality probes were used during the study for quality assurance and quality control purposes (discussed further in section 3.3.4). The YSI units were labeled ‘unit 1’ and ‘unit 2’ to avoid confusion when recording measurements and calibrations. Before placing the probes side-by-side in the water, dissolved oxygen was calibrated and left to stabilize for 10-15 minutes on the riverside at each of the 29 locations. Measurements of water temperature, dissolved oxygen, pH, conductivity, salinity and total dissolved solids were taken using CCME (2011) protocols for sampling depth, with the exception of a stream profile due to limited equipment.

- Site with water depth <2m: in situ measurements taken just below the surface of the water (0.1m depth)
- Site with water depth ≤2m: in situ measurements taken at mid-depth
- Site with water depth >4m: taken just below the surface of the water (0.1 m depth) and at 1 m intervals to 1 m above the lake bottom

Sampling was then conducted with the probes side-by-side and left to stabilize for approximately 5 minutes. The probes were faced upstream of the sampler to avoid contamination and to minimize the possibility of disturbed substances affecting the reading. To ensure safety, rubber gloves and boots were used and all sampling was conducted with another person on site. Water quality data were recorded by hand from both YSI ProPlus (professional Plus) units onto field data sheets (**Appendix A, Figure 3**).

Three sample sites were used to collect data from each of the 29 locations. Each YSI unit produced 87 data sets, for a total of 174 water quality data sets from the two units. Data from each of the units were then analyzed statistically for each transect. The means and standard deviations for the parameters tested were calculated to produce a general snapshot of the water quality at each of the 29 sampling locations.

Presence/Absence Lamotte Total Coliform Bacteria tubes were used to collect three samples at each location for a total of 87 tests. The tube was placed into the water and the sample filled to the 10ml mark in one motion, ensuring that the reagent tablet remained inside. If the 10 ml mark was not reached, the cap of the tube was rinsed in the water and then used to fill the tube. The tube was not placed back into the water. The top was then screwed on and the tube was left closed, undisturbed, away from direct sunlight, and at room temperature (approximately 25 °C) during the 48 hour incubation period. At the end of 48 hours, colour changes (yellow to orange) and gas bubble formation were recorded and interpreted as a positive result. The above procedures were then repeated for transects B and C.

3.3.4 Quality Assurance/Quality Control

As outlined in section 3.3.1, two water quality probes were used in this study for Quality Assurance/Quality Control (QA/QC) purposes. The YSI ProPlus multi-probe, marked unit 2, was used to collect replicate data at each location for temperature, pH, dissolved oxygen, conductivity, salinity and total dissolved solid readings. Replicate data were collected at the same time and location and both probes were placed side-by-side.

Table 3.2. Water Quality Parameters

Author: Melissa Healey. Sources: Modified from (CCME, 2007; World Health Organization, 2011; PASCO, 2007).

Parameter	Units	Definition	Guideline
Dissolved Oxygen Content (DO)	mg/l or %sat	Amount of oxygen present in the water that enables organisms to breath.	Warm Water: 5.5 mg/L - 6 mg/L Cold Water: 6.5 mg/L - 9.5 mg/L Should not drop below 5.0mg/l
Water Temperature	°C	Measures the average thermal energy of particles within a substance.	Human influence should not alter water temperature in excess of +/- 1 °C Human influence should not alter the temperature more in excess of 0.5 °C per hour
Conductivity	µS/cm	Ability of a substance to conduct electrical current.	150-500 µS/cm in freshwater environments
Total Dissolved Solids (TDS)	mg/L	Inorganic salts and organic matter that is dissolved in a substance.	0.5 to 1.0 times the conductivity Acceptable level is approximately 500ppt
Salinity	PPT	Amount of salt or dissolved salt content of a substance.	Should not exceed 1000 ppt
pH	Units	Measure of how acidic or basic a substance is. Ranges from 0-14, 7 being neutral and 14 basic.	6.5-8.5 units Human influence should not exceed natural pH of water by more than 0.2 units
Fecal Coliform		Chemical indicator for bacteria (animal/human waste)	Should not exceed 200 cells per 100 milliliters for / water containing any fecal coliform is unsuitable for drinking

Both of the YSI probes were calibrated by the researcher and recorded on a field calibration sheet (**Appendix A, Figures 4** and **5**). Calibration for pH and conductivity was conducted when switching from salt water to fresh water or when there was a change in the sampling environment (i.e. muddy versus clean water). Calibration solutions of a buffer 4.00, 7.00 and 10.00 were used to calibrate the pH probe, while a conductivity solution of 12880 µS/cm was used to calibrate the conductivity sensor. Dissolved oxygen was also calibrated at each of the 29 sampling locations prior to data collection. On days when a full calibration was not conducted, due to limited calibration solutions and the unnecessary need for a calibration, verification was made to determine if the meter had drifted by submerging the probes in a standard calibration solution to check for accuracy.

The calibration procedure used in this study followed procedures in YSI Inc. (2001). If a measurement appeared out of range compared to the previous readings at the site, or compared to the replicate sample, a site re-measurement was taken before moving onto the next transect, and both measurements were recorded.

The field equipment was regularly cleaned and checked for required calibrations and the integrity of the dissolved oxygen membrane; the membrane was replaced if necessary. At the end of every sampling day, both probes were allowed to dry in order to ensure the equipment had full functional capability for the next sampling day. Cleaning and calibration were conducted in the cleanest available location.

3.4 Secondary Evaluation: Procedures and Protocols

A smaller research study compared the accuracy of data collected by volunteers and professionals at three locations within The Gambia. This was conducted during a Nova Scotia- Gambia Association Peer Health Education training session.

In this study, field procedures were based on water quality data collection techniques designed by of the Canadian Council of Minister of the Environment (CCME) and the Canadian Aquatic Biomonitoring Network (CABIN). The calibration procedure was adapted from YSI and the Canadian Council of Ministers of the Environment (CCME) guidelines.

For the purposes of this study, the term ‘professional’ refers to a person holding a Certified Engineering Technologist (CET) certification (TechNova, 2011), a Bachelor of Science Degree, and a diploma in Environmental Engineering – Water Resources.

3.4.1 Study Design

This study design followed the same procedural design as section 3.3.1 for the main study. At no point did I engage in conversation with the volunteers. The volunteers were given a two day water workshop by the Nova Scotia – Gambia Association. Prior to this, the NSGA was provided with a training program on water and how to use the water monitoring equipment. During this training, they were briefed on how to use the YSI probe and told the purpose of the measurements. At the end of the second day, students were taken to the river so they could handle the YSI probe, unit 2. Data was simply given to me after sampling for comparison.

3.4.2 Site Description

Upon arrival, both the volunteer and the professional independently recorded GPS coordinates using a Garmin- Oregon 550 unit. Field site notes and descriptions were recorded in a preassembled field sheet by both the volunteer and me. This included such things as weather conditions, air temperature and humidity, time and date, etc. (**Appendix A, Figure 6**). A solar wireless weather station was placed away from direct sunlight and was left for 10-15 minutes to adjust before commencing measurements. At the end of each day, site descriptions were transferred from a field notebook to a computer and hard drive for back up purposes. Both groups worked independently of each other, with no contact.

3.4.3 Water Quality Field Measurements

The YSI ProPlus in-situ water quality probe was used to measure six water quality parameters: water temperature (°C), dissolved oxygen (%/mg/L), pH, conductivity (uS/cm), specific conductivity (uS/cm), total dissolved solids (mg/L), and salinity (ppt). Refer to **Table 3.2**, for details of each of the parameters with their respective guideline.

The professional calibrated dissolved oxygen on both units prior to data collection, while the Peer Health Educators were training the volunteer. I handled unit 1 at all times, while the volunteer handled unit 2. While the units were stabilizing, the professional carefully observed the volunteer treatment group to record potential errors. The professional made detailed field notes once the volunteer commenced sampling.

Six sites were used to collect data. Each YSI unit produced 18 data sets, for a total of 108 water quality data sets from the two units. Data from each of the units were then analyzed statistically to produce a general snapshot of the water quality at each location and a comparison between the volunteer and professional data.

Water quality measurements were collected by the volunteer and the professional. Measurements were taken upstream, in an area of flowing current. Approximately 10 minutes (YSI, 2011) was required before measurements were taken to ensure the unit had enough time to adjust and then data were recorded in the field notes. I, the professional, placed unit 1 probe next to the volunteer probe and moved to the next location once the volunteer did so, without providing any instruction to the volunteer. This process was then repeated for the other two transects.

3.4.4 Quality Assurance/Quality Control

The field equipment, calibrations, membrane replacements, and equipment maintenance were all controlled and standardized for each volunteer in the treatment group by the professional. Both the YSI probes were also calibrated by the professional and recorded on a field calibration sheet (**Appendix A, Figure 4** and **Figure 5**). Calibration for pH, conductivity and dissolved oxygen was conducted on the morning of sampling as described in the main study (section 3.3.3). To ensure that the equipment was maintained properly with full function capability, the field equipment was also cleaned, calibrated, and checked as in the main study (section 3.3.4) for required membrane replacements prior to sampling. Cleaning and calibration was conducted in the cleanest available location.

The capability of volunteers to record data and field notes properly was an uncontrolled variable. The professional was at all times assigned YSI ProPlus ‘unit 1’ for the controlled variable and the volunteers were assigned ‘unit 2’ as the uncontrolled variable. Both the professional and the volunteers shared the weather station which remained at one location.

3.5 Statistical analysis

Water quality data analysis for both studies in this thesis were statistically analyzed using Minitab and Microsoft Excel software for means and standard deviations, Data were plotted on imagery maps of The Gambia, to give a visual representation of the water quality data. All statistical analyses were completed using original data, and no unusual anomalies were found.

3.5.1 Main Study

Water quality data collected from the two YSI ProPlus units were analyzed. For each parameter, the arithmetic mean, standard deviation, geomean, and the maximum and minimum number were determined for the three sample sites at each of the 29 monitoring locations. In order to show patterns along the river, data were then plotted on line graphs and bar graphs, using Microsoft Excel. Using Minitab Software, additional statistical analyses were conducted using the Anderson-Darling Normality test to test the normality of the data for each probe and each parameter (water temperature, pH, dissolved oxygen, conductivity, total dissolved solids and salinity).

The two hypotheses for the Anderson-Darling test for normal distribution are as follows:

H_0: The data follow the normal distribution.
H_1: The data do not follow the normal distribution.

The null hypothesis is that the data are normally distributed; the alternative hypothesis is that the data are non-normal. If the p value is low (e.g., $\leq$ 0.05), it is concluded that the data do not follow the normal distribution.

For data that were normally distributed between the two probes, a Paired t-test was used as the paired t-test assumes that the differences between pairs are normally distributed. For data that were non-normally distributed, a nonparametric test, the Wilcoxon signed-rank test, was chosen as it is an acceptable replacement for the Paired T-test (Moore, 2008). The Wilcoxon signed-rank test involves calculating the differences of measurements between two probes. When the p-value is greater than the significance value, the null hypothesis is true, and there is no significant difference between the two probes.

The two hypotheses for the Wilcoxon signed-rank test as are as follows:

H_0: There is no significant difference between the two probes.
H_a: There is a significant difference between the two probes.

Lastly, the Pearson Correlation test was used to determine if there was a correlation between any of the parameters using the calculated means. The Pearson Correlation is a measure of how well things are related. It shows the linear relationship between two sets of data. If $p \leq 0.05$, is it a significant relationship. If $r \geq 0.6$, there is a fairly strong correlation, if $r = 0.9$ there is a very strong correlation, and if $r = 0.3$ there is a weak correlation.

3.5.2 Secondary Study

Water quality data were compared between volunteers and the professional, by undergoing qualitative and quantitative analysis. For each parameter, data from each of the three transects were calculated for basic statistics (arithmetic mean, standard deviation, maximum and minimum). Data were then plotted on line graphs and bar graphs using Microsoft Excel for visual analyses.

Chapter Four

RESULTS

Water quality data from the Gambia River were collected during the dry season of 2011 (December). For the main study, surface water quality data were collected across the entire country at 29 sampling locations, from the inland border with Senegal to the west coast of The Gambia at the Atlantic Ocean. With regard to the smaller secondary study, data were collected during the same time frame at a subset of three of the sampling locations used in the main surface water study, for a total of five data sets.

4.1 The Gambia River Water Quality Data

Raw data and statistical analyses for water temperature, pH, dissolved oxygen, conductivity, salinity, and total dissolved solids are shown in **Appendix B** (**Tables 1** to **8**). Data for the presence or absence of coliform bacteria were also collected. Each of these parameters will be discussed in the following sections.

4.1.1 Precipitation Amount

There is limited data available on the 2011 rainfall in The Gambia. In a study conducted by Yaffa (2013), over a 30 year period, 2011 was noted as the most recent severe drought in The Gambia. No rain fell during the data collection period, or within the seven weeks prior to sample collection. The last recorded rainfall in Banjul occurred on October 17th, 2011 in the amount of 22 millimetres (Weather Online, 2014).

4.1.2 Water Temperature (°C)

Although there are no set guidelines with regard to water temperature set by the World Health Organization, it is important to monitor water temperatures as biological and chemical processes depend on temperature for reactions to occur. The raw data and results from statistical analyses (MEAN, GEOMEAN, MIN, MAX, and STDEV) for water temperature at all locations for both probes are found in **Appendix B, Table 1** The results indicate that temperatures ranged from 21.6 °C at site 12 (Tendaba) to 27.7 °C at site 10 (Tankular). Site 10 had the highest mean and maximum temperature in the data set. The graphical and spatial data of the mean temperature at each location can be seen in **Figures 4.0** and **4.1.** These figures show there was a drop in temperature at sites 11 (Salikene), 12 (Tendaba), 13 (Farafenni) and 16 (Pakali Ba).

Further statistical analyses revealed that, according to the Anderson-Darling Normality Test, both probe one and probe two had non-normal distributions ($p = 0.017$ and $p = <0.005$ respectively) (**Appendix B, Figures 7** and **8)**. The Wilcoxon Signed Rank Test showed a Wilcoxon Statistic of $w = 220.0$ and a p value of 0.707 meaning the readings from the two probes were not statistically different.

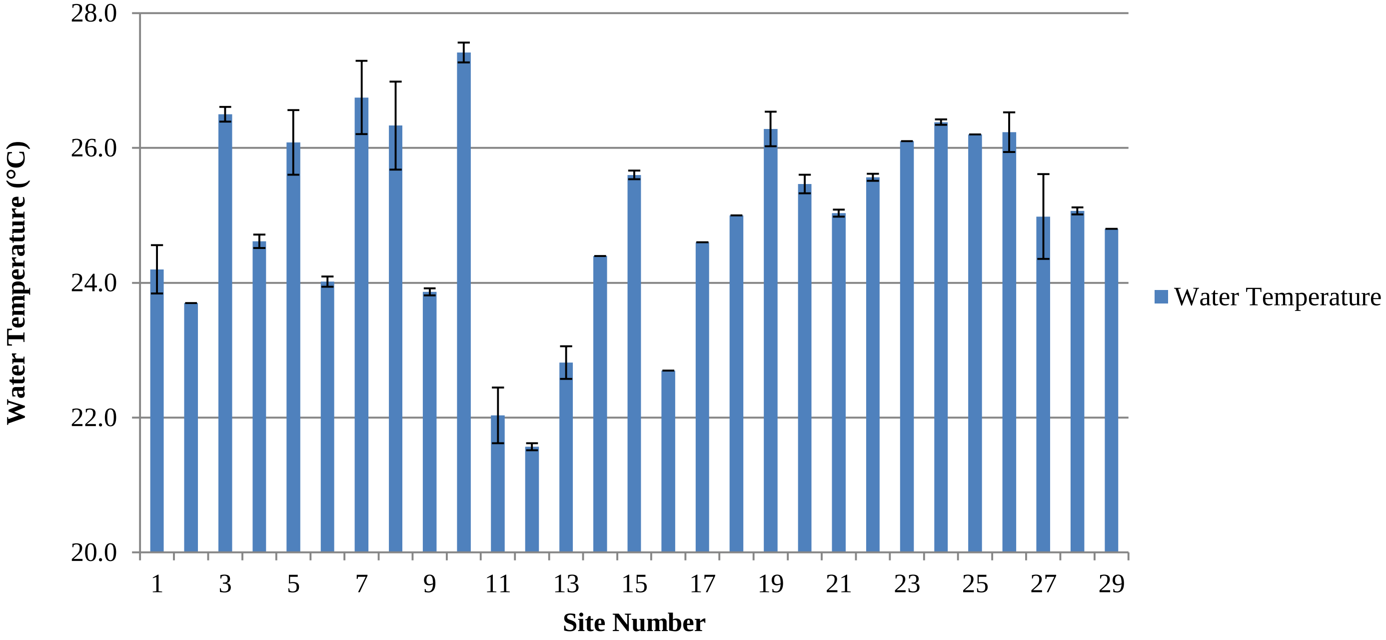

Figure 4.0. Surface water quality - mean water temperature (°C) results of surface water quality at sites sampled in the Gambia River, including standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

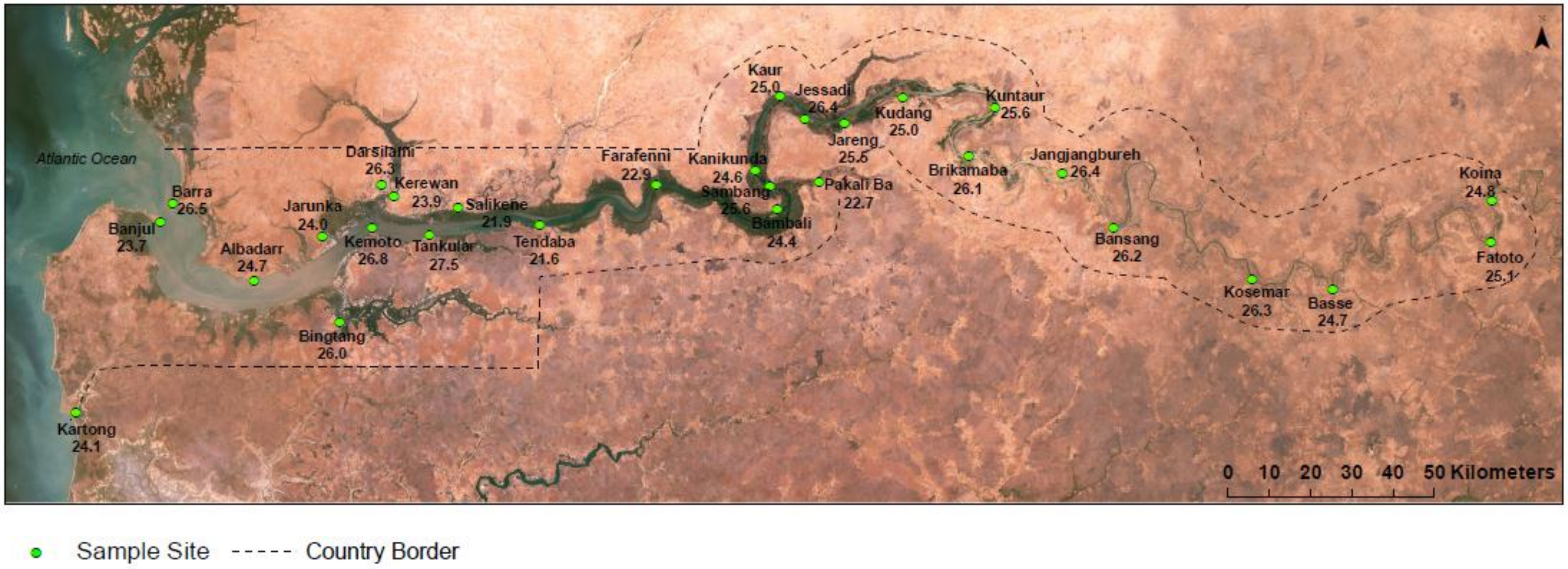

Figure 4.1. Surface water quality - mean water temperature (°C) results of surface water quality at sites sampled in the Gambia River. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

4.1.3 pH

The pH is used to measure the acidity of water. The World Health Organization (1996) provides a range of pH 6.5 to pH 8.5 for aquatic health in most raw water systems (for drinking water purposes). **Appendix B, Table 2** shows the raw data and results from statistical analyses (MEAN, GEOMEAN, MIN, MAX, and STDEV) for pH at all locations for both probes.

The results indicate that the pH of the Gambia River ranged from 6.76 at site 26 (Kosemar) to 8.15 at site 3 (Barra). Although most of the pH values fell within the 7.00 range, site 2 (Banjul) and site 3 (Barra) showed higher values in the 8.00 range, while site 26 (Kosemar) and 14 (Bambali) had values in the 6.00 range (**Figures 4.2** and **4.3**). Site 3 (Barra) also had the highest mean temperature within the data set.

The Anderson-Darling Normality test revealed that probe one had a normal distribution, p = 0.087 (**Appendix B, Figure 9**), while probe two had a non-normal distribution, p = <0.005 (**Appendix B, Figure 10**). The Wilcoxon Signed Rank Test revealed a Wilcoxon Statistic of w = 3130.5 and a p value of 0.00 meaning the readings from the two probes were statistically different.

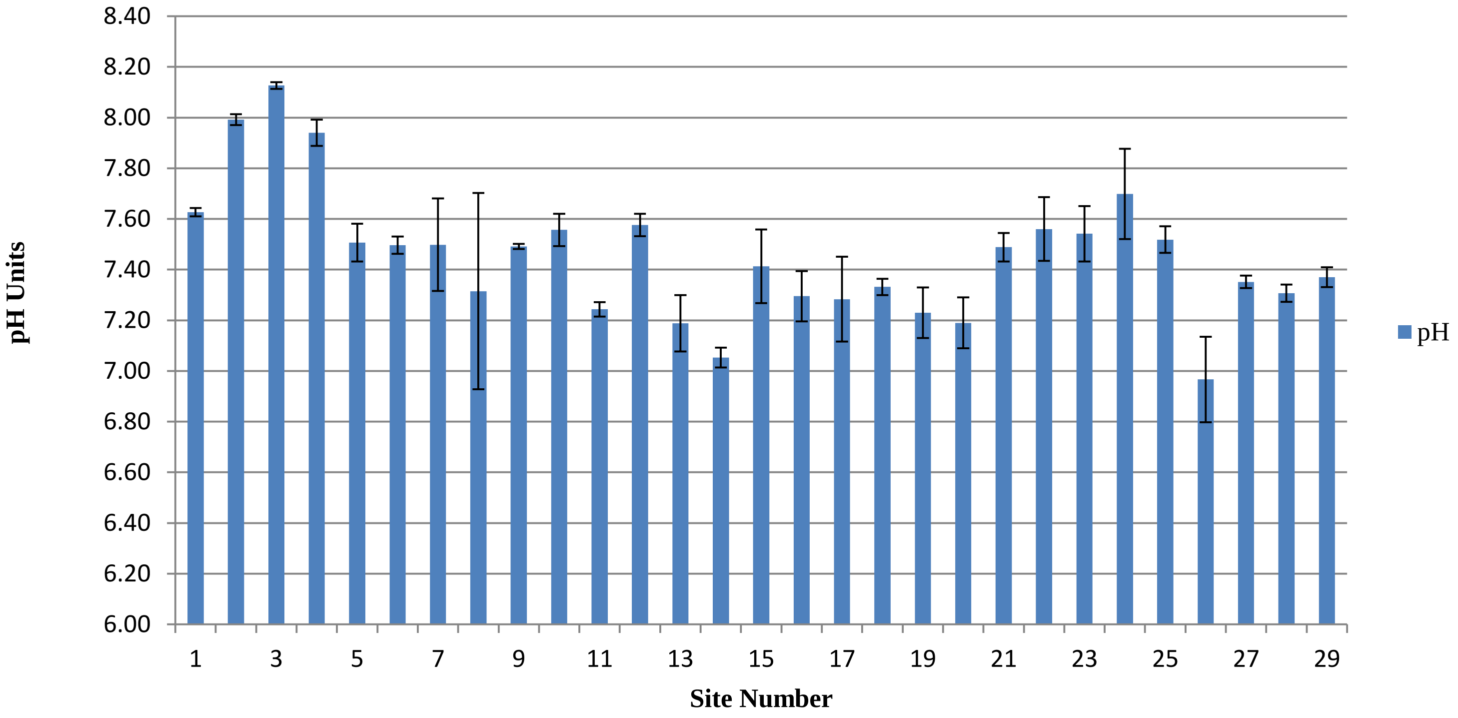

Figure 4.2. Surface water quality - mean pH results of surface water quality at sites sampled in the Gambia River, including standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

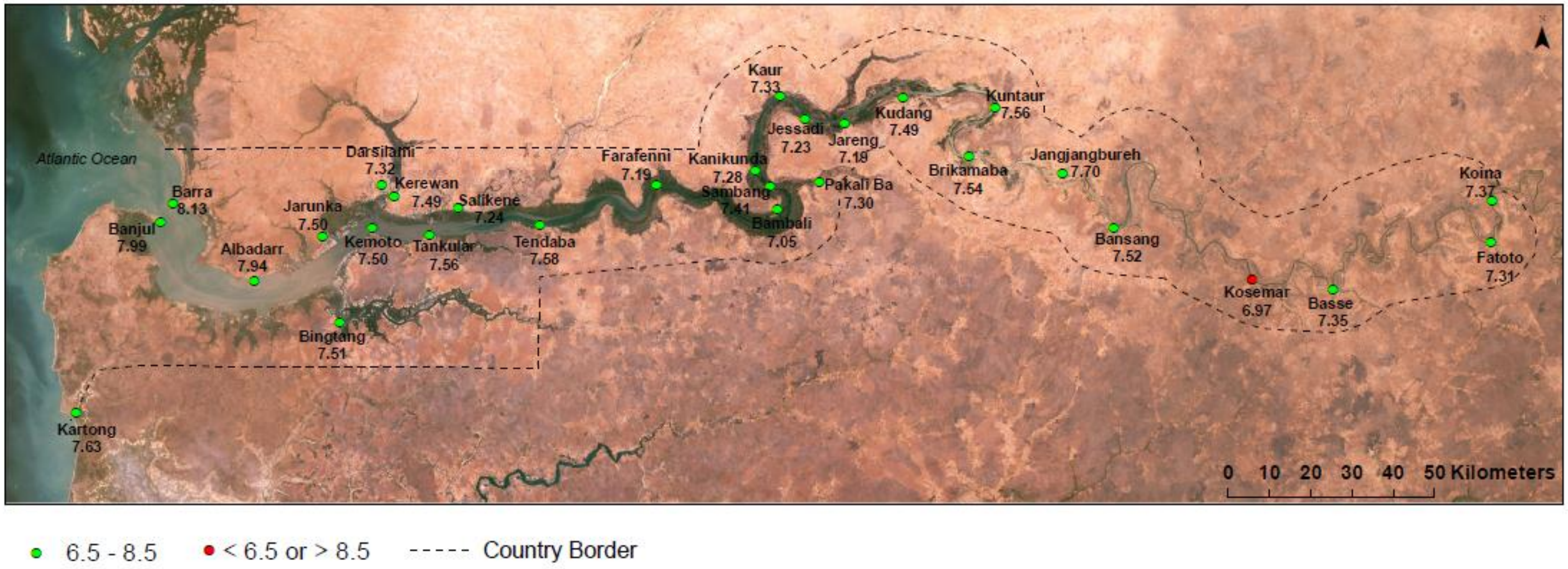

Figure 4.3. Surface water quality - mean pH results at sites sampled in the Gambia River. Green points indicate a value within the set range of the World Health Organization (6.5-8.5 units)

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

4.1.4 Dissolved Oxygen (mg/L)

Dissolved oxygen (DO) is important to aquatic life and ecosystems. As stated by the World Health Organization (1996), a low dissolved oxygen concentration (lower than 5.0-6.0 mg/L for warm water biota and 6.5-9.5 mg/L for cold water biota) can cause fish kills which can have adverse effects on ecosystem health. **Tables 3** and **4 in Appendix D**, provide the raw data and results from statistical analyses (MEAN, GEOMEAN, MIN, MAX, and STDEV) for DO at all locations for both probes (mg/L and % saturation). In this study, DO was expressed in mg/L. For a graph of dissolved oxygen expressed in % saturation refer to **Appendix B, Figure 11.**

The results indicate that the dissolved oxygen values of the Gambia River were above and below the recommended guidelines set by the WHO. The dissolved oxygen values ranged from 2.1 mg/L at site 19 (Jessadi) to 8.3 mg/L at site 24 (Jangjangbureh). Many of the sites had similar means and standard deviations, with the exception of several peaks (sites 3,7,10, 12, 15, 18, 22 and 28) and descents (6, 11, 13, 16, 19, 23, 26, and 29) in the data set (**Figures 4.4** and **4.5).** Site 22 (Kuntaur) had the highest mean within the data set, and site 24 (Jangjangbureh) had the highest standard deviation.

The Anderson-Darling Normality Test revealed that probes one and two had normal distributions ($p = 0.073$ and, $p = <0.599$ respectively) (**Appendix B, Figures 12** and **13**). The Paired T-test revealed a t value of 0.95 and a p value of 0.345, indicating that the readings from the two probes were not statistically different.

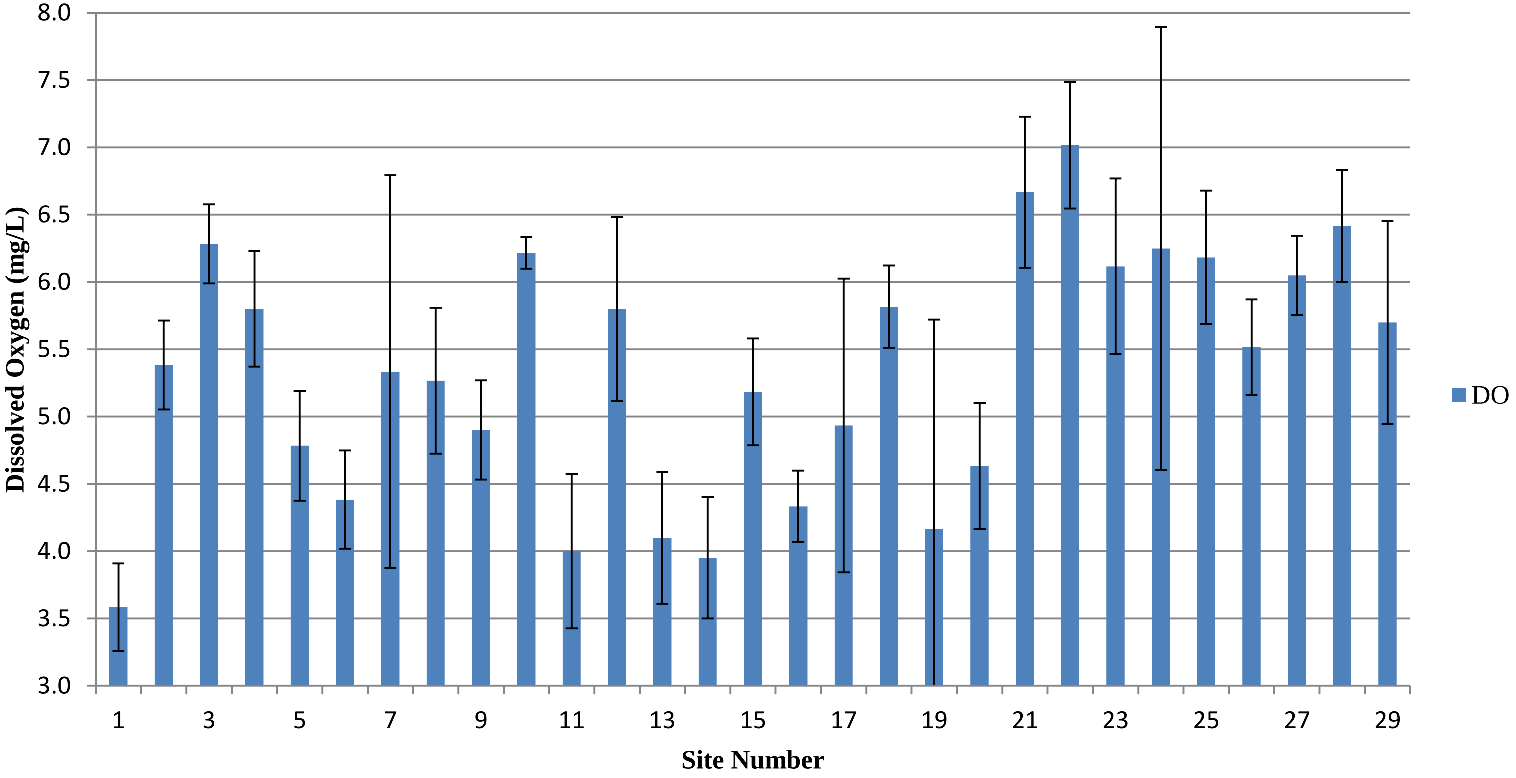

Figure 4.4. Surface water quality - mean dissolved oxygen (mg/L) results of surface water quality at sites sampled in the Gambia River, including standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

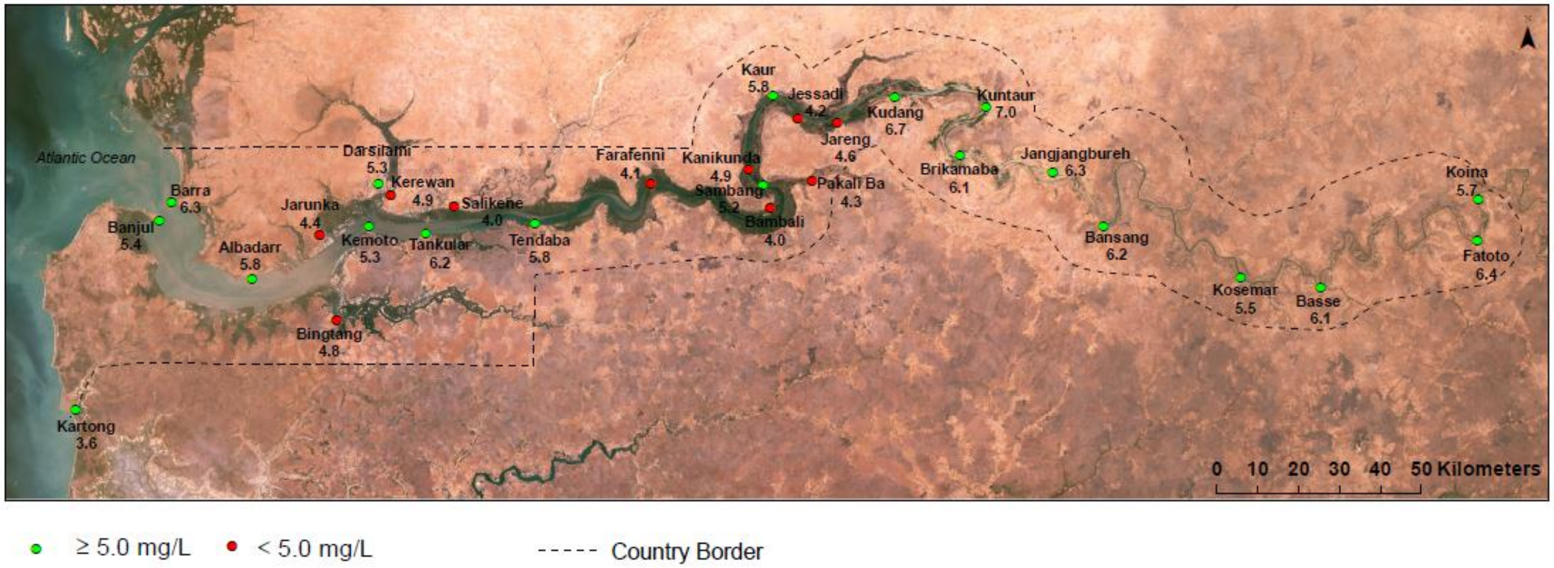

Figure 4.5. Surface water quality - mean dissolved oxygen mg/L results at sites sampled in the Gambia River. Green points indicate a value within the set range of the World Health Organization (above 5.0 mg/L) and red indicates the site is below (less than 5.0 mg/L).

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

4.1.5 Conductivity (µS/cm)

Conductivity can vary greatly depending on the surrounding geology and land use; this variability can be observed in this data set. **Appendix B, Tables 5** and **6** provides the raw data and results from statistical analyses (MEAN, GEOMEAN, MIN, MAX, and STDEV) for conductivity. Conductivity was expressed in µS/cm as the chosen unit for analyses. For a graph relating to specific conductivity, refer to **Appendix B, Figure 14**. It should be noted that conductivity can change following precipitation. However, no precipitation fell during the duration of data collection or within the seven weeks prior.

The results indicate that the conductivity of the Gambia River fluctuated in comparison to the Atlantic Ocean. The values ranged from 40.5 µS/cm at site 26 (Kosema) to 56386.3 µS/cm at site 1 (Kartong) (**Figure 4.6** and **Figure 4.7**). The highest mean conductivity was noted at site 1 (Kartong). There was a spike in conductivity at site 8 (Darsilami), while the values began to taper off at site 12 (Tendaba), inland towards the Senegalese border. Starting at site 13 (Farafenni), there was a drop in conductivity from 4932.3 µS/cm to 367.7 µS/cm at site 15 (Sambang). There was then an increase in values to 1814.7 µS/cm at site 16 (Pakali Ba). The values then began to drop significantly to 54.5 µS/cm at site 29 (Koina).

The Anderson-Darling Normality Test showed that probes one and two had non-normal distributions, (both had $p = < 0.005$) (**Appendix B, Figures 15** and **16**). The

Wilcoxon Signed Rank Test calculated a Wilcoxon Statistic of w = 23900 and a p value of 0.014 meaning that the readings from the two probes were statistically different.

4.1.7 Salinity (ppt)

Salinity is an important factor which can change with proximity to the ocean because of tidal infiltration of the waterway. **Figure 4.8** shows that the pattern of salinity is similar to and related to conductivity and total dissolved solids. **Figure 4.9** spatially characterizes the data into salinity levels typically found in oceans, brackish water, and freshwater. The Gambia River, on the Atlantic Coast, has salt water intrusion for a portion of the river's length. The raw data for salinity can be found in **Appendix B, Table 7**. Referring to **Figure 4.8**, site 1 (Kartong), had the highest salinity value of 38.57 ppt along with having the highest mean value in the data set. Sites 22 through 29 had the lowest salinity values reading 0.02 ppt, while also having the lowest means within the data set.

The data show that the salinity continually dropped from site 1 (Kartong) with increasing distance from the ocean. There was a peak at site 8 (Darsilami) and another smaller one at site 11 (Salikene). Salinity values then dropped to low levels with the transition to fresh water unaffected by the salt water intrusion.

The Anderson-Darling Normality Test showed that probe one and probe two had non- normal distributions (both had p = < 0.005) (**Appendix B, Figures 17** and **18**). The Wilcoxon Signed Rank Test showed a Wilcoxon Statistic of w = 596.0 and a p value of 0.379 meaning that the readings from the two probes were not statistically different.

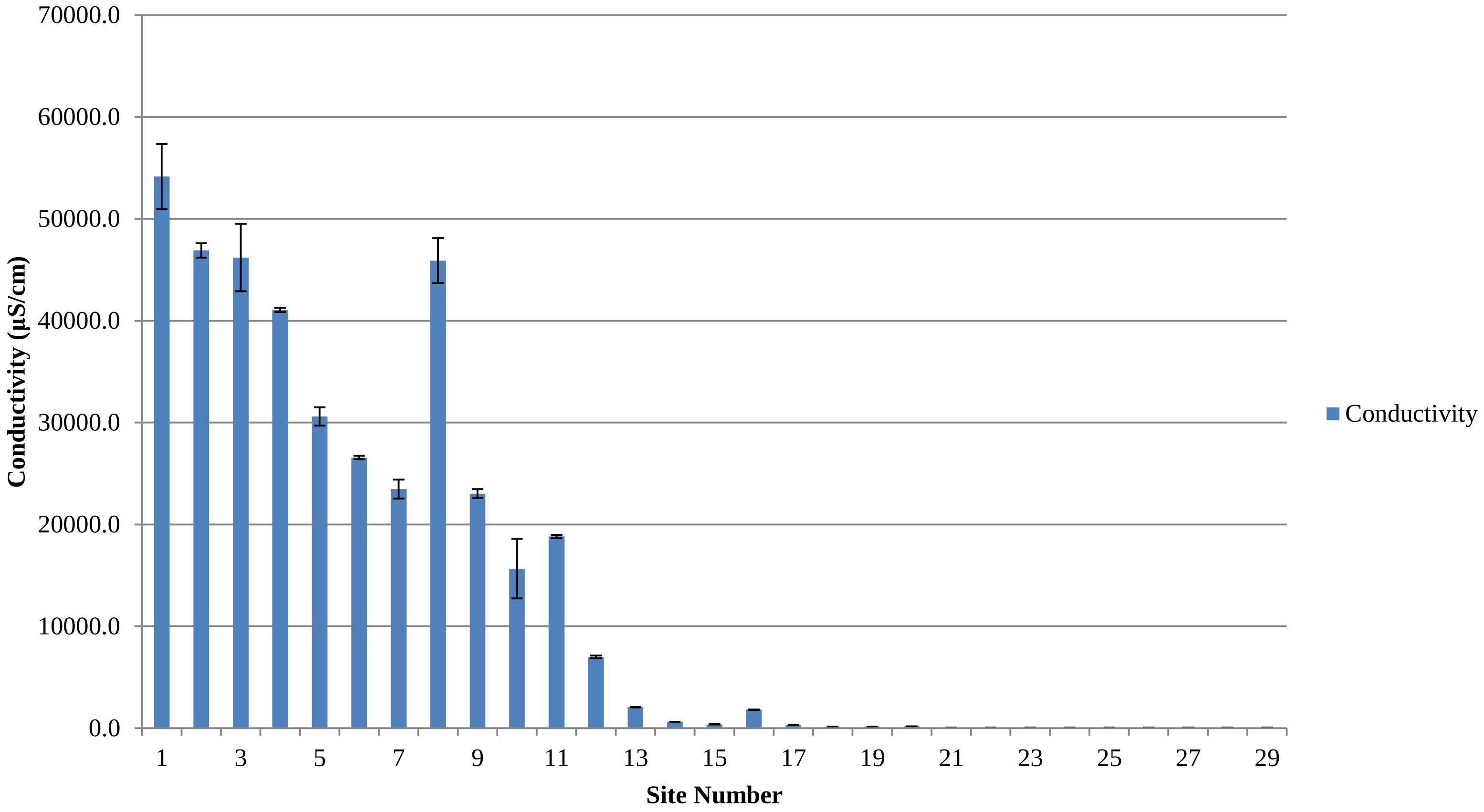

Figure 4.6. Surface water quality - mean conductivity (µS/cm) results of surface water quality at sites sampled in the Gambia River, including standard deviations (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

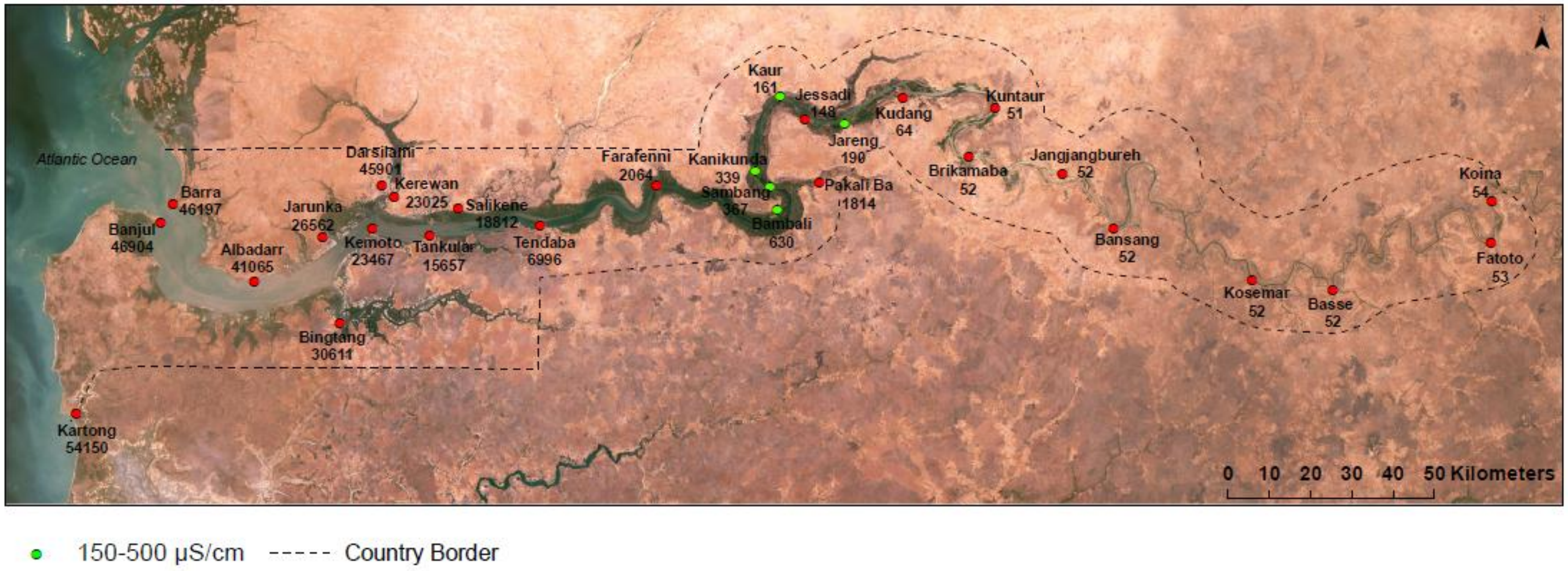

Figure 4.7. Surface water quality - mean conductivity (µS/cm) results of surface water quality at sites sampled in the Gambia River. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

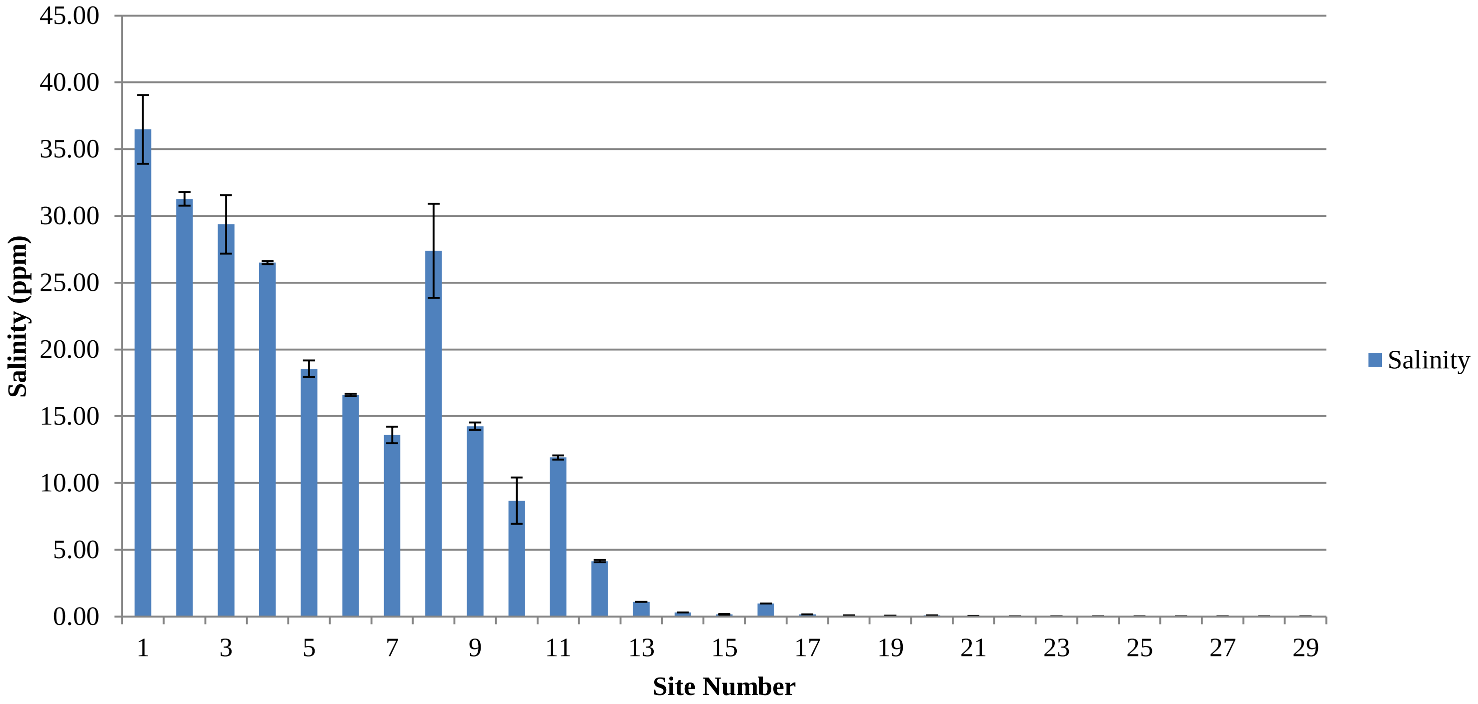

Figure 4.8. Surface water quality - mean salinity (ppt) results of surface water quality at sites sampled in the Gambia River, including standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

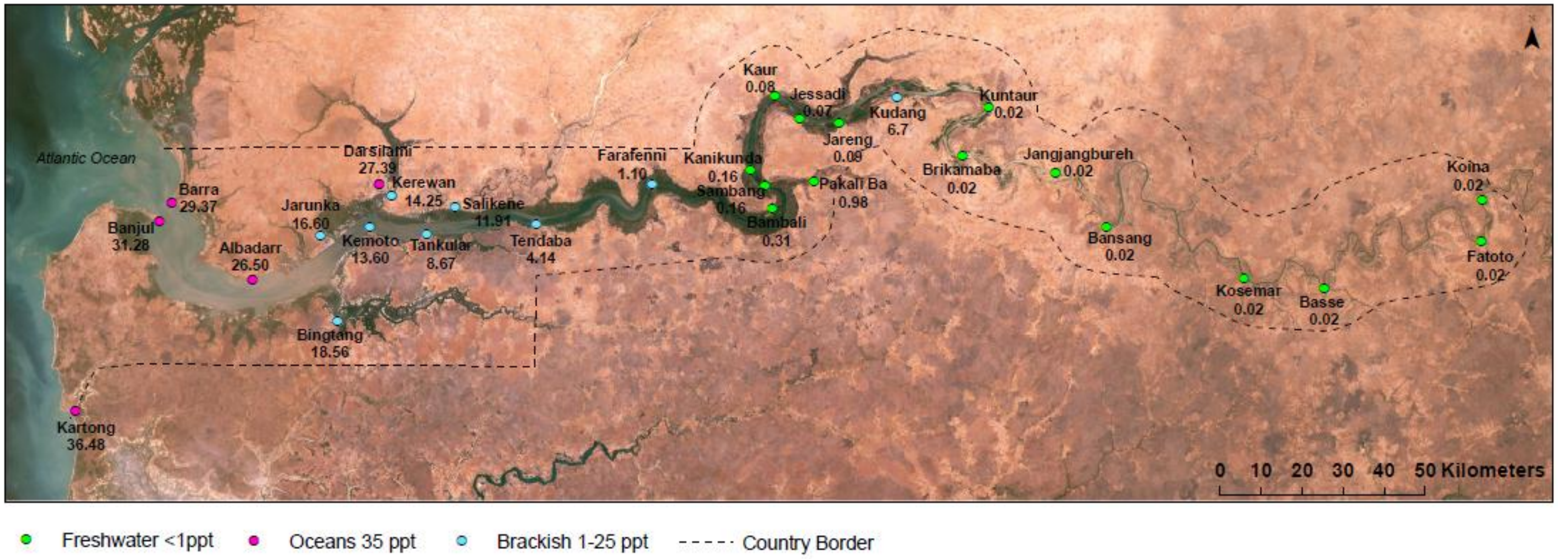

Figure 4.9. Surface water quality - mean salinity (ppt) results of surface water quality at sites sampled in the Gambia River. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

4.1.8 Total Dissolved Solids (mg/L)

Total Dissolved Solids (TDS) are directly related to salinity and conductivity and the plotted data points showed similar patterns (**Figures 4.6** and **4.8)**. Raw data and statistical analyses can be found in **Appendix B, Table 8**. Referring to **Figure 4.10**, site 1 (Kartong) had the highest TDS value of 42100 mg/L, and site 26 (Kosemar) had the lowest TDS value of 25.35 mg/L (similar to conductivity and salinity data). The data showed that TDS values continually dropped from site 1 (Kartong) with a peak at site 8 (Darsilami) and then dropped again. There was another peak at site 11 (Salikene) and then levels began to decrease.

The Anderson-Darling Normality Test revealed that both probe one and probe two had non- normal distributions (both had $p = < 0.005$) (**Appendix B, Figures 19 and 20)**. The Wilcoxon Signed Rank Test showed a Wilcoxon Statistic of $w = 1554.0$ and a p value of 0.069 meaning that the readings from the two probes were not statistically different.

4.1.9 Correlations

The Pearson Correlation test was used to determine if there was a correlation between any of the sets of data (parameters) using the calculated mean in Minitab Software. The Pearson Correlation is a measure of how well two variables are related. It shows the linear relationship between two sets of data. If $p \leq 0.05$ is it a significant relationship. If $r = 0.6$ or higher there is a fairly strong correlation, $r = 0.9$ there is a very strong correlation, and if $r = 0.3$ there is a weak correlation.

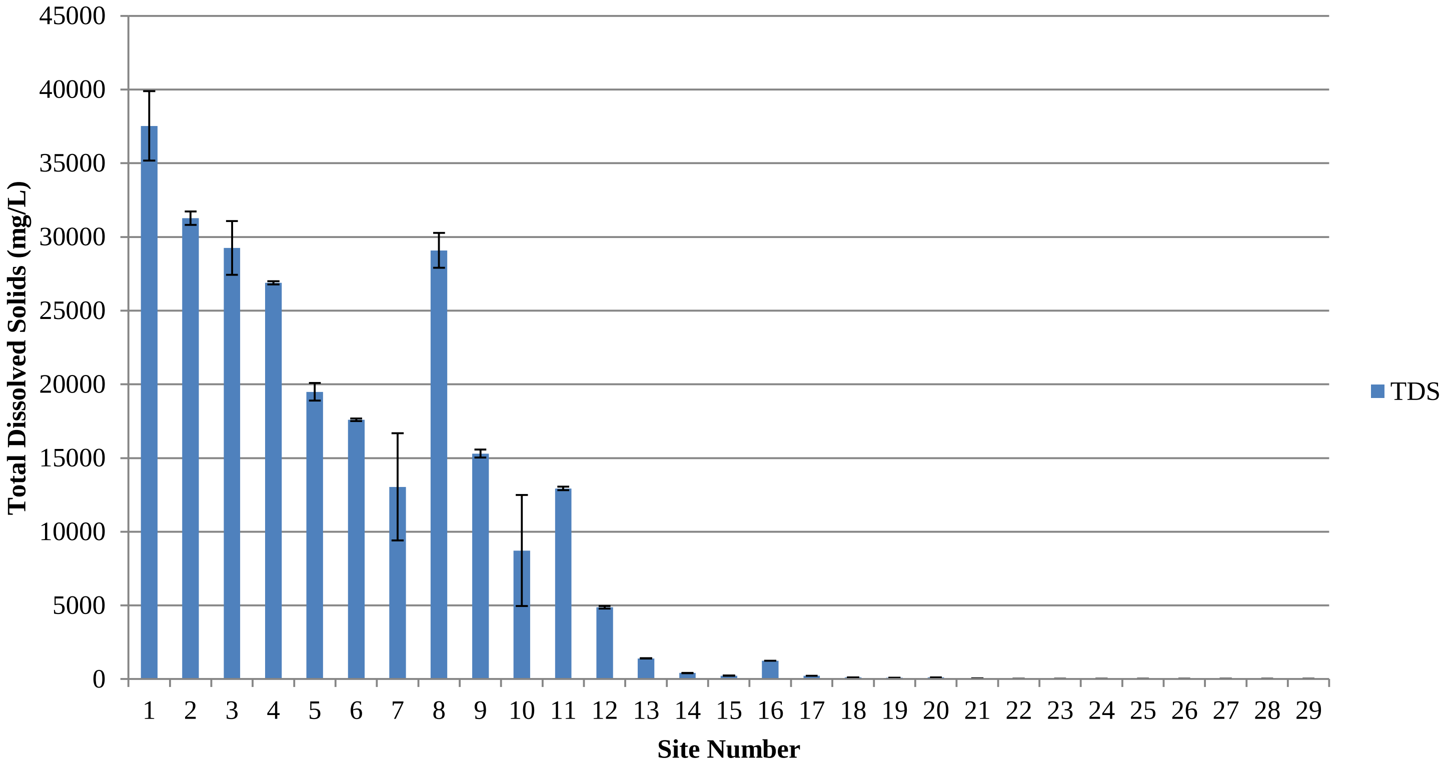

Figure 4.10. Surface water quality - mean total dissolved solids (mg/L) results of surface water quality at sites sampled in the Gambia River, including standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

The Pearson Correlation for each parameter was determined by using MiniTab and recorded in **Table 4.1**. Of the eight parameters measured, total dissolved solids, salinity, conductivity, specific conductivity and pH all had a significant relationship ($p \leq 0.05$) with each other, while pH also had a significant relationship with dissolved oxygen mg/L and dissolved oxygen %. Water temperature, dissolved oxygen mg/L, and dissolved oxygen % also shared a significant relationship. All other relationships were deemed not significant as $p > 0.05$.

Salinity, total dissolved solids, conductivity, and specific conductivity all had a strong correlation as $r > 0.9$. Dissolved oxygen, mg/L and %, both correlated strongly with each other. Water temperature had a weak correlation with all parameters as $r = 0.3$. There was also a weak correlation between dissolved oxygen (mg/L), salinity, total dissolved solids, conductivity, specific conductivity, and pH. Additionally, there was a weak correlation between dissolved oxygen (%), salinity, total dissolved solids, conductivity, and specific conductivity.

4.1.10 Presence/Absence Coliform

Twenty-nine locations were sampled for coliform data using Lamotte Coliform indicator tests at each of the three transects for a total of 87 tests. All tests, after 48 hours, tested positive for coliform. This was indicated by the formation of gas bubbles and a colour change from clear to yellow (**Figure 4.11**). In general, coliform bacteria make up a form of bacteria that are found in soils, plants, and in surface water. Certain types of

Table 4.1. Summary of Pearson Correlation by p Value and r Value. Calculated by means of raw surface water data (n=6)

	p Values							
	TDS (mg/L)	DO (mg/L)	DO (%)	Conductivity (µS/cm)	SPC (µS/cm)	pH	Water Temperature (°C)	Salinity (ppm)
Salinity (ppm)	0.000	0.256	0.457	0.000	0.000	0.000	0.867	
TDS (mg/L)		0.227	0.509	0.000	0.000	0.000	0.808	0.000
DO (mg/L)	0.227		0.000	0.273	0.249	0.032	0.018	0.256
DO (%)	0.509	0.000		0.445	0.480	0.000	0.015	0.457
Conductivity (µS/cm)	0.000	0.237	0.445		0.000	0.000	0.951	0.000
SPC (µS/cm)	0.000	0.249	0.480	0.000		0.000	0.862	0.000
pH	0.000	0.032	0.000	0.000	0.000		0.589	0.000
Water Temperature (°C)	0.808	0.018	0.015	0.951	0.862	0.589		0.867
	r Values							
	TDS (mg/L)	DO (mg/L)	DO (%)	Conductivity (µS/cm)	SPC (µS/cm)	pH	Water Temperature (°C)	Salinity (ppm)
Salinity (ppm)	0.999	-0.218	0.144	0.998	0.999	0.623	-0.033	
TDS (mg/L)		-0.232	0.128	0.998	0.999	0.608	-0.047	0.999
DO (mg/L)	-0.232		0.856	-0.211	-0.221	0.398	0.436	-0.218
DO (%)	0.128	0.856		0.148	0.136	0.663	0.447	0.144
Conductivity (µS/cm)	0.998	-0.211	0.148		1.000	0.613	-0.012	0.998
SPC (µS/cm)	0.999	-0.221	0.136	1.000		0.612	-0.034	0.999
pH	0.608	0.398	0.663	0.613	0.612		0.105	0.623
Water Temperature (°C)	-0.047	0.436	0.447	-0.012	-0.034	0.105		-0.033

	Legend
(p Value)	Significant Relationship($p \leq 0.05$)
(r Value)	Weak Correlation ($r = 0.3$)
	Fairly Stong Correlation ($r > 0.6 < 0.9$)
	Strong Correlation ($r > 0.9$)

coliform also live in the intestines of humans and animals. The water can be contaminated by the bacteria occurring naturally in the soils, decayed animal waste or human activities. **Figure 4.12** spatially represents the presence of coliform at all 29 locations sampled.

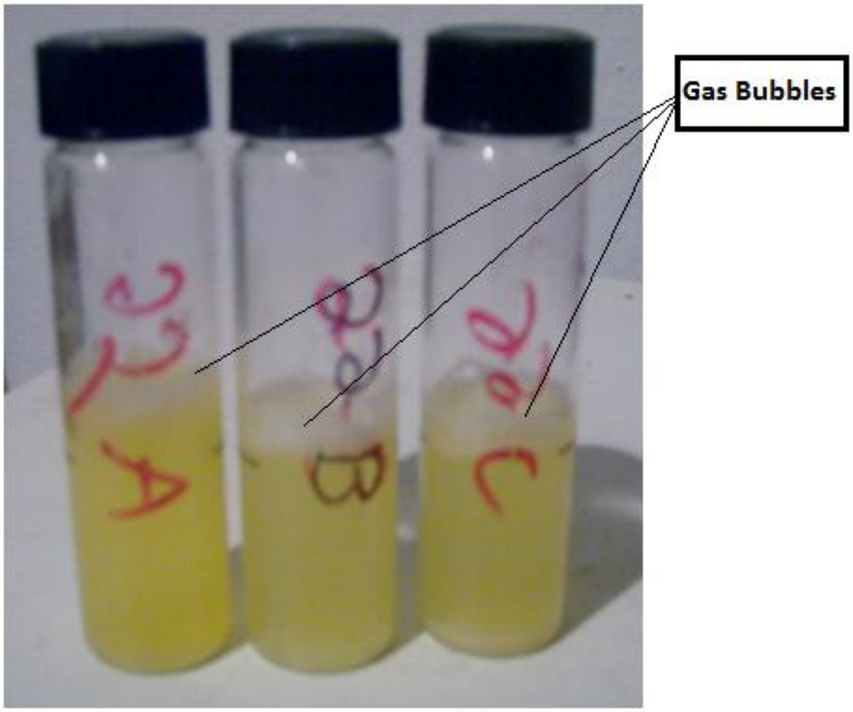

Figure 4.11. Example of positive coliform. (A yellow colour and the formation of gas bubbles indicates a positive result)

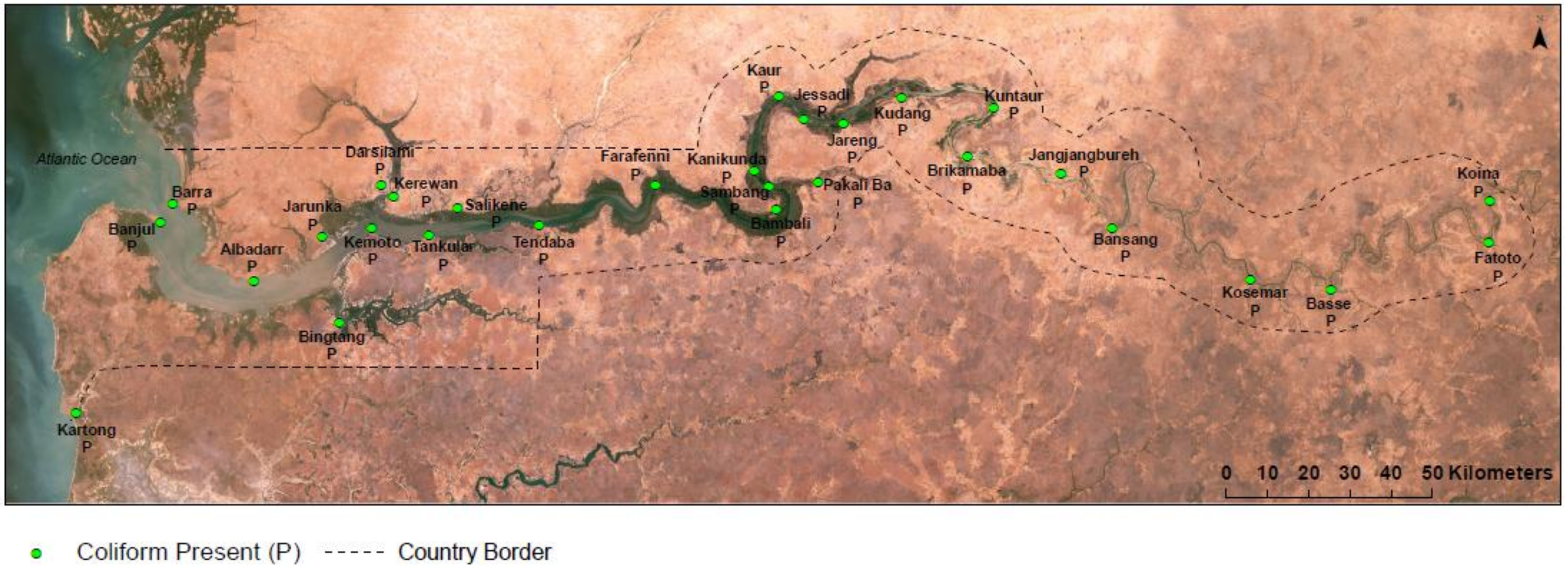

Figure 4.12. Surface water quality –presence/absence coliform results of surface water quality at sites sampled in the Gambia River. (n = 3 for each site and site number 1 is closest to the Atlantic Ocean)

Source: Cartography by Melissa Healey/Base data compiled by Greg Baker: Saint Mary's University, Halifax, NS. Imagery captured 02-04/2003 by the Landsat 7 ETM, provided by the United States Geological Survey

4.2 Volunteer versus Professional Results

There is much uncertainty regarding the credibility of water quality data collected by citizen scientists. This secondary study examined the relationship between five sets of data collected by a professional and by various volunteers at different locations. The treatment group consisted of the volunteers (i.e. citizen scientists) and the control for this study was the professional scientist. The raw data collected by both the volunteers and the professional at each site are given in **Tables 9-18** (**Appendix B**).

Due to the low number of volunteer groups involved in this study, the means, the standard deviations, and the maximum and minimum numbers were the only statistics determined for each site (**Appendix B**, **Tables 19** and **20**). For statistical purposes, a larger number of volunteers would have resulted in a more in-depth analysis. However, due to time constraints, there were five volunteers used in the study. Only the differences between the professional measurement and the volunteer measurement at each transect, per site is of importance.

4.2.1 Water Temperature (°C)

The water temperature data from three transects at the five study sites were very close between the professional and the volunteer **(Figure 4.13)**. **Table 4.2** summarizes the mean water temperature (°C) plus and minus the standard deviation. The data from sites one, two, four and five showed very small differences between the professional and the volunteers. Site three was the only study site which reflected a minor change of 0.2 °C. Referring to **Figure 4.13,** there were really no differences in the results between the professional and the volunteer, and furthermore, there were no sampling errors.

4.2.2 pH

The data for pH recorded by the professional and the volunteer at each of the three transects were very close, with the exception of a slight decrease in the volunteer data for site two (**Table 4.2**). **Figure 4.14** shows the volunteer and professional raw water quality data for water temperature, along with standard deviation error bars. Study sites two and three both had one reading below the 7.00 range and into the high 6.00 range.

4.2.3 Dissolved Oxygen (mg/L)

Dissolved oxygen in mg/L is the chosen unit for this study, but data for percent oxygen saturation are found in **Tables 9-18 (Appendix B)**. As shown in **Figure 4.15**, there were some fluctuations within the sites between data collected by the professional and volunteers.

4.2.4 Conductivity (µS/cm)

For the five data sets, the conductivity recorded by the professional and the volunteer at all of the transects were extremely close (**Figure 4.16** and **Table 4.2**). There was very little variation between the two readings at any of the study sites.

4.2.5 Salinity (ppt)

For all data sets, the salinity recorded at each of the three transects showed little or no differences between the professional and the volunteer (**Figure 4.17)**. **Table 4.2** shows the mean salinity levels together with the standard deviations. Only at sites three and five was there a slight difference. Thus, there were no major sampling errors made by either the professional or the volunteer.

Table 4.2. Summary of surface water data by variable and study site, including standard deviation by individual study site (n=3)

Parameter	Variable	Site 1	Site 2	Site 3	Site 4	Site 5
Temperature (°C)	Controlled (professional)	26.1 ± 0.115	26.2 ± 0.058	26.0 ± 0.058	26.0 ± 0.00	25.0 ± 0.000
	Uncontrolled (volunteer)	26.1 ± 0.115	26.2 ± 0.058	26.2 ± 0.058	26.0 ± 0.058	25.0 ± 0.000
pH	Controlled (professional)	7.34 ± 0.161	7.45 ± 0.147	7.32 ± 0.411	7.53 ± 0.062	7.58 ± 0.036
	Uncontrolled (volunteer)	7.64 ± 0.086	7.32 ± 0.411	7.45 ± 0.147	7.54± 0.055	7.31 ± 0.015
Dissolved Oxygen (mg/L)	Controlled (professional)	6.1 ± 0.854	6.6 ± 0.153	5.6 ± 0.351	6.5 ± 1.168	6.5 ± 0.929
	Uncontrolled (volunteer)	5.6 ± 0.702	5.6 ± 0.351	6.6 ± 0.153	5.7± 0.700	5.6 ± 0.153
Conductivity (µS/cm)	Controlled (professional)	52.3 ± 0.635	52.4 ± 0.252	52.6 ± 0.635	52.3 ± 0.379	161.2 ± 0.709
	Uncontrolled (volunteer)	53.0 ± 1.582	53.0 ± 1.328	52.4 ± 0.252	52.2± 0.265	161.1 ± 0.874
Salinity (ppt)	Controlled (professional)	0.20 ± 0.000	0.20 ± 0.000	0.20 ± 0.000	0.20 ± 0.000	0.10 ± 0.006
	Uncontrolled (volunteer)	0.20 ± 0.000	0.20 ± 0.000	0.20 ± 0.000	0.20 ± 0.000	0.10 ± 0.006
Total Dissolved Solids (mg/L)	Controlled (professional)	33.4 ± 0.346	33.2± 0.000	35.1 ± 3.349	33.4 ± 0.346	104.6 ± 0.513
	Uncontrolled (volunteer)	33.6 ± 1.015	35.1 ± 3.349	33.2 ± 0.000	33.2± 0.000	104.9 ± 0.346

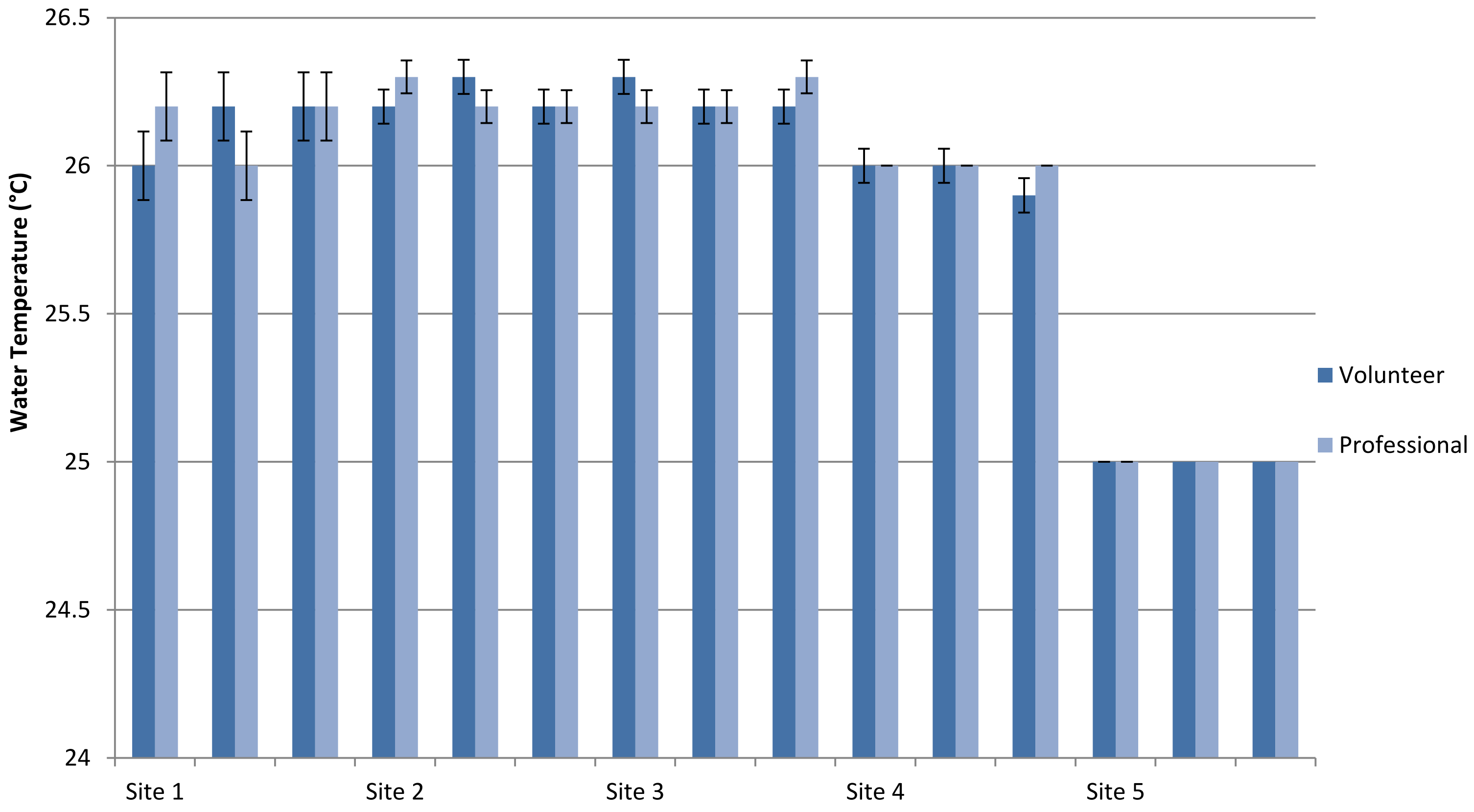

Figure 4.13. Volunteer versus professional raw water quality data for water temperature (°C) including standard deviations. (Both professional and volunteer measured three transects at each site.)

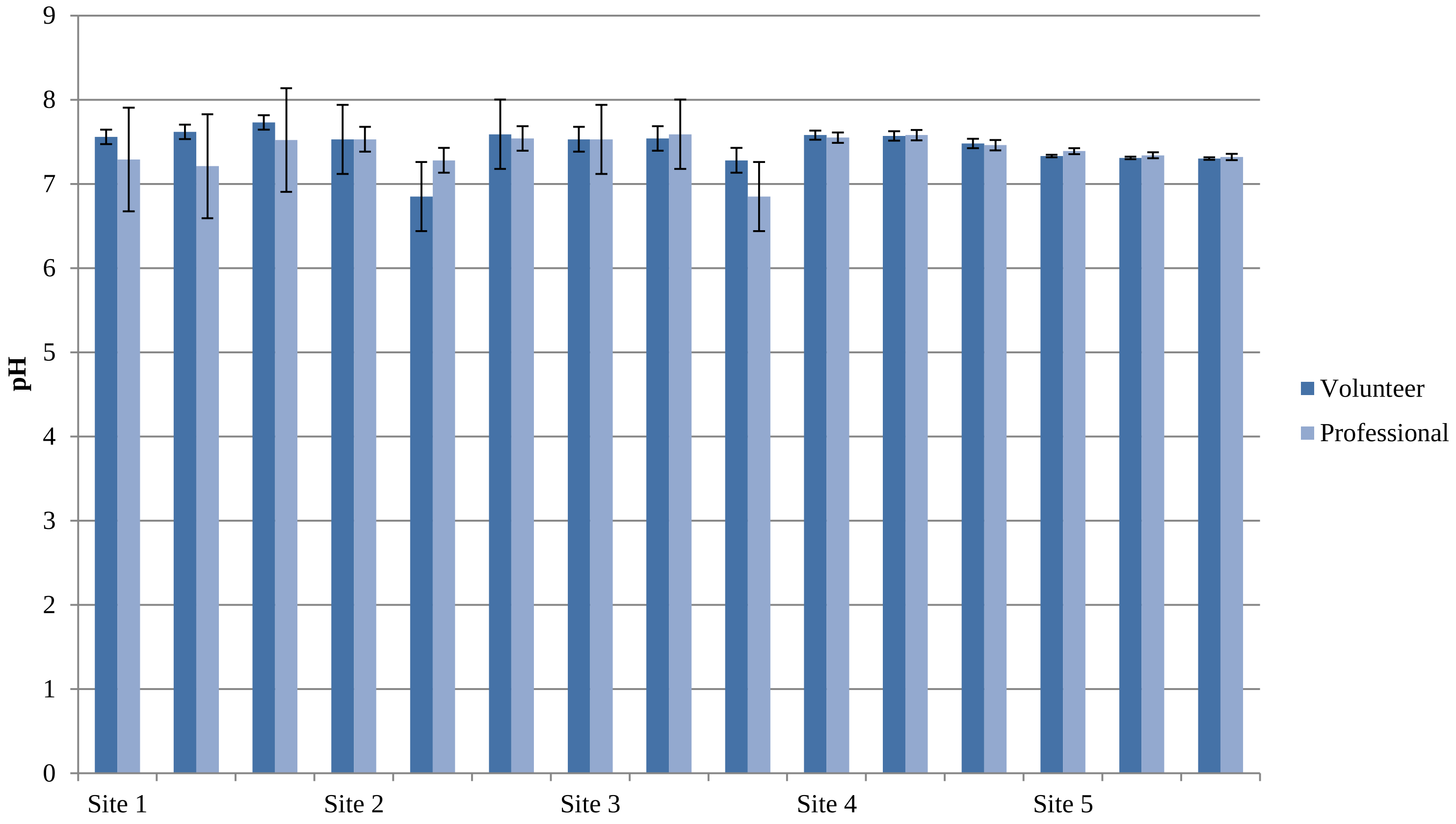

Figure 4.14. **Volunteer versus professional raw water quality data for pH including standard deviations.** (Both professional and volunteer measured three transects at each site.)

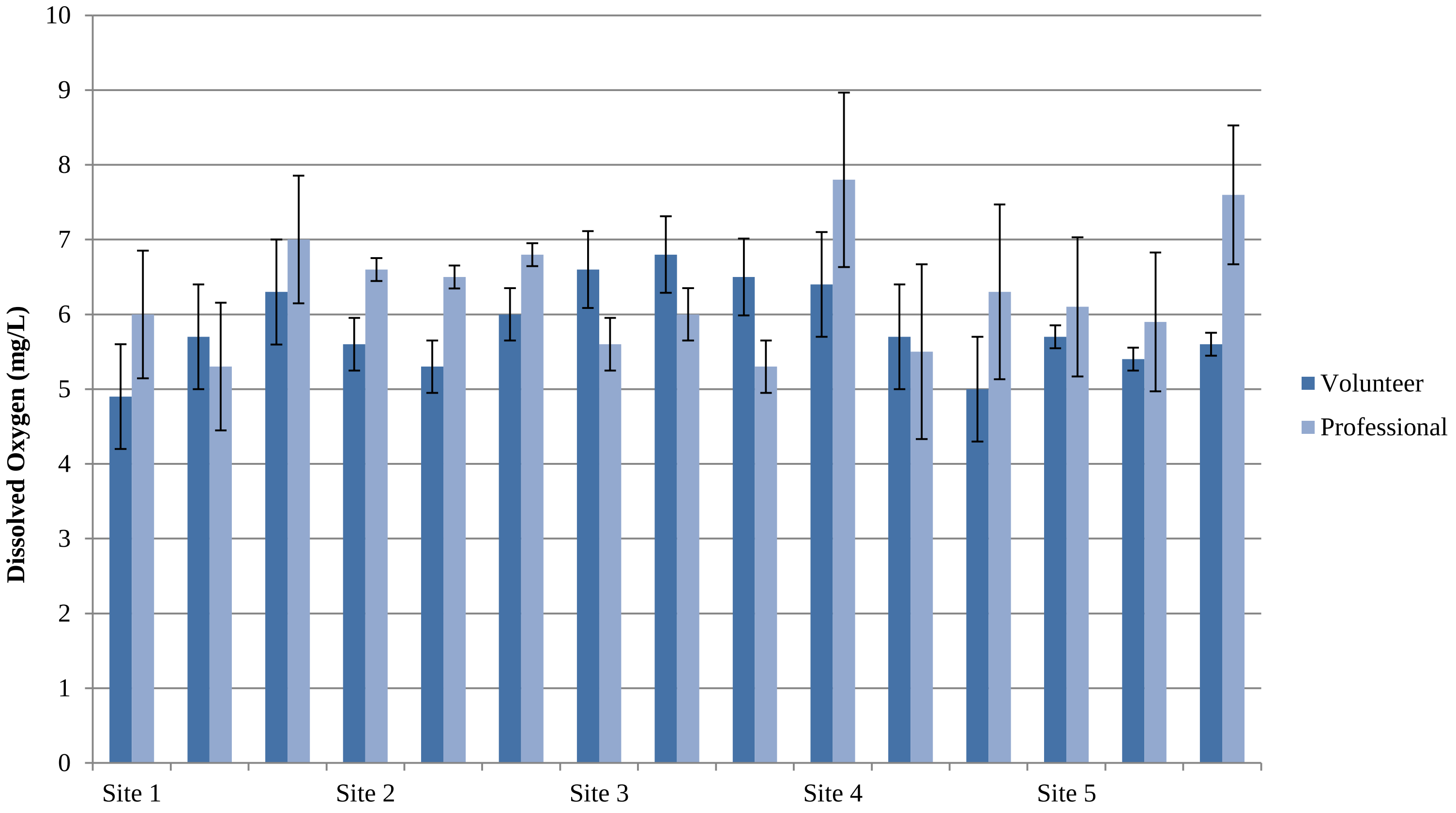

Figure 4.15. Volunteer versus professional raw water quality data for dissolved oxygen (mg/L). (Both professional and volunteer measured three transects at each site.)

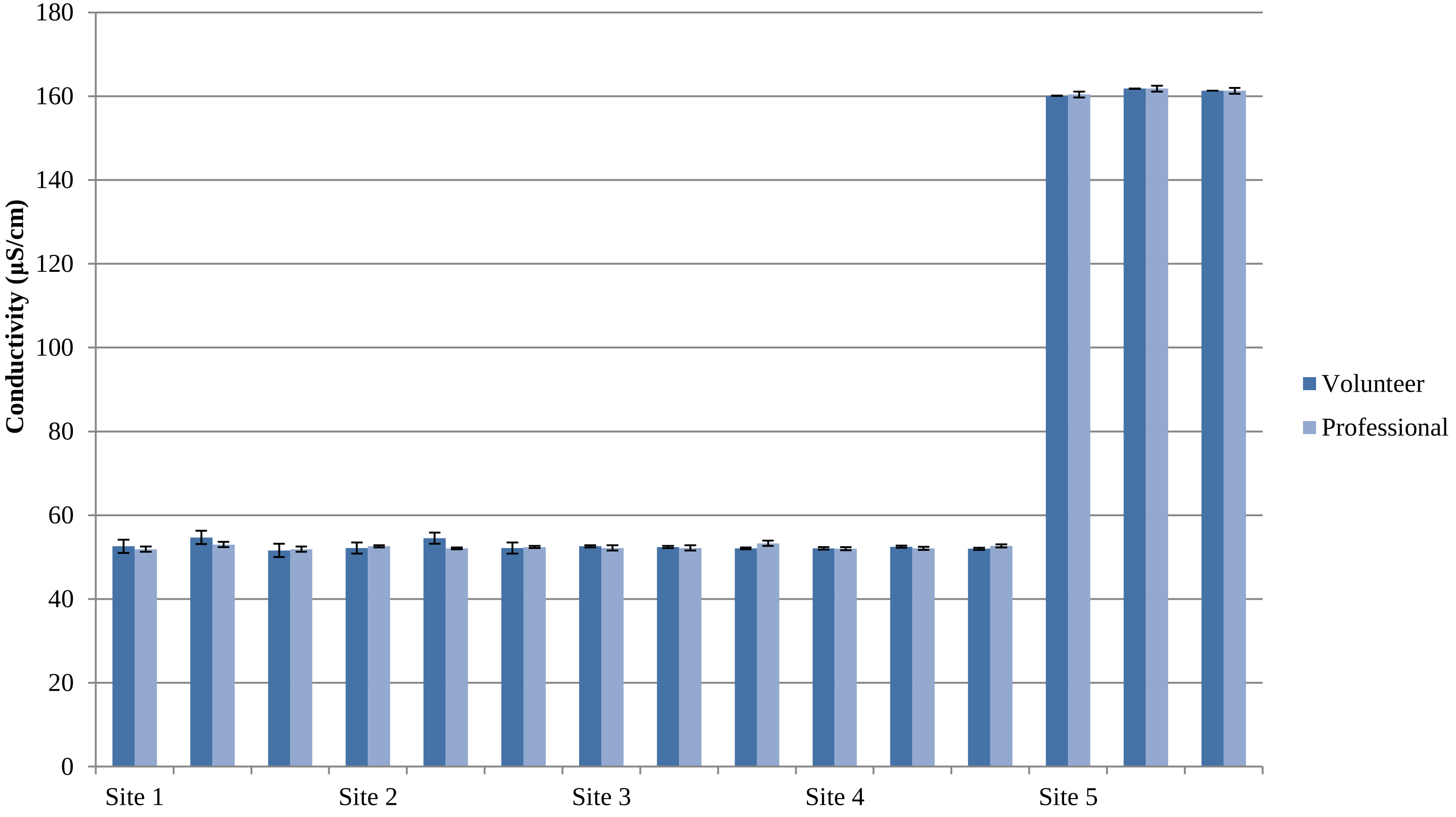

Figure 4.16. Volunteer versus professional raw water quality data for conductivity (µS/cm). (Both professional and volunteer measured three transects at each site.)

4.2.6 Total Dissolved Solids (mg/L)

The total dissolved solid data recorded by the professional and the volunteer, from three transects at the three study sites (total of five volunteers), were very close with the exception of one transect at both sites two and three where there was a greater variation in the collected data (**Figure 4.18**)**.** The raw data are shown, along with standard deviation error bars in this figure. **Table 4.2** summarizes the mean total dissolved solids data collected by the professional and the volunteer. The small differences are not significant and do not indicate any sampling errors by the professional or the volunteers.

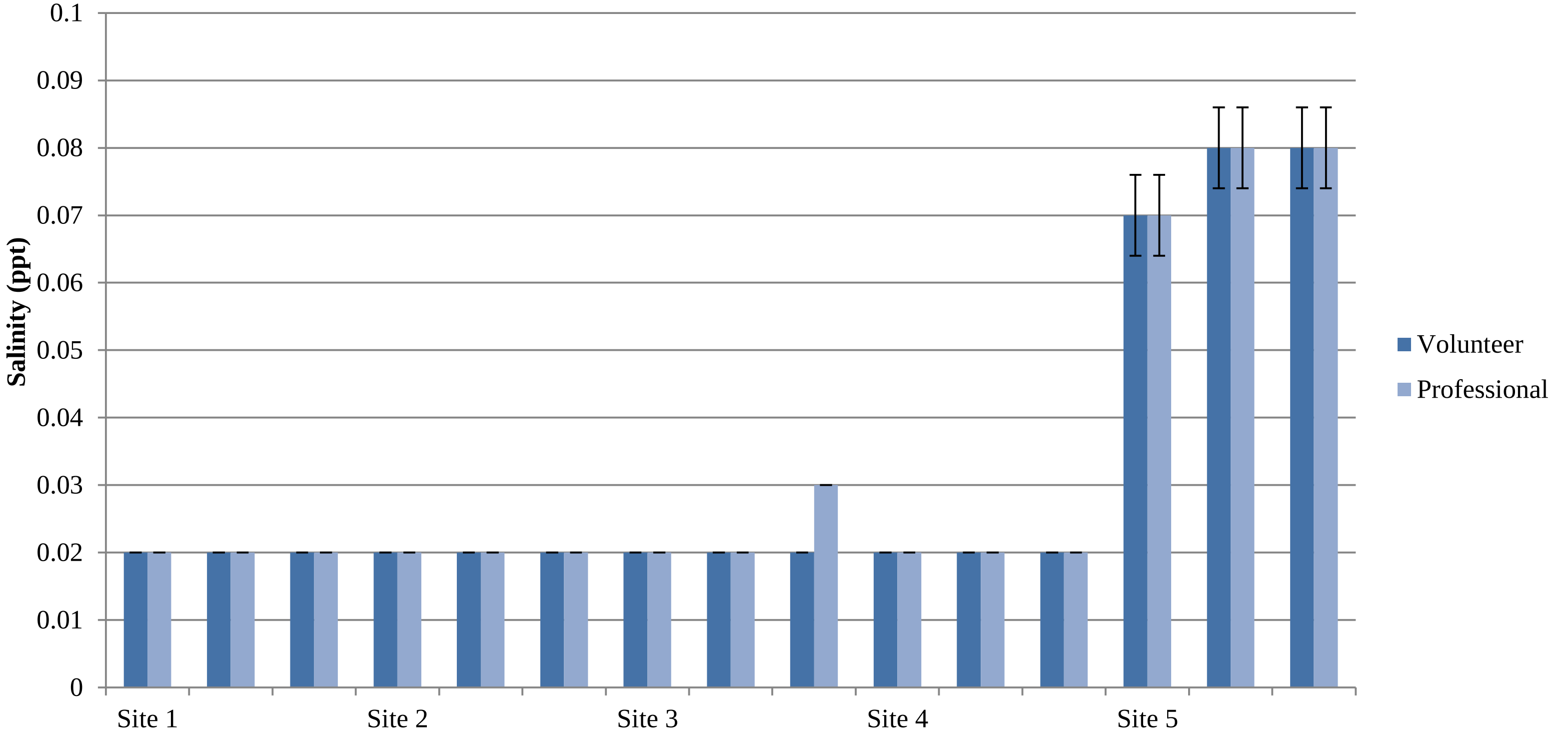

Figure 4.17. Volunteer versus professional raw water quality data for salinity (ppt). (Both professional and volunteer measured three transects at each site.)

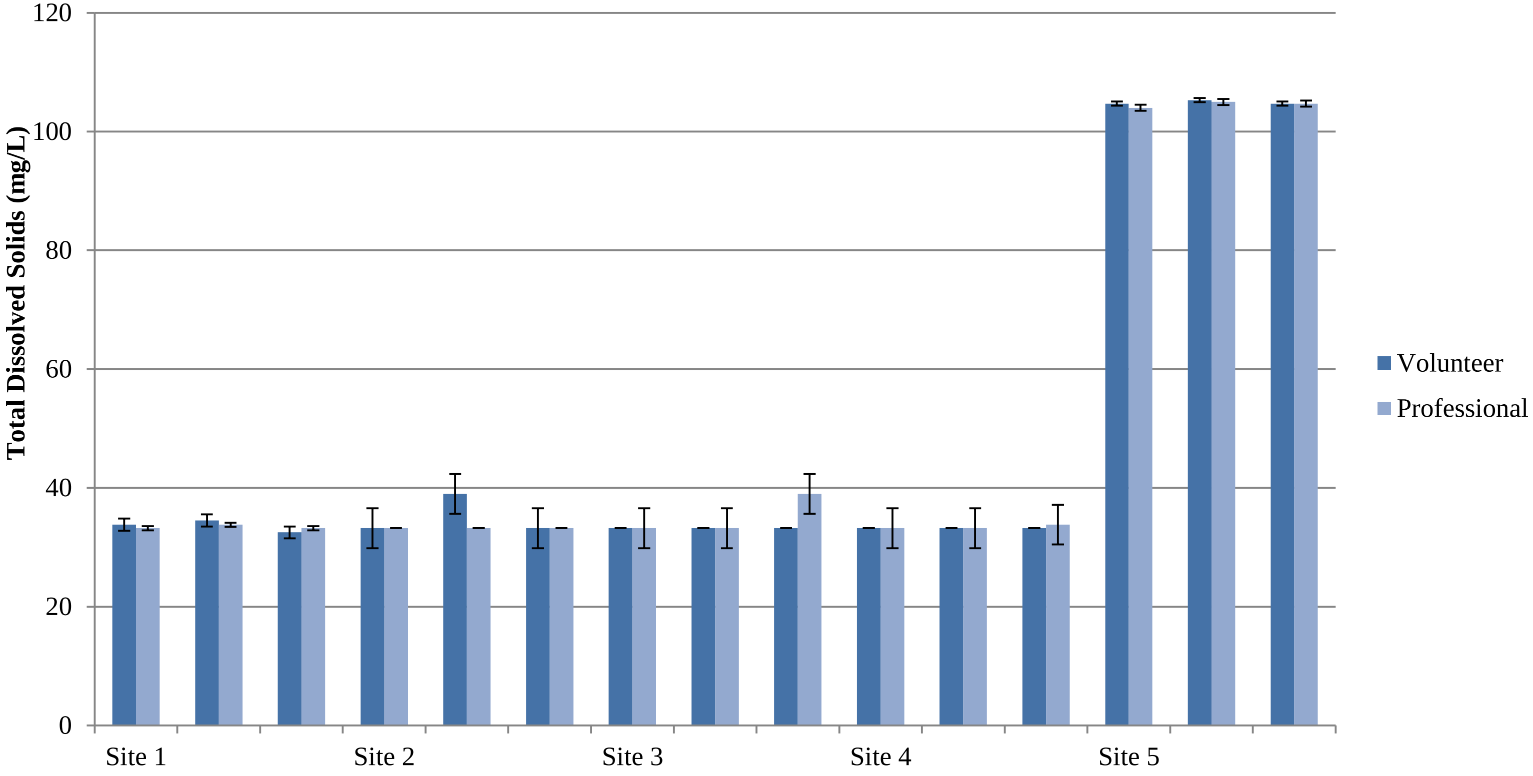

Figure 4.18. Volunteer versus professional raw water quality data for total dissolved solids (mg/L). (Both professional and volunteer measured three transects at each site.)

Chapter Five

DISCUSSION AND CONCLUSIONS

5.1 Introduction

The results provided from Chapter 4 are discussed to help draw conclusions regarding the two studies presented in this thesis. A focus of this chapter is to provide answers to the research questions provided in **Chapter 1**, **Section 1.2.2**.

5.2 Discussion – Surface Water Quality Study

This study sought to reveal a change in surface water quality, from the sites close to the mouth of The Gambia River (near the Atlantic Ocean), to the last study site located near the Senegalese border. It was hypothesized that the data would reflect natural and anthropogenic changes, as well as land use in different parts of the river. It was also hypothesized that anthropogenic disturbances have altered the distribution of water quality. Water quality is best monitored in real-time to allow for more accurate and precise data (Ahuja, 2013, p.10). Real-time data provide the ability to discover early warning signs of possible contamination. Real time water quality data sets are usually based on one or more of the following parameters: turbidity, conductivity, temperature, dissolved oxygen, salinity, and pH (Ahuja, 2013, p.11; Nicholson, Ryan & Hodgkins, 2002).

5.2.1 Water Temperature and Dissolved Oxygen

The lowest temperature recorded at the 29 sampling sites was 21.5 °C at site 12 (Tendaba) and the highest temperature was 27.7 °C at site 10 (Tankular) (**Figures 4.0** and **4.1**). The difference could be attributed to the time of day the water was sampled. It is normal for water bodies to exhibit changes in temperature diurnally. For example, Tendaba was sampled at 9:04 AM when the sun had just risen and not had time to heat the water, while Tankular was sampled at 5:42 PM when the sun was past its hottest point, and had heated up the surface water. This could also be why the temperatures at sites 11 (Salikene), 12 (Tendaba), 13 (Farafenni), and 16 (Pakali Ba) were lower as they were also sampled before noon. Additionally, some sampling sites were more or less shaded by vegetation which would again influence the rate of heating of the surface water. Finally, many rivers and streams exhibit vertical thermal stratification as the sun warms the upper water during the day, while the deeper water remains cooler.

The concentration of dissolved oxygen (DO) is influenced by a number of factors. Turbulence and water velocity tend to increase oxygen levels whereas aquatic life, such as bacteria, tends to decrease them as they use oxygen in the water during the decomposition of organic matter. For example, agriculture, development, and logging can increase the amount of organic matter entering waterways and therefore increase the activity of decomposers (Minnesota Pollution Control Agency, 2009). Dissolved oxygen levels also decrease as elevation, salinity and water temperature increase. As discussed in **Section 4.1.9**, there is a significant relationship (p=0.018) between water temperature and dissolved oxygen, with a moderately strong correlation of p=0.44 (**Table 4.1**). Riparian vegetation can have a positive effect on DO levels as not only do plants release oxygen into the water during photosynthesis, but the shade they provide may decrease the water temperature.

The DO readings did not differ dramatically along the river. Since values may reflect photosynthesis by aquatic plants, there may be daily fluctuations with increased dissolved oxygen levels during the day, and decreased ones at night. Vegetation identification within the river, however, was limited due to the presence of cloudy water, rocks and mud. In the upper reaches of the river, DO oxygen levels tended to be slightly higher than in the lower reaches of the river, perhaps due to the differences in salinity. The lowest DO reading was at site 19 (Jessadi) with a reading of 2.1mg/L at 3:30 PM while the highest dissolved oxygen reading was at site 24 (Jangjangbureh) with a reading of 8.3 mg/L at 5:00 PM. Site 19 was located within close proximity to the road and a busy wharf, which could potentially increase organic matter in the water from erosion or waste discharges from boats. There was no riparian vegetation shading the water at this site, but temperatures were not unduly high here. The river velocity appeared to be lower, perhaps due to the presence of surrounding boats and the wharf; these factors can lead to a decrease in aeration bubbles (United States Environmental Protection Agency, 2014). The highest recorded value, site 24, was located in an area with thick riparian vegetation and was located away from potential run-off from roads; both of these factors can impact DO readings.

Dissolved oxygen levels of 5mg/L, and especially those less than 2mg/L, can stress aquatic life. Dissolved oxygen levels less than 2mg/L could potentially cause a fish kill. According to a report by Darboe (2002), there were no fish kills in The Gambia River between 1993 and 2002. However, in 2003, the presence of black water resulted in a fish kill in the freshwater zone. After further investigation, the fish kill was attributed to organic surface run-off, following heavy rains resulting in a high biological oxygen demand, which led to anoxia.

The results from this study showed that 11 sampling sites out of 29 were recorded to have individual readings below the recommended minimum of 5mg/L (sites 1, 5, 6, 9, 11, 13, 14, 16, 17, 19, 20). Many other sites had readings with just above 5mg/L and others were as low as 2mg/L (**Appendix B**, **Table 3**). Low readings were present in only the lower and middle reaches of the river; this could reflect the higher salinity content in the water and the effects of increased human activity. At many of these sites there were eroded banks and/or farms adjacent to the riverbank.

5.2.2 pH

Overall, pH values observed in this study did not fall outside the recommended levels of 6.5-8.5 for aquatic life (according to the CCME guidelines previously discussed). It is important to remember that a difference of one pH unit changes the hydrogen ion concentration by a factor of ten ($pH = -\log [H^+]$). The highest recorded pH values were at sites 2 and 3 (Banjul and Barra) with a value of 8.02 and 8.15 respectively (**Appendix B, Table 2**). These two sites were the only sampling locations with values exceeding 8.00. This was due to the high proportion of seawater mixing with river water as these sites are near the mouth of the river. Urban and industrial developments are evident here and a high percentage of the Gambian population (approximately 34,589 people in 2010) is found near these two sites (GeoName, 2010).

The present study took place during the dry season, and the high pH values in the estuary reflects the fact that there is little fresh water input at this time of year. The discharge rate was low and any runoff has a higher interaction time with the surrounding soils (Kelso *et. al*, 1986). Ocean water has a pH of approximately 8.1, so these results were expected. In a study by Louca *et. al* (2009), the pH levels in the estuary began to decline due to the influx of fresh water during the rainy season.

5.2.3 Salinity, Conductivity, and Total Dissolved Solids

Salinity, electrical conductivity, and total dissolved solids had significant and very strong correlations (r=0.998) (**Table 4.1**). These concentrations were highest at site 1 (Kartong) with values of 36.48 ppt, 54,150.6 µS/cm, and 37,534.1 mg/L for salinity, conductivity and total dissolved solids respectively. These high values are the result of the site being located near the Atlantic Ocean. The average salinity of ocean water is 35 ppt, with values ranging between 32 and 37 ppt (Office of Naval Research, N.D). A high salt content of irrigation water can affect crops as salts accumulate near the roots (Colorado State University, 2014). This is an ongoing concern for The Gambia due to the tidal insurgence which reaches approximately 240 kilometers upriver. Rice crops, grown in the upper reaches of The Gambia River, cannot grow in areas reached by saline water (Carney, 1998). As expected, salinity values fell drastically at site 12, the limit of the salt water intrusion. There is a peak in salinity at site 8 (Darsilami) and another smaller one at site 11 (Salikene) where there is an influx of saltwater from the ocean.

A sudden increase or decrease in conductivity could be an indication of a pollution event. Agricultural runoff or sewage can increase conductivity values due to the additional phosphate and nitrate ions being deposited (Fondriest Environmental Inc., 2014). Site 8 (Darsilami) had a high spike in conductivity values which may be due to a large number of people living in the area. Conductivity can increase following the discharge of industrial pollutants and untreated sewage effluent, and with higher temperatures (the warmer the water the higher the conductivity) (USGS, 2014). Also, dust, oil and industrial debris on roads can wash into the river system during rain events and site 8 was close to the road.

The natural source of dissolved solids is from the weathering of rocks. High levels of total dissolved solids (TDS) are often associated with high levels of calcium and magnesium. These elements do not pose a threat to human health but they can result in hard water. High levels of TDS can also be an indicator of pollution by iron, manganese, sulphate, arsenic and nitrates which can be harmful to human health. The areas along the coast are comprised of mainly sedimentary rocks which are slightly thicker towards the West of the country (Camara & Jobe, 2011; Jallow, Barrow & Leatherman, 1996;

Schlüter & Trauth, 2006). This is evident in **Figure 4.10** where you can see the TDS dropping rapidly at site 12. Total dissolved solids can have an effect on ecosystem health and limit the growth of aquatic organisms if the values are too high or too low. Increased TDS values may indicate the presence of point or non-point sources of pollution.

5.2.4 Coliform

Water can be contaminated by coliform bacteria originating in soils, decayed animal waste or human excreta. Coliform was tested at each sampling station at each of the 29 locations for a total of 87 tests. All 87 tests results were positive, indicating that the water, without treatment, was unsuitable for human consumption. With respect to water quality, the requirement in Canada is for no coliform bacteria to be present in drinking water (Health Canada, 2013). Some coliform strains live in the intestines of humans and animals which is why coliform bacteria are used to assess fecal contamination; surface waters generally contain coliform bacteria, but are usually treated before being consumed by humans. Many Gambians drink the river water without treating the water (Personal Communication, Conteh, December, 2011). This practice makes them more susceptible to water borne diseases such as dysentery or diarrhea which can lead to severe illness or death. Typically, people affected by water borne diseases in The Gambia do not receive the medical treatment needed to cure them quickly (Personal Communication, Suso, December, 2012).

5.3 Observations

The data collected at each of the 29 sampling locations indicate that specific areas of the Gambia River, such as those located further downriver, have inferior water quality, with respect to irrigation and consumption, due to the presence of salt water, anthropogenic disturbances, and effluents. The entire river is deemed unfit for water consumption by humans due to high salt levels, from the mouth of the river to site 12, and the presence of coliform bacteria at all sties (**Figures 4.9** and **4.12**). However, the river water is widely used, ecosystem health appears to be good, and the upper reaches are suitable for agricultural purposes. The lower areas of the river, though unsuitable for irrigation due to its brackish nature, have a more diverse fish fauna (Albaret *et. al*, 2006).

The upper reaches of The Gambia River (approximately 250 kilometers or more upriver) are freshwater and are valuable for rice and groundnut production due to the freshwater swamp area (Carney, 1998). There is no tidal (salt water) influence and the growing conditions are ideal for these crops. The quality of water here is sufficient for human consumption, if treated, and for irrigation.

5.4 Limitations and Recommendations

There were time limitations for this study which prevented repetitive sampling to obtain a larger set of baseline data, and the cost of travel prohibited a return trip to The Gambia in the wet season. Sampling in both the wet and dry season would allow for comparison from season to season.

Throughout the duration of this study, and afterwards, a number of observations were made which resulted in the following recommendations for future studies.

1) Repetitive sampling in each season would allow for a better understanding of water quality in the river. The availability of more chemical standards would permit daily calibrations of the probes. In this study, limits in baggage capacity prevented taking sufficient standards.
2) With access to additional testing equipment, more information on nitrates and phosphate levels in the Gambia River could be collected.
3) The addition of more sampling sites at known intervals along the river would provide a more comprehensive and representative data set, as would sampling at a standard time of day at each site. In this study, it was not possible to do this due to time constraints and travel issues.
4) Sampling the river at different depths at each site would result in a better understanding of the thermal layers in the Gambia River.
5) Sampling over a number of years should be done in order to reveal trends in the data.
6) Undertaking more sophisticated coliform tests would enable the most probable number of coliforms per ml of water to be assessed and hence the level of coliform contamination at different parts of the river.
7) Collaboration with a certified Water Resources Laboratory would be useful for testing for further contaminants.

8) An educational program to discuss, with communities, the risks of drinking the river water would be useful to help with safe water education country wide.
9) It would be interesting to include a study of benthic macroinvertebrates and fish populations to provide more insight into water quality.
10) Using tidal data would be a great benefit in future studies.
11) Conducting separate studies to find out people's perceptions of water quality in the Gambia River would provide insight into why people are still drinking and using the untreated river water daily.

5.5 Conclusions

The focus of water quality studies is starting to shift from the principal focus of human health to a more equal focus on both human and ecosystem health (Karr, 1992). Water quality testing has become increasingly important, particularly within the past 75 years (Gibbs, 1972; Niemi, Devore, Detenbeck, Taylor & Lima, 1990; Sacomani & Silva, 2000). Water contaminated by pathogenic microorganisms, or chemical contaminants, causes many diseases in humans, especially in developing countries (Gadgil, 2008). Diseases can be contracted by ingesting contaminated food or water, or from coming into contact with contaminated water through bathing or washing. There is limited research and documentation on African water sources, despite concern about water quality and water scarcity in the continent (Mwanza, 2005). The data presented in **Chapter 4**, indicated that the water from the Gambia River is not suitable, when untreated, for human consumption.

In response to the first research question, ‘What are the spatial variations in water quality in the Gambia River?’ the study revealed that water quality did indeed vary along the Gambia River. Tidal influences, estuaries, and runoff from agricultural land all contributed to the differences in water quality. The water quality does in fact vary moving West to East up the river as a result of salt influence, erosion, plant species, geology, etc.

In response to the second research question, ‘What factors have influenced the spatial variations in water quality in The Gambia River?’ the results revealed that, although human disturbances have influenced the water quality of the river in terms of bacterial contamination, disturbance to date has not drastically affected the river.

5.6 Discussion – Citizen Science Study

It was expected that there would be little difference between the data collected by the volunteer compared to the data collected by the professional for the water quality parameters sampled. This was confirmed and the value of training the volunteers was evident.

Water temperature was the most accurate parameter measured in the study, falling within 100% of an acceptable range according to Nova Scotia Environment (NSE), 2010. The study revealed that citizen science sampling for all the parameters examined was successful, given the limitations and study design which were presented in this study (i.e., calibration being done by a trained professional, volunteer training for the equipment being used and a brief introduction about water quality, conducting similar field methods, and restricting spatial and temporal variability by sampling the same location at the same time (in-situ).

Nicholson *et al.* (2002) found differences in the dataset between volunteer and professional data. In their study, there were several days between each data collection and the equipment used was not standardized. This resulted in inaccuracy of the citizen scientists' data due to spatial and temporal differences, and differences in equipment used. In another study by Shelton (2013), participants were provided with individual training and were asked to calibrate equipment on their own. They were given an online course which provided them with an introduction to water quality monitoring which tested their knowledge of the course. They were also provided with a calibration manual and given the opportunity to calibrate their own unit. This was not possible for the present study due to lack of internet availability, time, and calibration solutions. This limitation is one which should be address in futures studies in order for the volunteer to become knowledgeable with water quality and the equipment being used.

5.6.1 Water Temperature, pH, Conductivity, Salinity and Total Dissolved Solids

Water temperature was the most accurate parameter measured in the study, most likely as a result of not having to calibrate the temperature sensor and sampling side-by-side to avoid differences in environmental conditions. One hundred percent of the results were within an acceptable range according to Nova Scotia Environment (NSE), United

States Geological Survey (USGS) and Environment Canada for the accuracy of the data from the two probes (**Appendix C**, **Table 21**). All values, except dissolved oxygen, fell within an acceptable range with no major errors. Observational data revealed minor to no field note bias or sampling error within the citizen science data.

The results for pH fell within the guidelines for the Nova Scotia Environment (NSE) and the United States Geological Survey (USGS); however, some individual values were slightly out of range according to Environment Canada guidelines. This was most likely due to the influence of ocean pH in the lower reaches of the river.

The conductivity datasets also showed little variability between the two groups. This high accuracy level could be due to the calibration carried out by the professional prior to data collection. One potential source of error for this parameter could be the possibility of not submerging the probe 100% in the water, thus not receiving an accurate result. Salinity is calibrated during the conductivity calibration process as they are related. Total dissolved solids are also related to conductivity and showed little to no minor fluctuations between the control and treatment groups.

5.6.2 Dissolved Oxygen

A higher inaccuracy in this parameter was found with respect to the data collected by the control and treatment groups for both mg/L and percent saturation measurements (**Tables 9** to **18**). For citizen scientists, this parameter is fairly complex, requiring more knowledge and difficult field procedures and calibrations.

Dissolved oxygen is influenced by a number of factors such as salinity, water flow temperature, the presence of wastewater, and algal growth (Wang & Cresser, 2007). It is therefore essential that this parameter be sampled more carefully. Probe placement and a sufficient stabilization time is imperative for sampling DO. Explanations for the large variation between groups could be the result of probe misplacement. For example, the DO membrane requires a flow of water to pass over the sensor, resulting in the need for the probe to be moved up and down slightly if the flow is low (YSI, 2011). Observational data revealed that not all participants followed this procedure, resulting in an incorrect measurement.

5.7 Observations

Conducting side-by-side water quality data in this study showed that volunteer citizen scientists are able to collect data that is accurately within the range of data collected by a trained professional. This is achieved by carefully selecting parameters, having adequate training, and by removing spatial and temporal limitations. This study lacked a significant direct training component which is necessary to provide the highest level of training for water quality monitoring with volunteers due to time and internet constraints.

5.8 Limitations and Recommendations

During the duration of this study, limitations arose which could be addressed for future studies.

Limitations and recommendations:

1) Increase the number of treatment group participants so that a more in-depth statistical analysis could be conducted.
2) Have more study locations to make sure that the problems of sampling in different types of environments along the Gambia River are addressed.
3) Allow for more time and training for the volunteers so they can conduct their own calibration of their probes. This would strengthen the study by providing more proof of the ability of citizen scientists.
4) Have more diverse participants within the treatment groups (i.e., trained scientists, students, and someone with no scientific experience). This study focused on school children as they were already being trained in water education by the Nova Scotia - Gambia Association.
5) Select parameters that are relevant to local environmental problems and which are easy to monitor.
6) Devise well-designed monitoring programs which will allow citizen scientists to follow a standard operating procedure.
7) Future studies could focus more on human error while sampling and recording field notes.

8) Increase the level of training available to volunteers to ensure that volunteers are very familiar with their equipment. For example, a one-on-one session with each participant could prove to be useful.
9) Limit the location and time of sample collection to ensure that results are comparable at different sites.

5.9 Conclusions

Volunteer-based monitoring has many advantages which have been documented and have contributed to ecosystem monitoring worldwide (Conrad & Daoust, 2008). Citizen science data have been collected previously for water quality monitoring by Au *et al*., (2000), and for fish studies by Caselle *et al*., (2011). However, even though there have been numerous studies (Bonney *et al*., 2009), there is still some skepticism as to whether volunteers can collect credible data, as there is some concern about the quality of data collected by citizen scientists, and if it is comparable to that collected by professional scientists (Breed *et al.*, 2012; Gillett *et al.*, 2011). However, more recently, Shelton (2013) shows that citizen scientists do have the capacity to collect accurate water quality data.

In response to the first research question, ‘Are volunteer citizen scientists able to collect data that are considered comparable to data that are collected by a trained professional?’ the present study revealed that citizen scientists were indeed capable of collecting data which were considered to be accurate.

In response to the second research question, ‘What conditions make it possible for volunteer citizen scientists to collect the most accurate data?’ the results indicated that adequate training, calibration, and sampling design are the key components of reliable data and results that are valuable at the community level. In conclusion, this study showed clearly that citizen scientists can, with suitable training, collect high quality data that can be used for monitoring, even in developing countries, where the level of education is not as high as elsewhere.

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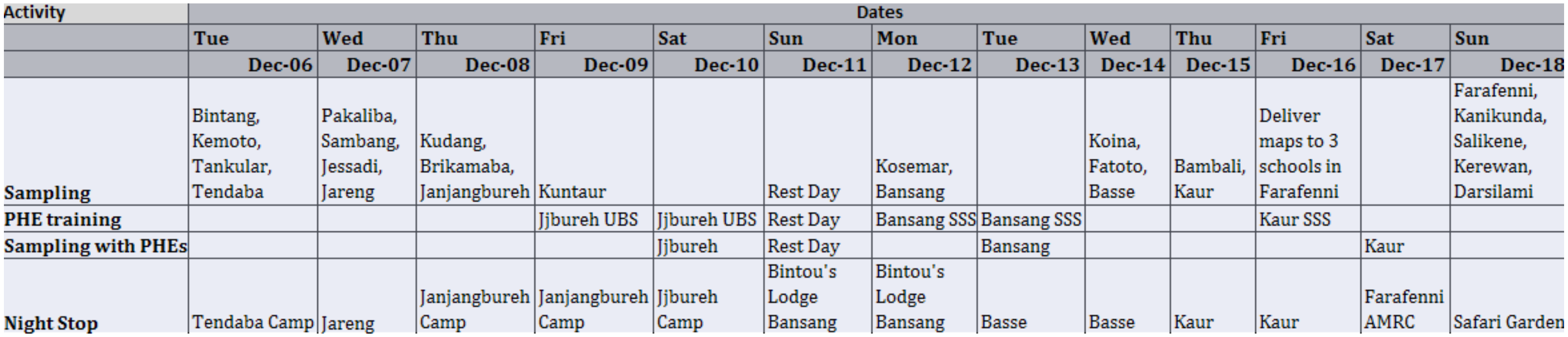
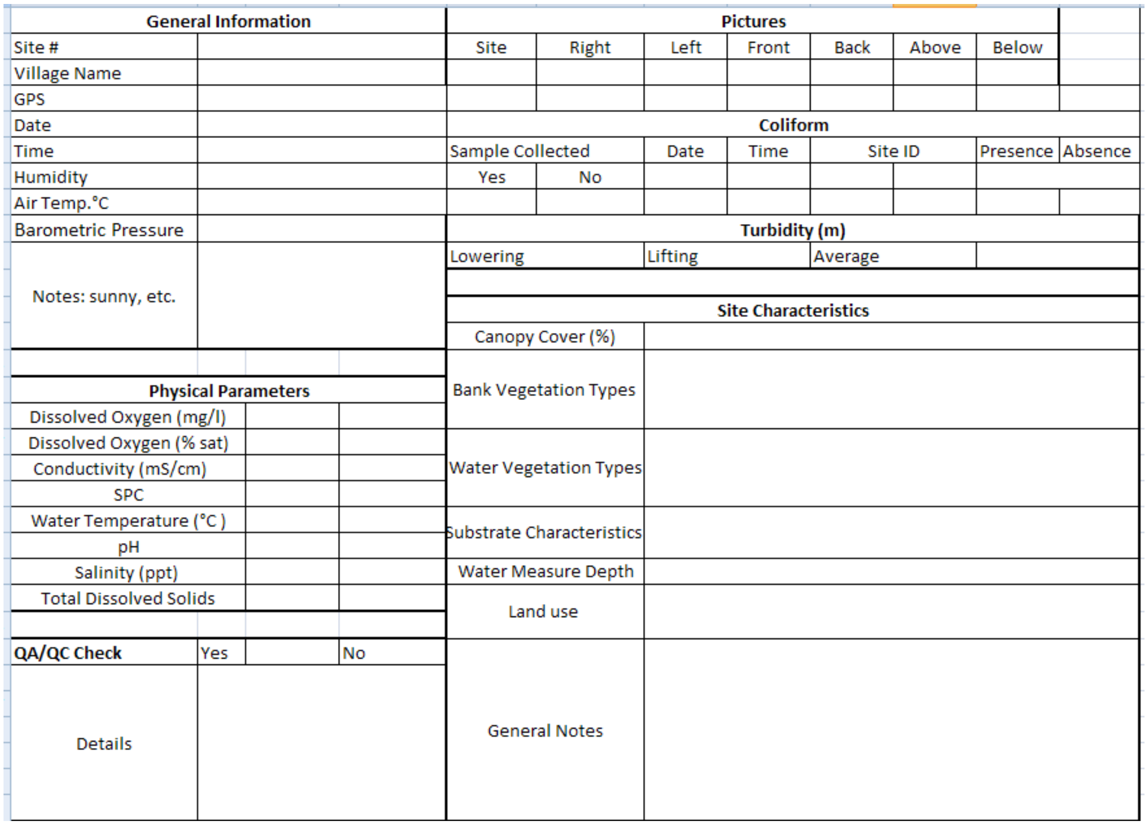
Appendix A



Activity	Dates												
	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	Dec-06	Dec-07	Dec-08	Dec-09	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-18
Sampling	Bintang, Kemoto, Tankular, Tendaba	Pakaliba, Sambang, Jessadi, Jareng	Kudang, Brikamaba, Janjangbureh	Kuntaur		Rest Day	Kosemar, Bansang		Koina, Fatoto, Basse	Bambali, Kaur	Deliver maps to 3 schools in Farafenni		Farafenni, Kanikunda, Salikene, Kerewan, Darsilami
PHE training				Jjbureh UBS	Jjbureh UBS	Rest Day	Bansang SSS	Bansang SSS			Kaur SSS		
Sampling with PHEs					Jjbureh	Rest Day		Bansang				Kaur	
Night Stop	Tendaba Camp	Jareng	Janjangbureh Camp	Janjangbureh Camp	Jjbureh Camp	Bintou's Lodge Bansang	Bintou's Lodge Bansang	Basse	Basse	Kaur	Kaur	Farafenni AMRC	Safari Garden

Figure 1. Sampling Itinerary



General Information	
Site #	
Village Name	
GPS	
Date	
Time	
Humidity	
Air Temp.°C	
Barometric Pressure	
Notes: sunny, etc.	

Physical Parameters		
Dissolved Oxygen (mg/l)		
Dissolved Oxygen (% sat)		
Conductivity (mS/cm)		
SPC		
Water Temperature (°C)		
pH		
Salinity (ppt)		
Total Dissolved Solids		

QA/QC Check	Yes		No
Details			

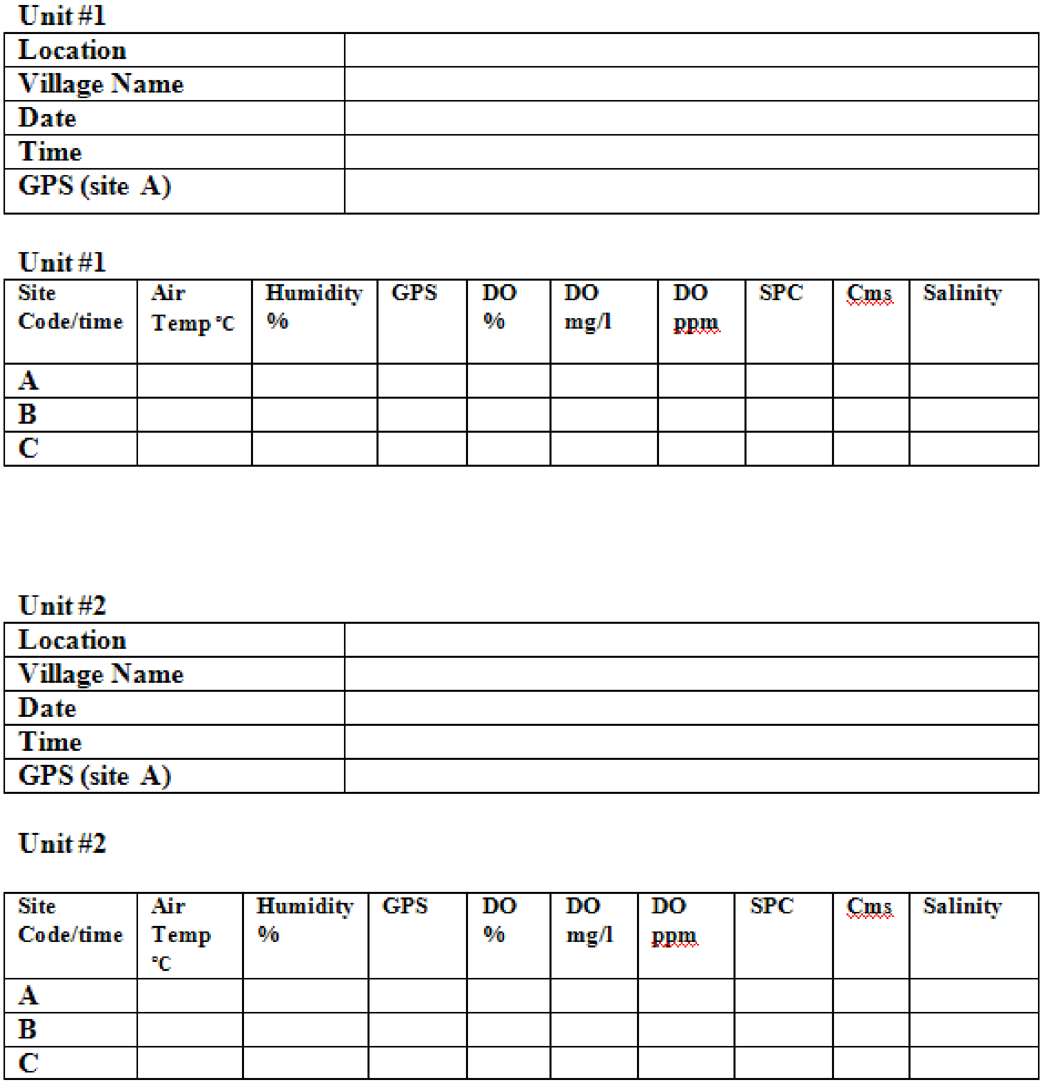
Pictures						
Site	Right	Left	Front	Back	Above	Below

Coliform						
Sample Collected		Date	Time	Site ID	Presence	Absence
Yes	No					

Turbidity (m)			
Lowering	Lifting	Average	

Site Characteristics	
Canopy Cover (%)	
Bank Vegetation Types	
Water Vegetation Types	
Substrate Characteristics	
Water Measure Depth	
Land use	
General Notes	

Figure 2. Site Description Sheet



Unit #1

Location	
Village Name	
Date	
Time	
GPS (site A)	

Unit #1

Site Code/time	Air Temp °C	Humidity %	GPS	DO %	DO mg/l	DO ppm	SPC	Cms	Salinity
A									
B									
C									

Unit #2

Location	
Village Name	
Date	
Time	
GPS (site A)	

Unit #2

Site Code/time	Air Temp °C	Humidity %	GPS	DO %	DO mg/l	DO ppm	SPC	Cms	Salinity
A									
B									
C									

Figure 3. Field Data Sheet

Date/Time			
Name of Operator			
Sonde Serial Number			
Parameter	**Buffer Standard Used**	**Pre-Calibration**	**Post-Calibration**
Specific Conductivity (µS/cm)	12880	________ µS/cm __________°C	__________µS/cm __________ °C
pH Buffer Point #1	Buffer Value 4.00 7.00 10.00	pH= __________ __________ mV __________°C	N/A N/A
pH Buffer Point #2	Buffer Value 4.00 7.00 10.00	pH= _________ __________ mV __________°C	pH=___________ __________mV __________°C
Dissolved Oxygen (% Sat)	N/A	__________ % __________ °C	___________ % ___________ °C
Observations/Comments			

pH 7 mV value = 0 mV +/- 50 mV (note: A value of +50 or -50 mV in buffer 7 does not indicate a bad sensor)

pH 4 mV value = +165 to +180 from 7 buffer mV value

pH 10 mV value = -165 to -180 from 7 buffer mV value

The mV span between pH 4 and 7 and 7 and 10 mV values should be ≈ 165 to 180 mV. 177 is the ideal distance. The slope can be 55 to 60 mV per pH unit with an ideal of 59 mV per pH unit. If the mV span between pH 4 and 7 or 7 and 10 drops below 160, clean the sensor and try to recalibrate.

Figure 4. Calibration Sheet (2 point pH calibration)

Date/Time			
Name of Operator			
Sonde Serial Number			
Parameter	**Buffer Standard Used**	**Pre-Calibration**	**Post-Calibration**
Specific Conductivity (µS/cm)	12880	________ µS/cm __________°C	__________µS/cm __________ °C
pH Buffer Point #1	Buffer Value 4.00 7.00 10.00	pH= __________	N/A
		__________ mV __________°C	N/A
pH Buffer Point #2	Buffer Value 4.00 7.00 10.00	pH= _________	N/A
		__________ mV __________°C	N/A
pH Buffer Point #3	Buffer Value 4.00 7.00 10.00	pH= _________	pH=___________
		__________ mV __________°C	__________ mV __________°C
Dissolved Oxygen (% Sat)	N/A	__________ % __________ °C	___________ % ___________ °C
Observations/Comments			

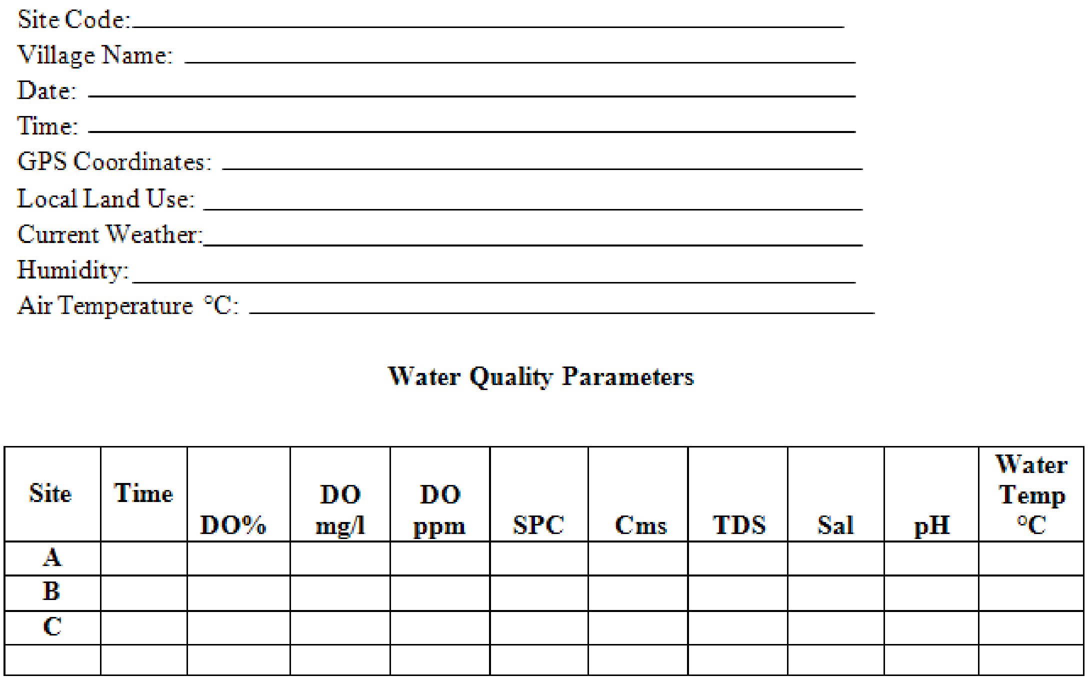
pH 7 mV value = 0 mV +/- 50 mV (note: A value of +50 or -50 mV in buffer 7 does not indicate a bad sensor)

pH 4 mV value = +165 to +180 from 7 buffer mV value

pH 10 mV value = -165 to -180 from 7 buffer mV value

The mV span between pH 4 and 7 and 7 and 10 mV values should be ≈ 165 to 180 mV. 177 is the ideal distance. The slope can be 55 to 60 mV per pH unit with an ideal of 59 mV per pH unit. If the mV span between pH 4 and 7 or 7 and 10 drops below 160, clean the sensor and try to recalibrate.

Figure 5. Calibration Sheet (3 point pH calibration)



Site Code: ______________________________

Village Name: ______________________________

Date: ______________________________

Time: ______________________________

GPS Coordinates: ______________________________

Local Land Use: ______________________________

Current Weather: ______________________________

Humidity: ______________________________

Air Temperature °C: ______________________________

Water Quality Parameters

Site	Time	DO%	DO mg/l	DO ppm	SPC	Cms	TDS	Sal	pH	Water Temp °C
A										
B										
C										

Figure 6. Volunteer data and water quality sheet

Appendix B

Table 1. Summary of water temperature (°C) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are included

Date	Site Location and Number	Water Temperature °C						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe #1			Probe #2								
21-Dec-11	Kartong (1)	24.3	24.4	23.7	24.5	24.5	23.8	6	24.2	24.2	24.5	23.7	0.4
20-Dec-11	Banjul (2)	23.7	23.7	23.7	23.7	23.7	23.7	6	23.7	23.7	23.7	23.7	0.0
20-Dec-11	Barra (3)	26.5	26.6	26.5	26.5	26.6	26.3	6	26.5	26.5	26.6	26.3	0.1
20-Dec-11	Albadarr (4)	24.6	24.8	24.6	24.6	24.5	24.6	6	24.6	24.6	24.8	24.5	0.1
06-Dec-11	Bintang (5)	25.5	26.2	26.5	25.5	26.2	26.6	6	26.1	26.1	26.6	25.5	0.5
20-Dec-11	Jurunka (6)	24.0	24.1	24.0	24.0	24.1	23.9	6	24.0	24.0	24.1	23.9	0.1
06-Dec-11	Kemoto (7)	26.0	27.1	27.4	26.2	27.0	26.8	6	26.8	26.7	27.4	26.0	0.5
17-Dec-11	Darsilami (8)	27.0	25.5	26.3	26.9	25.6	26.7	6	26.3	26.3	27.0	25.5	0.7
17-Dec-11	Kerewan (9)	23.8	23.9	23.9	23.8	23.9	23.9	6	23.9	23.9	23.9	23.8	0.1
06-Dec-11	Tankular (10)	27.3	27.4	27.7	27.4	27.3	27.4	6	27.4	27.4	27.7	27.3	0.1
17-Dec-11	Salikene (11)	21.7	21.7	22.3	22.7	21.7	22.1	6	22.0	22.0	22.7	21.7	0.4
07-Dec-11	Tendaba (12)	21.6	21.5	21.6	21.6	21.5	21.6	6	21.6	21.6	21.6	21.5	0.1
16-Dec-11	Farafenni (13)	22.6	22.8	23.2	22.6	22.7	23.0	6	22.8	22.8	23.2	22.6	0.2
15-Dec-11	Bambali (14)	24.4	24.4	24.4	24.4	24.4	24.4	6	24.4	24.4	24.4	24.4	0.0
07-Dec-11	Sambang (15)	25.6	25.6	25.6	25.5	25.6	25.7	6	25.6	25.6	25.7	25.5	0.1
07-Dec-11	Pakali Ba (16)	22.7	22.7	22.7	22.7	22.7	22.7	6	22.7	22.7	22.7	22.7	0.0
15-Dec-11	Kanikunda (17)	24.6	24.6	24.6	24.6	24.6	24.6	6	24.6	24.6	24.6	24.6	0.0
15-Dec-11	Kaur (18)	25.0	25.0	25.0	25.0	25.0	25.0	6	25.0	25.0	25.0	25.0	0.0
07-Dec-11	Jessadi (19)	26.8	26.1	26.2	26.2	26.2	26.2	6	26.3	26.3	26.8	26.1	0.3
07-Dec-11	Jareng (20)	25.6	25.5	25.3	25.6	25.5	25.3	6	25.5	25.5	25.6	25.3	0.1
08-Dec-11	Kudang (21)	25.0	25.0	25.1	25.0	25.0	25.1	6	25.0	25.0	25.1	25.0	0.1
09-Dec-11	Kuntaur (22)	25.6	25.6	25.5	25.6	25.6	25.5	6	25.6	25.6	25.6	25.5	0.1
08-Dec-11	Brikamaba (23)	26.1	26.1	26.1	26.1	26.1	26.1	6	26.1	26.1	26.1	26.1	0.0
08-Dec-11	Jangjangbureh (24)	26.4	26.3	26.4	26.4	26.4	26.4	6	26.4	26.4	26.4	26.3	0.0
12-Dec-11	Bansang (25)	26.2	26.2	26.2	26.2	26.2	26.2	6	26.2	26.2	26.2	26.2	0.0
13-Dec-11	Kosemar (26)	26.5	26.5	25.9	26.0	26.5	26.0	6	26.2	26.2	26.5	25.9	0.3
14-Dec-11	Basse (27)	25.2	23.7	25.3	25.2	25.2	25.3	6	25.0	25.0	25.3	23.7	0.6
14-Dec-11	Fatoto (28)	25.0	25.1	25.1	25.0	25.1	25.1	6	25.1	25.1	25.1	25.0	0.1
14-Dec-11	Koina (29)	24.8	24.8	24.8	24.8	24.8	24.8	6	24.8	24.8	24.8	24.8	0.0

Table 2. Summary of pH measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	pH						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	7.64	7.63	7.61	7.62	7.65	7.61	6	7.63	7.63	7.65	7.61	0.02
20-Dec-11	Banjul (2)	8.02	8.01	8.00	7.98	7.97	7.97	6	7.99	7.99	8.02	7.97	0.02
20-Dec-11	Barra (3)	8.13	8.13	8.15	8.12	8.11	8.12	6	8.13	8.13	8.15	8.11	0.01
20-Dec-11	Albadarr (4)	7.97	7.84	7.99	7.94	7.95	7.95	6	7.94	7.94	7.99	7.84	0.05
06-Dec-11	Bintang (5)	7.57	7.58	7.57	7.47	7.43	7.42	6	7.51	7.51	7.58	7.42	0.08
20-Dec-11	Jurunka (6)	7.55	7.52	7.50	7.48	7.47	7.46	6	7.50	7.50	7.55	7.46	0.03
06-Dec-11	Kemoto (7)	7.75	7.46	7.51	7.58	7.50	7.19	6	7.50	7.50	7.75	7.19	0.18
17-Dec-11	Darsilami (8)	7.83	7.07	7.09	7.80	7.04	7.06	6	7.32	7.31	7.83	7.04	0.39
17-Dec-11	Kerewan (9)	7.49	7.51	7.49	7.49	7.49	7.48	6	7.49	7.49	7.51	7.48	0.01
06-Dec-11	Tankular (10)	7.56	7.58	7.65	7.49	7.48	7.58	6	7.56	7.56	7.65	7.48	0.06
17-Dec-11	Salikene (11)	7.27	7.26	7.24	7.20	7.22	7.27	6	7.24	7.24	7.27	7.20	0.03
07-Dec-11	Tendaba (12)	7.63	7.54	7.62	7.59	7.56	7.52	6	7.58	7.58	7.63	7.52	0.04
16-Dec-11	Farafenni (13)	7.15	7.10	7.37	7.11	7.12	7.28	6	7.19	7.19	7.37	7.10	0.11
15-Dec-11	Bambali (14)	7.07	7.11	7.05	7.06	7.04	6.99	6	7.05	7.05	7.11	6.99	0.04
07-Dec-11	Sambang (15)	7.40	7.48	7.58	7.15	7.40	7.47	6	7.41	7.41	7.58	7.15	0.15
07-Dec-11	Pakali Ba (16)	7.44	7.29	7.24	7.38	7.25	7.17	6	7.30	7.29	7.44	7.17	0.10
15-Dec-11	Kanikunda (17)	7.21	7.18	7.51	7.20	7.12	7.48	6	7.28	7.28	7.51	7.12	0.17
15-Dec-11	Kaur (18)	7.39	7.34	7.32	7.33	7.31	7.30	6	7.33	7.33	7.39	7.30	0.03
07-Dec-11	Jessadi (19)	7.19	7.13	7.36	7.19	7.16	7.35	6	7.23	7.23	7.36	7.13	0.10
07-Dec-11	Jareng (20)	7.28	7.10	7.25	7.25	7.03	7.23	6	7.19	7.19	7.28	7.03	0.10
08-Dec-11	Kudang (21)	7.49	7.48	7.48	7.59	7.42	7.47	6	7.49	7.49	7.59	7.42	0.06
09-Dec-11	Kuntaur (22)	7.70	7.64	7.68	7.45	7.43	7.46	6	7.56	7.56	7.70	7.43	0.13
08-Dec-11	Brikamaba (23)	7.65	7.64	7.59	7.46	7.54	7.37	6	7.54	7.54	7.65	7.37	0.11
08-Dec-11	Jangjangbureh (24)	7.82	7.48	7.85	7.79	7.46	7.79	6	7.70	7.70	7.85	7.46	0.18
12-Dec-11	Bansang (25)	7.55	7.57	7.53	7.51	7.42	7.53	6	7.52	7.52	7.57	7.42	0.05
13-Dec-11	Kosemar (26)	6.98	6.76	7.16	7.02	6.77	7.11	6	6.97	6.96	7.16	6.76	0.17
14-Dec-11	Basse (27)	7.38	7.38	7.35	7.35	7.33	7.32	6	7.35	7.35	7.38	7.32	0.02
14-Dec-11	Fatoto (28)	7.31	7.35	7.34	7.30	7.27	7.27	6	7.31	7.31	7.35	7.27	0.03
14-Dec-11	Koina (29)	7.42	7.34	7.39	7.31	7.39	7.37	6	7.37	7.37	7.42	7.31	0.04

Table 3. Summary of dissolved oxygen (mg/L) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	Dissolved Oxygen (mg/L)						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	3.3	3.7	4.1	3.2	3.5	3.7	6	3.6	3.6	4.1	3.2	0.3
20-Dec-11	Banjul (2)	5.7	5.5	5.8	5.2	5.1	5.0	6	5.4	5.4	5.8	5.0	0.3
20-Dec-11	Barra (3)	6.5	6.4	6.7	6.0	6.1	6.0	6	6.3	6.3	6.7	6.0	0.3
20-Dec-11	Albadarr (4)	5.9	5.5	6.4	6.1	5.2	5.7	6	5.8	5.8	6.4	5.2	0.4
06-Dec-11	Bintang (5)	4.8	4.1	4.6	4.9	5.3	5.0	6	4.8	4.8	5.3	4.1	0.4
20-Dec-11	Jurunka (6)	4.4	4.5	4.7	4.8	3.9	4.0	6	4.4	4.4	4.8	3.9	0.4
06-Dec-11	Kemoto (7)	6.3	6.7	3.8	6.5	5.4	3.3	6	5.3	5.1	6.7	3.3	1.5
17-Dec-11	Darsilami (8)	5.4	5.1	5.0	6.3	5.0	4.8	6	5.3	5.2	6.3	4.8	0.5
17-Dec-11	Kerewan (9)	5.4	5.2	4.9	4.9	4.6	4.4	6	4.9	4.9	5.4	4.4	0.4
06-Dec-11	Tankular (10)	6.4	6.3	6.2	6.2	6.1	6.1	6	6.2	6.2	6.4	6.1	0.1
17-Dec-11	Salikene (11)	4.7	4.5	3.1	3.8	4.1	3.8	6	4.0	4.0	4.7	3.1	0.6
07-Dec-11	Tendaba (12)	5.4	4.8	5.6	5.9	6.6	6.5	6	5.8	5.8	6.6	4.8	0.7
16-Dec-11	Farafenni (13)	4.9	3.5	4.1	4.3	4.1	3.7	6	4.1	4.1	4.9	3.5	0.5
15-Dec-11	Bambali (14)	4.7	3.8	3.9	4.2	3.4	3.7	6	4.0	3.9	4.7	3.4	0.5
07-Dec-11	Sambang (15)	4.5	5.2	5.2	5.4	5.7	5.1	6	5.2	5.2	5.7	4.5	0.4
07-Dec-11	Pakali Ba (16)	4.2	4.1	4.0	4.6	4.6	4.5	6	4.3	4.3	4.6	4.0	0.3
15-Dec-11	Kanikunda (17)	5.8	4.5	6.0	5.0	3.0	5.3	6	4.9	4.8	6.0	3.0	1.1
15-Dec-11	Kaur (18)	6.1	5.9	6.2	5.7	5.4	5.6	6	5.8	5.8	6.2	5.4	0.3
07-Dec-11	Jessadi (19)	2.3	5.2	5.5	4.6	2.1	5.3	6	4.2	3.9	5.5	2.1	1.6
07-Dec-11	Jareng (20)	5.4	4.2	4.3	5.0	4.4	4.5	6	4.6	4.6	5.4	4.2	0.5
08-Dec-11	Kudang (21)	6.4	6.8	6.2	7.2	7.4	6.0	6	6.7	6.6	7.4	6.0	0.6
09-Dec-11	Kuntaur (22)	6.9	6.7	6.4	7.4	7.7	7.0	6	7.0	7.0	7.7	6.4	0.5
08-Dec-11	Brikamaba (23)	6.6	5.6	5.2	6.2	6.1	7.0	6	6.1	6.1	7.0	5.2	0.7
08-Dec-11	Jangjangbureh (24)	5.8	4.4	7.5	7.1	4.4	8.3	6	6.3	6.1	8.3	4.4	1.6
12-Dec-11	Bansang (25)	6.8	5.6	6.7	6.2	6.1	5.7	6	6.2	6.2	6.8	5.6	0.5
13-Dec-11	Kosemar (26)	5.9	5.1	5.8	5.8	5.2	5.3	6	5.5	5.5	5.9	5.1	0.4
14-Dec-11	Basse (27)	6.1	6.6	5.8	6.0	6.0	5.8	6	6.1	6.0	6.6	5.8	0.3
14-Dec-11	Fatoto (28)	6.8	6.6	6.9	6.3	5.9	6.0	6	6.4	6.4	6.9	5.9	0.4
14-Dec-11	Koina (29)	6.4	5.6	5.7	4.4	6.5	5.6	6	5.7	5.7	6.5	4.4	0.8

Table 4. Summary of dissolved Oxygen (%) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	Dissolved Oxygen (%)						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	49	54	62	48	49	55	6	53	53	62	48	5.3
20-Dec-11	Banjul (2)	80	78	82	74	72	70	6	76	76	82	70	4.7
20-Dec-11	Barra (3)	95	95	99	87	87	87	6	92	92	99	87	5.3
20-Dec-11	Albadarr (4)	82	77	90	85	73	79	6	81	81	90	73	6.0
06-Dec-11	Bintang (5)	65	57	63	67	58	67	6	63	63	67	57	4.4
20-Dec-11	Jurunka (6)	57	60	61	62	51	52	6	57	57	62	51	4.7
06-Dec-11	Kemoto (7)	84	91	51	82	83	47	6	73	71	91	47	18.9
17-Dec-11	Darsilami (8)	79	72	70	95	68	65	6	75	74	95	65	10.9
17-Dec-11	Kerewan (9)	70	66	61	63	61	57	6	63	63	70	57	4.5
06-Dec-11	Tankular (10)	84	82	24	80	83	23	6	63	54	84	23	30.4
17-Dec-11	Salikene (11)	57	35	39	48	49	47	6	46	45	57	35	7.8
07-Dec-11	Tendaba (12)	64	55	65	69	77	76	6	68	67	77	55	8.2
16-Dec-11	Farafenni (13)	57	41	48	51	48	44	6	48	48	57	41	5.6
15-Dec-11	Bambali (14)	56	45	46	50	40	44	6	47	47	56	40	5.5
07-Dec-11	Sambang (15)	55	64	64	54	70	62	6	62	61	70	54	6.1
07-Dec-11	Pakali Ba (16)	49	49	47	54	54	52	6	51	51	54	47	2.9
15-Dec-11	Kanikunda (17)	71	55	72	61	36	64	6	60	58	72	36	13.3
15-Dec-11	Kaur (18)	74	71	76	69	66	68	6	71	71	76	66	3.8
07-Dec-11	Jessadi (19)	52	64	68	57	62	66	6	62	61	68	52	6.0
07-Dec-11	Jareng (20)	66	52	53	61	50	55	6	56	56	66	50	6.1
08-Dec-11	Kudang (21)	77	82	77	87	90	73	6	81	81	90	73	6.5
09-Dec-11	Kuntaur (22)	84	82	79	90	94	86	6	86	86	94	79	5.5
08-Dec-11	Brikamaba (23)	82	69	64	77	76	86	6	76	75	86	64	8.1
08-Dec-11	Jangjangbureh (24)	75	54	93	88	55	104	6	78	76	104	54	20.6
12-Dec-11	Bansang (25)	82	69	81	76	75	74	6	76	76	82	69	4.8
13-Dec-11	Kosemar (26)	73	22	71	72	25	66	6	55	49	73	22	24.4
14-Dec-11	Basse (27)	75	76	72	77	71	72	6	74	74	77	71	2.5
14-Dec-11	Fatoto (28)	83	81	83	77	71	72	6	78	78	83	71	5.4
14-Dec-11	Koina (29)	77	66	80	54	78	63	6	70	69	80	54	10.3

Table 5. Summary of conductivity (µS/cm) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	Conductivity µS/cm						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	55203.9	54606.0	56386.3	54705.5	47796.1	56205.5	6	54150.6	54066.9	56386.3	47796.1	3200.8
20-Dec-11	Banjul (2)	47187.5	47382.5	47330.9	46937.9	47086.1	45503.4	6	46904.7	46900.2	47382.5	45503.4	705.4
20-Dec-11	Barra (3)	48204.6	47408.4	50262.9	42679.7	41715.0	46911.6	6	46197.0	46096.1	50262.9	41715.0	3316.6
20-Dec-11	Albadarr (4)	41010.3	41383.3	41221.6	40802.9	40988.8	40984.5	6	41065.2	41064.8	41383.3	40802.9	204.9
06-Dec-11	Bintang (5)	31194.1	31454.8	30544.7	29510.2	31403.6	29558.5	6	30611.0	30600.0	31454.8	29510.2	894.9
20-Dec-11	Jurunka (6)	26677.5	26782.6	26322.5	26492.1	26632.2	26466.0	6	26562.1	26561.7	26782.6	26322.5	166.4
06-Dec-11	Kemoto (7)	23575.9	23555.4	22984.4	24794.6	23896.2	21997.1	6	23467.3	23451.7	24794.6	21997.1	933.8
17-Dec-11	Darsilami (8)	47612.9	42935.2	43490.7	46852.7	46267.2	48248.4	6	45901.2	45856.8	48248.4	42935.2	2194.8
17-Dec-11	Kerewan (9)	22177.8	23316.6	23299.0	22953.6	23268.6	23139.4	6	23025.8	23022.3	23316.6	22177.8	437.1
06-Dec-11	Tankular (10)	11486.4	12374.4	17511.4	17345.3	18005.7	17222.9	6	15657.7	15409.5	18005.7	11486.4	2913.0
17-Dec-11	Salikene (11)	18779.7	18747.8	18891.8	18652.9	18716.0	19088.7	6	18812.8	18812.3	19088.7	18652.9	156.6
07-Dec-11	Tendaba (12)	6827.8	7008.0	7078.4	6851.2	7091.0	7123.3	6	6996.6	6995.6	7123.3	6827.8	127.6
16-Dec-11	Farafenni (13)	2082.0	2067.3	2077.0	2056.2	2038.3	2065.0	6	2064.3	2064.3	2082.0	2038.3	15.6
15-Dec-11	Bambali (14)	638.6	633.7	632.7	614.9	628.7	636.6	6	630.9	630.8	638.6	614.9	8.5
07-Dec-11	Sambang (15)	360.5	366.2	368.3	362.0	367.0	382.4	6	367.7	367.7	382.4	360.5	7.8
07-Dec-11	Pakali Ba (16)	1841.4	1829.9	1817.5	1815.9	1796.3	1787.8	6	1814.8	1814.7	1841.4	1787.8	20.1
15-Dec-11	Kanikunda (17)	342.5	334.4	336.0	341.6	339.7	339.9	6	339.0	339.0	342.5	334.4	3.2
15-Dec-11	Kaur (18)	160.4	161.8	161.3	160.1	161.8	161.3	6	161.1	161.1	161.8	160.1	0.7
07-Dec-11	Jessadi (19)	167.2	156.3	138.2	138.3	150.8	138.8	6	148.3	147.9	167.2	138.2	12.0
07-Dec-11	Jareng (20)	188.4	193.6	189.6	189.1	190.9	188.6	6	190.0	190.0	193.6	188.4	2.0
08-Dec-11	Kudang (21)	61.2	60.7	60.6	61.4	61.0	79.1	6	64.0	63.7	79.1	60.6	7.4
09-Dec-11	Kuntaur (22)	50.8	50.8	51.0	51.2	51.2	51.3	6	51.0	51.0	51.3	50.8	0.2
08-Dec-11	Brikamaba (23)	56.7	51.8	52.0	52.3	52.0	52.2	6	52.8	52.8	56.7	51.8	1.9
08-Dec-11	Jangjangbureh (24)	51.7	51.8	51.5	52.2	53.3	52.0	6	52.1	52.1	53.3	51.5	0.6
12-Dec-11	Bansang (25)	52.4	52.4	52.4	52.2	52.1	52.1	6	52.2	52.2	52.4	52.1	0.2
13-Dec-11	Kosemar (26)	53.6	58.9	53.3	53.1	40.5	53.0	6	52.1	51.7	58.9	40.5	6.1
14-Dec-11	Basse (27)	52.2	51.7	53.4	53.1	53.0	53.3	6	52.8	52.8	53.4	51.7	0.7
14-Dec-11	Fatoto (28)	53.3	53.7	53.4	53.0	53.1	53.2	6	53.3	53.3	53.7	53.0	0.2
14-Dec-11	Koina (29)	53.0	57.6	57.8	52.9	53.1	52.8	6	54.5	54.5	57.8	52.8	2.4

Table 6. Summary of specific conductivity (µS/cm) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	SPC (µS/cm)						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	55952.0	55239.0	57822.0	55233.0	48257.0	57524.0	6	55004.5	54906.9	57822.0	48257.0	3487.7
20-Dec-11	Banjul (2)	48389.0	48589.0	48536.0	48133.0	48285.0	46662.0	6	48099.0	48094.4	48589.0	46662.0	723.3
20-Dec-11	Barra (3)	46862.0	46088.0	48863.0	41491.0	40478.0	45775.0	6	44926.2	44826.2	48863.0	40478.0	3252.8
20-Dec-11	Albadarr (4)	41326.0	41542.0	41539.0	41117.0	41384.0	41300.0	6	41368.0	41367.7	41542.0	41117.0	160.7
06-Dec-11	Bintang (5)	30899.0	30750.0	29694.0	29231.0	30700.0	28682.0	6	29992.7	29980.7	30899.0	28682.0	925.5
20-Dec-11	Jurunka (6)	27197.0	27251.0	26835.0	27008.0	27098.0	27034.0	6	27070.5	27070.2	27251.0	26835.0	148.3
06-Dec-11	Kemoto (7)	23134.0	22647.0	21977.0	24239.0	23017.0	21266.0	6	22713.3	22694.1	24239.0	21266.0	1023.5
17-Dec-11	Darsilami (8)	45861.0	42529.0	42437.0	45212.0	45743.0	46731.0	6	44752.2	44720.8	46731.0	42437.0	1824.3
17-Dec-11	Kerewan (9)	22698.0	23817.0	23799.0	23492.0	23768.0	23636.0	6	23535.0	23531.7	23817.0	22698.0	428.0
06-Dec-11	Tankular (10)	11003.0	11832.0	16652.0	16585.0	17248.0	16468.0	6	14964.7	14729.5	17248.0	11003.0	2773.3
17-Dec-11	Salikene (11)	20043.0	20009.0	19919.0	19510.0	19975.0	20208.0	6	19944.0	19942.8	20208.0	19510.0	234.0
07-Dec-11	Tendaba (12)	7302.0	7510.0	7570.0	7327.0	7599.0	7618.0	6	7487.7	7486.6	7618.0	7302.0	139.2
16-Dec-11	Farafenni (13)	2182.0	2158.0	2151.0	2155.0	2132.0	2147.0	6	2154.2	2154.1	2182.0	2132.0	16.4
15-Dec-11	Bambali (14)	646.0	641.0	640.0	622.0	636.0	644.0	6	638.2	638.1	646.0	622.0	8.6
07-Dec-11	Sambang (15)	356.4	362.1	364.1	358.6	362.8	377.4	6	363.6	363.5	377.4	356.4	7.4
07-Dec-11	Pakali Ba (16)	1926.0	1914.0	1901.0	1942.0	1921.0	1912.0	6	1919.3	1919.3	1942.0	1901.0	14.0
15-Dec-11	Kanikunda (17)	345.1	337.0	338.6	344.2	342.3	342.5	6	341.6	341.6	345.1	337.0	3.2
15-Dec-11	Kaur (18)	160.4	161.8	161.3	160.1	161.8	161.3	6	161.1	161.1	161.8	160.1	0.7
07-Dec-11	Jessadi (19)	161.6	153.1	135.1	135.2	147.4	135.7	6	144.7	144.3	161.6	135.1	11.2
07-Dec-11	Jareng (20)	186.3	191.8	188.5	187.0	189.1	187.5	6	188.4	188.4	191.8	186.3	2.0
08-Dec-11	Kudang (21)	61.2	60.7	60.5	61.4	61.0	78.9	6	64.0	63.6	78.9	60.5	7.3
09-Dec-11	Kuntaur (22)	50.2	50.2	50.5	50.6	50.6	50.8	6	50.5	50.5	50.8	50.2	0.2
08-Dec-11	Brikamaba (23)	55.5	50.7	50.9	51.2	50.9	51.1	6	51.7	51.7	55.5	50.7	1.9
08-Dec-11	Jangjangbureh (24)	50.4	50.5	50.2	50.8	51.9	50.6	6	50.7	50.7	51.9	50.2	0.6
12-Dec-11	Bansang (25)	51.2	51.2	51.2	51.0	50.9	50.9	6	51.1	51.1	51.2	50.9	0.2
13-Dec-11	Kosemar (26)	52.1	57.3	52.4	52.1	39.4	52.0	6	50.9	50.6	57.3	39.4	6.0
14-Dec-11	Basse (27)	52.0	53.0	53.1	52.9	52.8	53.0	6	52.8	52.8	53.1	52.0	0.4
14-Dec-11	Fatoto (28)	53.3	53.6	53.3	53.0	53.0	53.1	6	53.2	53.2	53.6	53.0	0.2
14-Dec-11	Koina (29)	53.2	57.8	58.0	53.1	53.3	53.0	6	54.7	54.7	58.0	53.0	2.5

Table 7. Summary of salinity (ppt) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures within the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	Salinity (ppt)						n	MEAN	GEOMEAN	MAX	MIN	STDEV
21-Dec-11	Kartong (1)	37.17	36.64	38.57	36.62	31.53	38.35	6	36.48	36.40	38.57	31.53	2.56
20-Dec-11	Banjul (2)	31.00	31.73	31.68	31.38	31.50	30.36	6	31.28	31.27	31.73	30.36	0.52
20-Dec-11	Barra (3)	29.36	29.22	31.80	28.26	25.93	31.64	6	29.37	29.30	31.80	25.93	2.20
20-Dec-11	Albadarr (4)	26.47	26.63	26.62	26.32	26.51	26.45	6	26.50	26.50	26.63	26.32	0.12
06-Dec-11	Bintang (5)	19.17	19.07	18.35	18.04	19.04	17.66	6	18.56	18.55	19.17	17.66	0.63
20-Dec-11	Jurunka (6)	16.66	16.72	16.44	16.56	16.62	16.58	6	16.60	16.60	16.72	16.44	0.10
06-Dec-11	Kemoto (7)	13.81	13.50	13.17	14.51	13.87	12.72	6	13.60	13.58	14.51	12.72	0.62
17-Dec-11	Darsilami (8)	20.66	27.31	27.22	29.20	29.65	30.30	6	27.39	27.18	30.30	20.66	3.53
17-Dec-11	Kerewan (9)	13.71	14.43	14.43	14.23	14.40	14.32	6	14.25	14.25	14.43	13.71	0.28
06-Dec-11	Tankular (10)	6.22	6.69	9.72	9.69	10.11	9.61	6	8.67	8.51	10.11	6.22	1.73
17-Dec-11	Salikene (11)	11.97	11.96	11.89	11.63	11.94	12.09	6	11.91	11.91	12.09	11.63	0.15
07-Dec-11	Tendaba (12)	4.03	4.16	4.19	4.05	4.21	4.22	6	4.14	4.14	4.22	4.03	0.08
16-Dec-11	Farafenni (13)	1.11	1.10	1.10	1.10	1.09	1.10	6	1.10	1.10	1.11	1.09	0.01
15-Dec-11	Bambali (14)	0.31	0.31	0.31	0.30	0.31	0.31	6	0.31	0.31	0.31	0.30	0.00
07-Dec-11	Sambang (15)	0.17	0.17	0.10	0.17	0.17	0.18	6	0.16	0.16	0.18	0.10	0.03
07-Dec-11	Pakali Ba (16)	0.98	0.97	0.97	0.99	0.98	0.97	6	0.98	0.98	0.99	0.97	0.01
15-Dec-11	Kanikunda (17)	0.16	0.16	0.16	0.16	0.16	0.16	6	0.16	0.16	0.16	0.16	0.00
15-Dec-11	Kaur (18)	0.07	0.08	0.08	0.07	0.08	0.08	6	0.08	0.08	0.08	0.07	0.01
07-Dec-11	Jessadi (19)	0.08	0.07	0.06	0.06	0.07	0.06	6	0.07	0.07	0.08	0.06	0.01
07-Dec-11	Jareng (20)	0.09	0.09	0.09	0.09	0.09	0.09	6	0.09	0.09	0.09	0.09	0.00
08-Dec-11	Kudang (21)	0.03	0.03	0.03	0.03	0.03	0.03	6	0.03	0.03	0.03	0.03	0.00
09-Dec-11	Kuntaur (22)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
08-Dec-11	Brikamaba (23)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
08-Dec-11	Jangjangbureh (24)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
12-Dec-11	Bansang (25)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
13-Dec-11	Kosemar (26)	0.02	0.03	0.02	0.02	0.02	0.02	6	0.02	0.02	0.03	0.02	0.00
14-D ec-11	Basse (27)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
14-Dec-11	Fatoto (28)	0.02	0.02	0.02	0.02	0.02	0.02	6	0.02	0.02	0.02	0.02	0.00
14-Dec-11	Koina (29)	0.02	0.03	0.02	0.02	0.02	0.02	6	0.02	0.02	0.03	0.02	0.00

Table 8. Summary of TDS (mg/L) measurements for surface water quality. Yellow indicates the minimum and maximum temperatures in the data set. Statistical analyses for arithmetic mean, geomean, and standard deviation (STDEV) are also included.

Date	Site Location and Number	Total Dissolved Solids (mg/L)						n	MEAN	GEOMEAN	MAX	MIN	STDEV
		Probe One			Probe Two								
21-Dec-11	Kartong (1)	36400.00	35880.00	37570.00	35880.00	42100.00	37375.00	6	37534.17	37475.88	42100.00	35880.00	2350.84
20-Dec-11	Banjul (2)	31466.50	31583.50	31555.00	31278.00	31388.50	30355.00	6	31271.08	31268.19	31583.50	30355.00	462.48
20-Dec-11	Barra (3)	30134.60	29614.00	31713.50	27852.50	26487.00	29718.50	6	29253.35	29204.86	31713.50	26487.00	1832.51
20-Dec-11	Albadarr (4)	26858.00	27014.00	27001.00	26728.00	26897.00	26845.00	6	26890.50	26890.32	27014.00	26728.00	106.81
06-Dec-11	Bintang (5)	20078.50	19981.00	19298.50	18999.50	19955.00	18642.00	6	19492.42	19484.67	20078.50	18642.00	599.99
20-Dec-11	Jurunka (6)	17654.00	17712.50	17439.50	17556.40	17615.00	17576.00	6	17592.23	17592.03	17712.50	17439.50	93.46
06-Dec-11	Kemoto (7)	14881.00	14618.00	14287.00	5665.00	14963.00	13825.50	6	13039.92	12403.95	14963.00	5665.00	3637.03
17-Dec-11	Darsilami (8)	29809.50	27651.00	27579.50	29380.00	29750.00	30368.00	6	29089.67	29069.29	30368.00	27579.50	1185.16
17-Dec-11	Kerewan (9)	14768.00	15483.00	15476.50	15288.00	15444.00	15366.00	6	15304.25	15302.19	15483.00	14768.00	273.05
06-Dec-11	Tankular (10)	7156.50	1663.50	10816.70	10783.50	11206.50	10699.00	6	8720.95	7417.06	11206.50	1663.50	3768.08
17-Dec-11	Salikene (11)	13026.00	13006.50	12948.00	12694.50	12987.00	12923.00	6	12930.83	12930.35	13026.00	12694.50	121.78
07-Dec-11	Tendaba (12)	4745.00	4881.50	4920.50	4764.50	4940.00	4953.00	6	4867.42	4866.71	4953.00	4745.00	90.76
16-Dec-11	Farafenni (13)	1417.00	1404.00	1397.50	1404.00	1384.50	1397.50	6	1400.75	1400.72	1417.00	1384.50	10.68
15-Dec-11	Bambali (14)	422.50	416.00	416.00	403.00	416.00	422.50	6	416.00	415.95	422.50	403.00	7.12
07-Dec-11	Sambang (15)	231.40	235.30	236.60	233.35	235.95	245.05	6	236.28	236.24	245.05	231.40	4.70
07-Dec-11	Pakali Ba (16)	1254.50	1241.50	1235.00	1261.00	1248.00	1241.50	6	1246.92	1246.89	1261.00	1235.00	9.57
15-Dec-11	Kanikunda (17)	224.60	218.48	220.75	223.60	223.60	221.65	6	222.11	222.10	224.60	218.48	2.28
15-Dec-11	Kaur (18)	104.00	105.30	104.65	104.65	105.30	140.65	6	110.76	110.05	140.65	104.00	14.65
07-Dec-11	Jessadi (19)	105.60	99.45	87.75	87.75	95.55	88.40	6	94.08	93.84	105.60	87.75	7.43
07-Dec-11	Jareng (20)	120.90	124.80	122.85	121.55	122.85	122.20	6	122.53	122.52	124.80	120.90	1.35
08-Dec-11	Kudang (21)	39.65	39.65	39.65	39.65	39.65	50.05	6	41.38	41.22	50.05	39.65	4.25
09-Dec-11	Kuntaur (22)	32.50	32.50	32.50	33.15	33.15	33.15	6	32.83	32.82	33.15	32.50	0.36
08-Dec-11	Brikamaba (23)	36.40	33.15	33.15	33.15	33.15	33.15	6	33.69	33.67	36.40	33.15	1.33
08-Dec-11	Jangjangbureh (24)	32.50	32.50	32.50	33.15	32.80	33.15	6	32.77	32.77	33.15	32.50	0.32
12-Dec-11	Bansang (25)	33.15	33.15	33.15	33.15	33.15	33.15	6	33.15	33.15	33.15	33.15	0.00
13-Dec-11	Kosemar (26)	33.80	37.05	34.45	33.80	25.35	33.80	6	33.04	32.82	37.05	25.35	3.97
14-Dec-11	Basse (27)	34.35	34.45	34.45	34.45	34.45	34.45	6	34.43	34.43	34.45	34.35	0.04
14-Dec-11	Fatoto (28)	34.45	35.10	34.45	34.45	34.45	34.45	6	34.56	34.56	35.10	34.45	0.27
14-Dec-11	Koina (29)	34.45	37.70	34.45	34.45	34.45	34.45	6	34.99	34.97	37.70	34.45	1.33

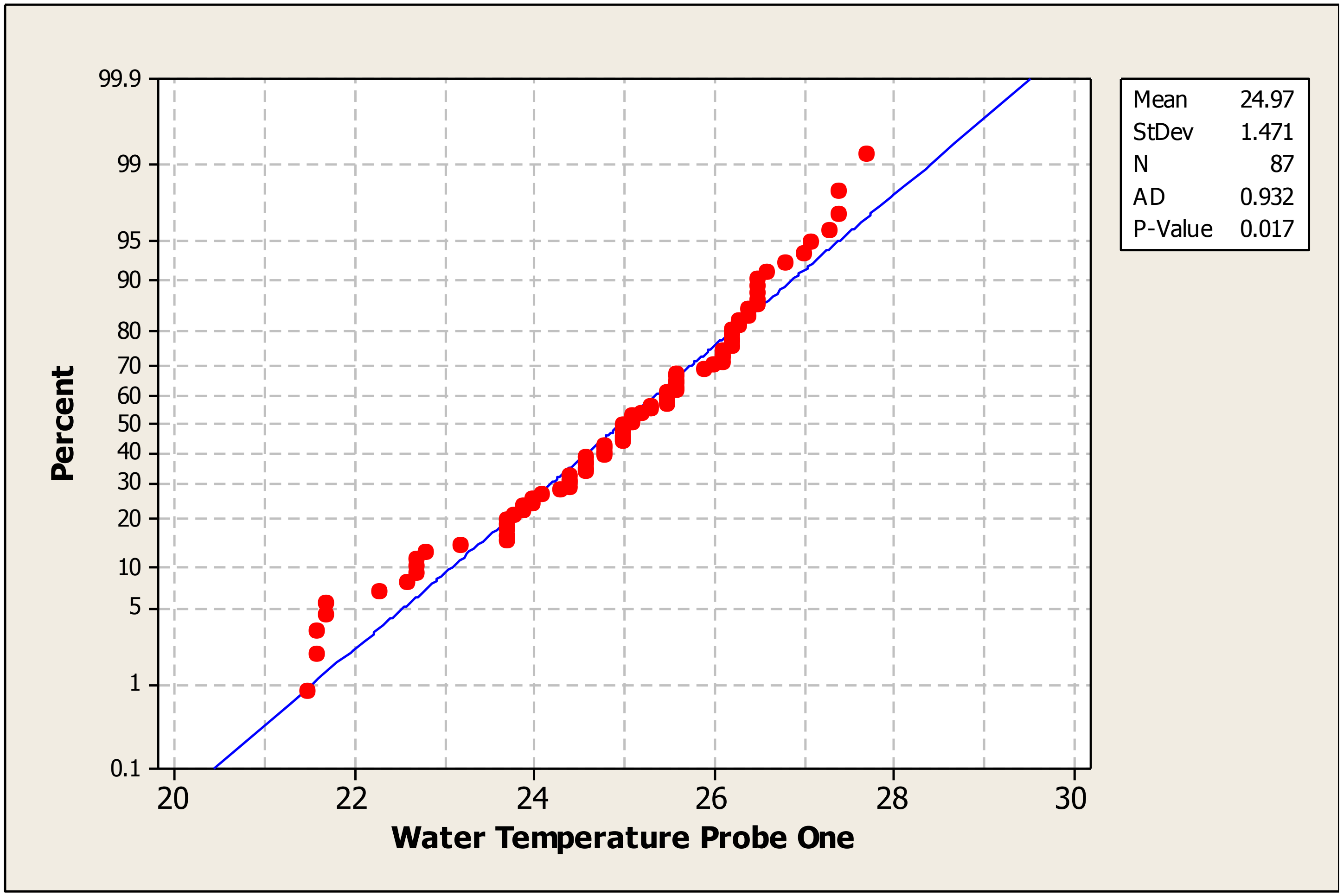


Figure 7. Anderson-Darling Normality test of probe one for water temperature (°C).

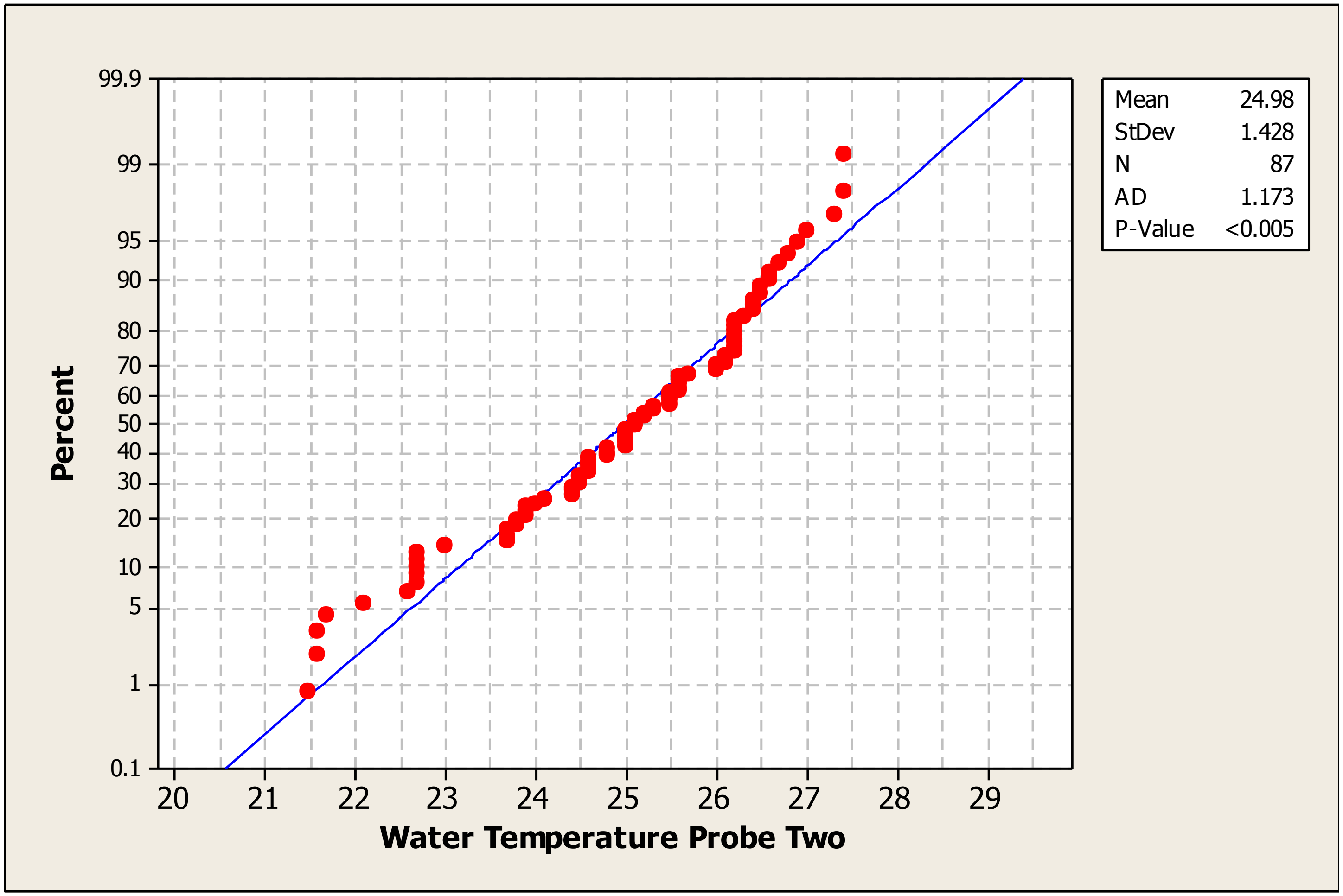


Figure 8. Anderson-Darling Normality test of probe two for water temperature (°C).

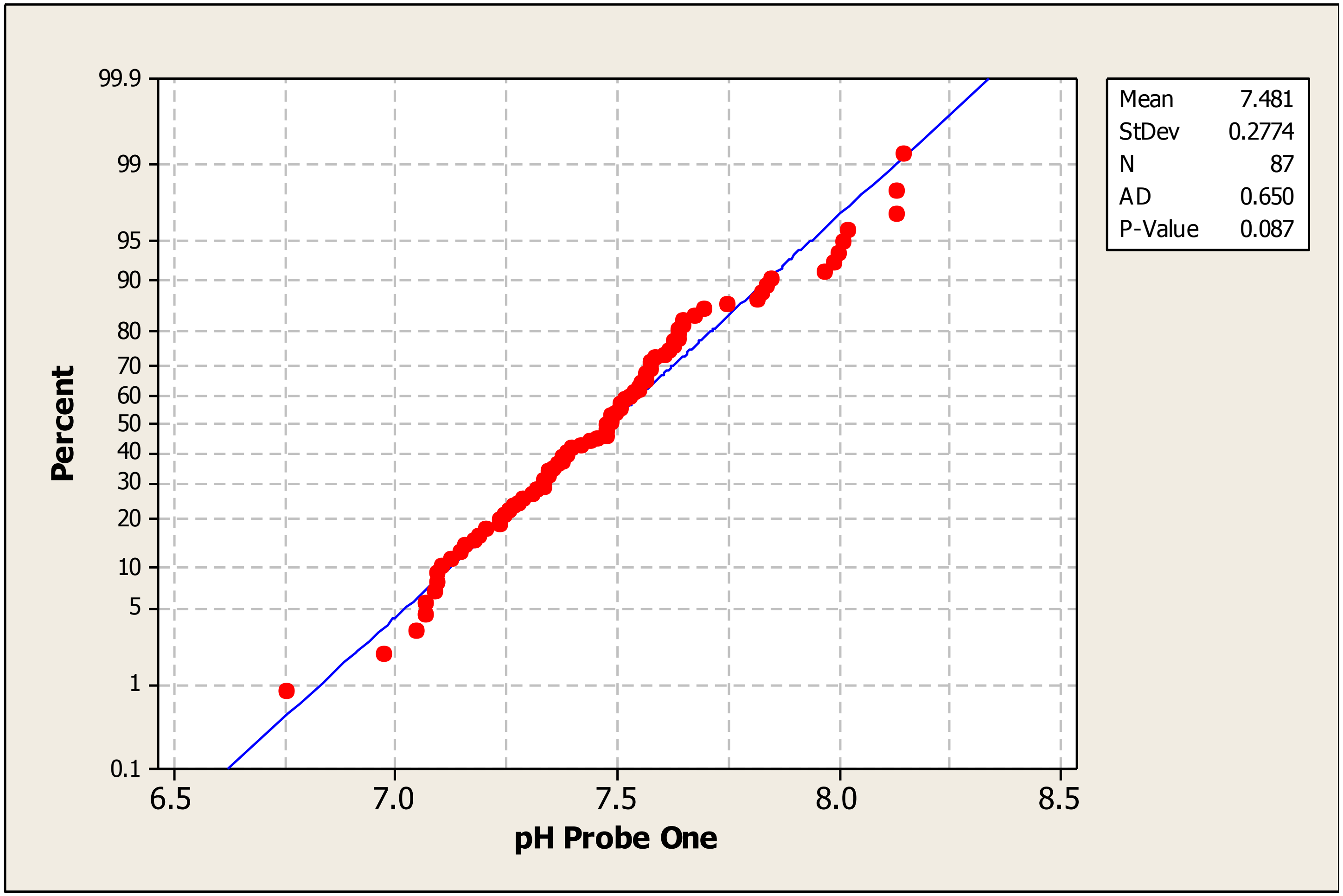


Figure 9. Anderson-Darling Normality test of probe one for pH.

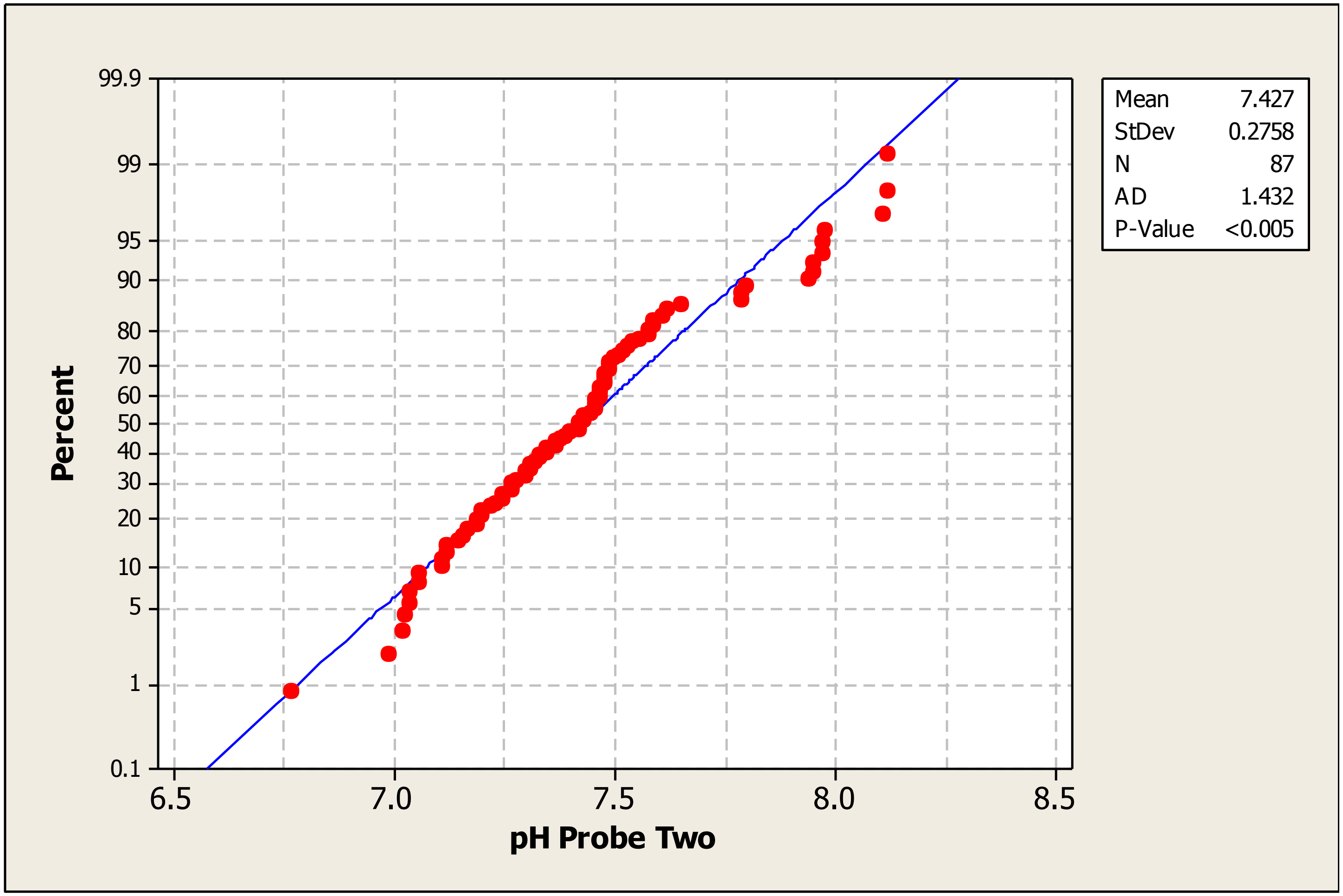


Figure 10. **Anderson-Darling Normality test of probe two for pH.**

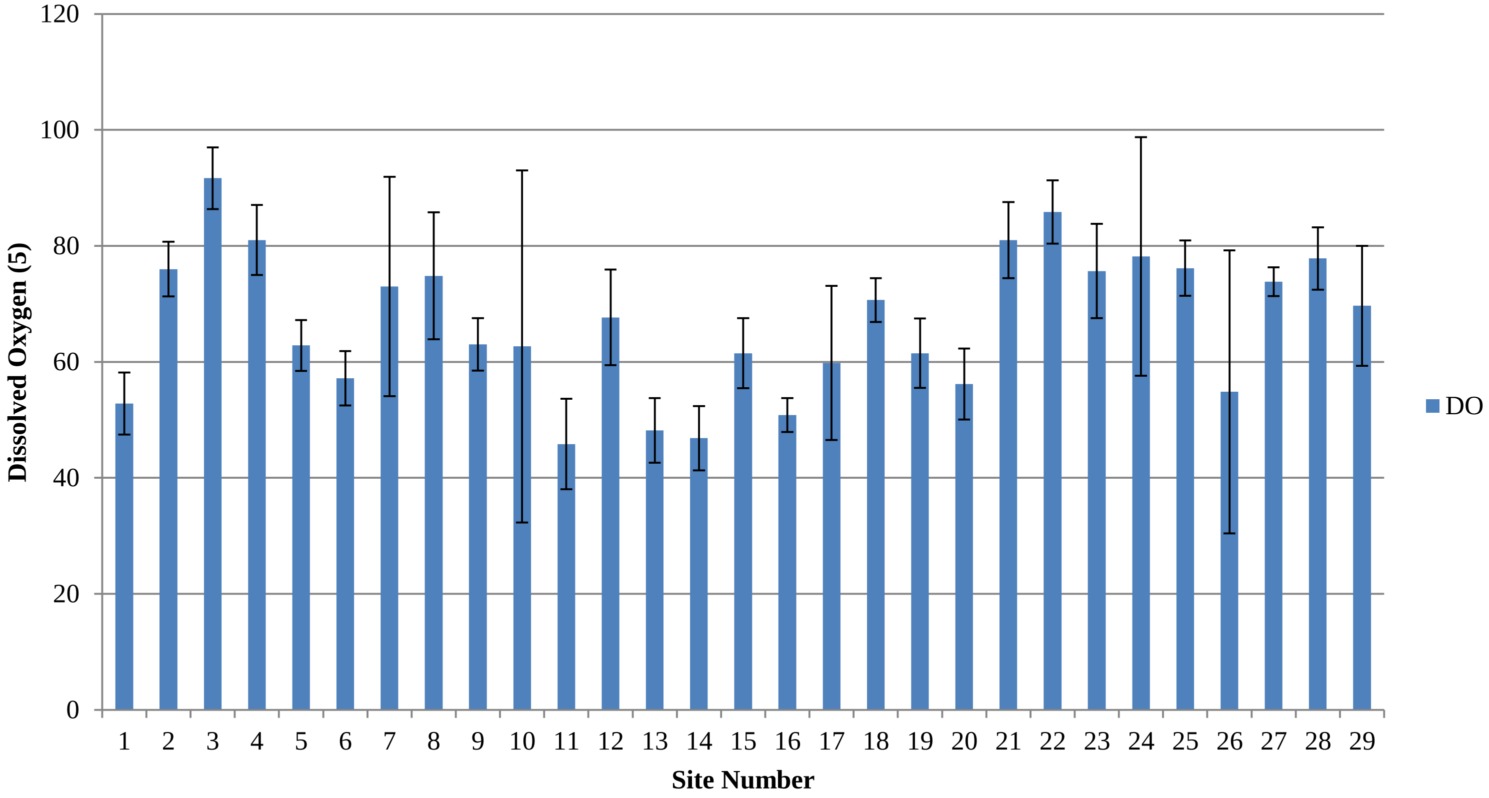


Figure 11. Surface water quality - mean dissolved oxygen (%) - at sites sampled in the Gambia River, including the standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean)

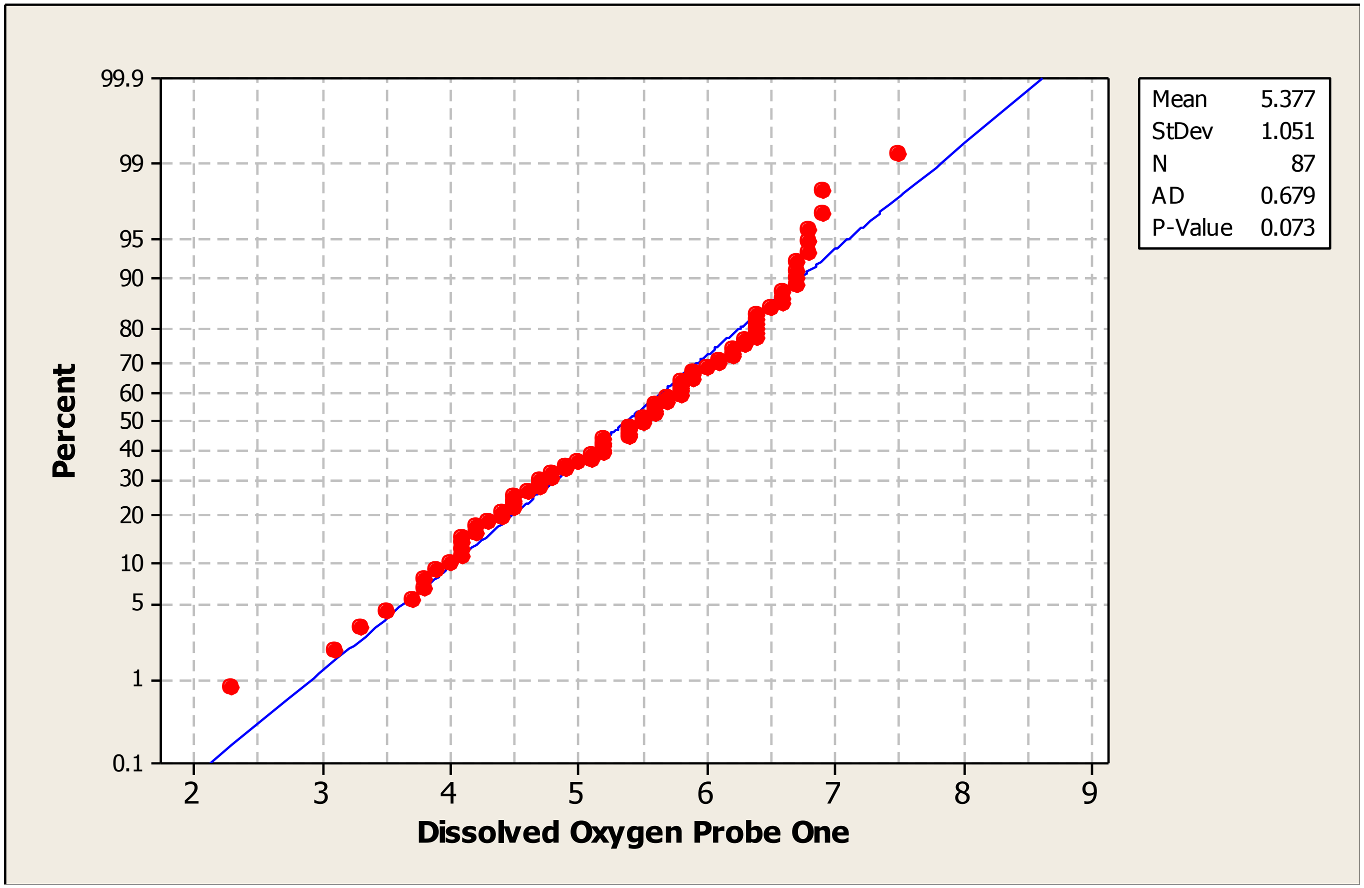


Figure 12. Anderson-Darling Normality test of probe one for dissolved oxygen (mg/L).

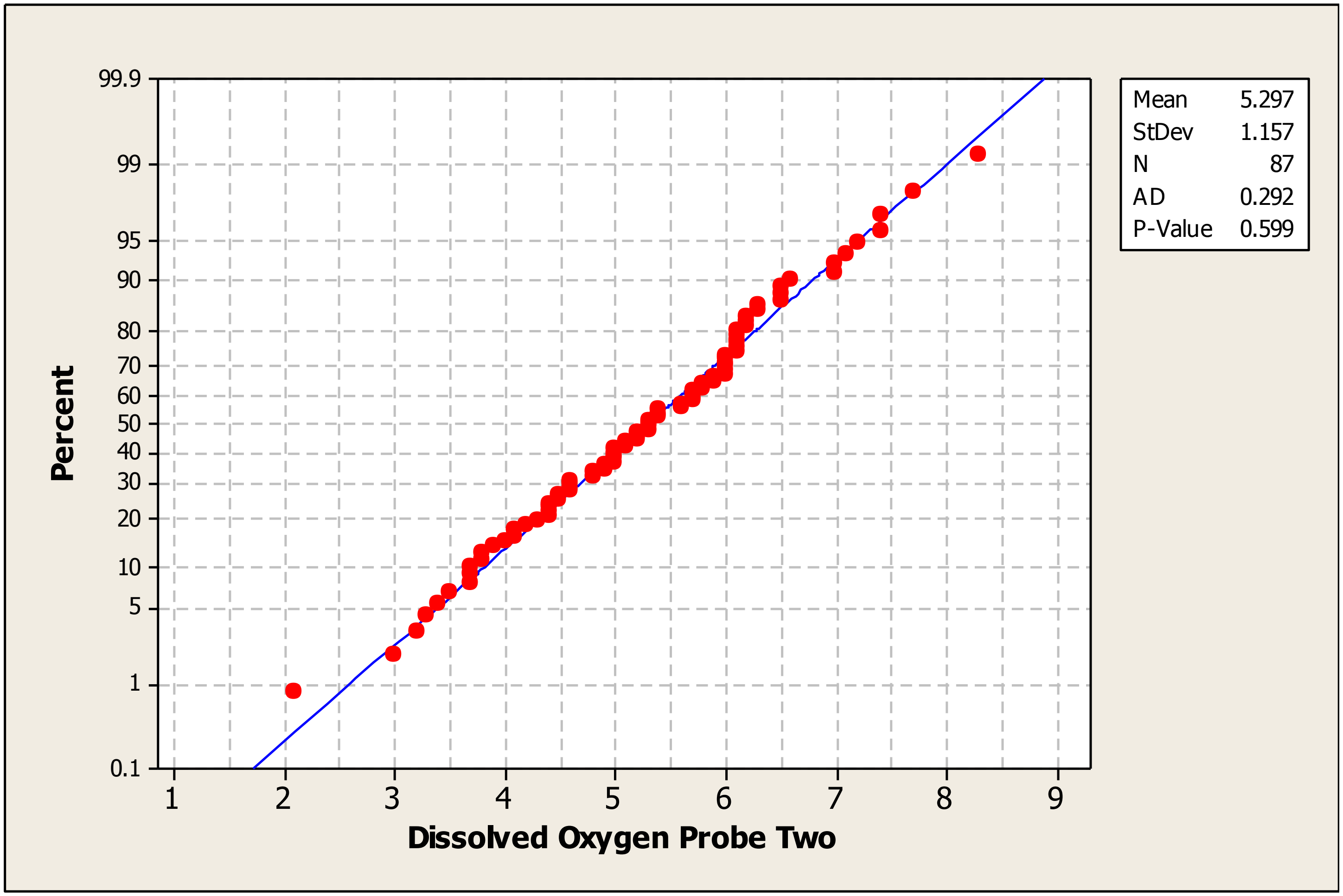


Figure 13.Anderson-Darling Normality test of probe two for dissolved oxygen (mg/L).

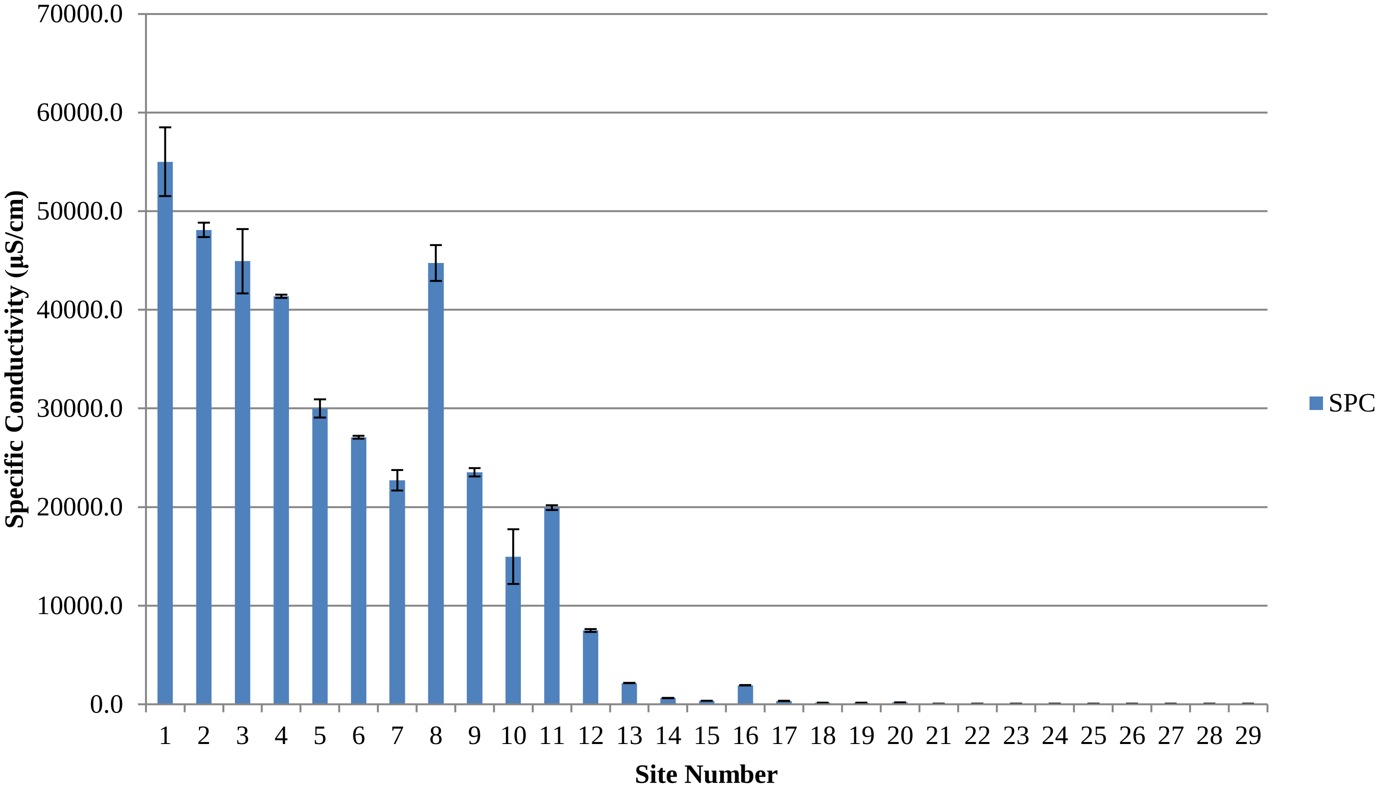


Figure 14. Surface water quality - mean specific conductivity (µS/cm) at sites sampled in the Gambia River, including the standard deviations. (n = 6 for each site and site number 1 is closest to the Atlantic Ocean.

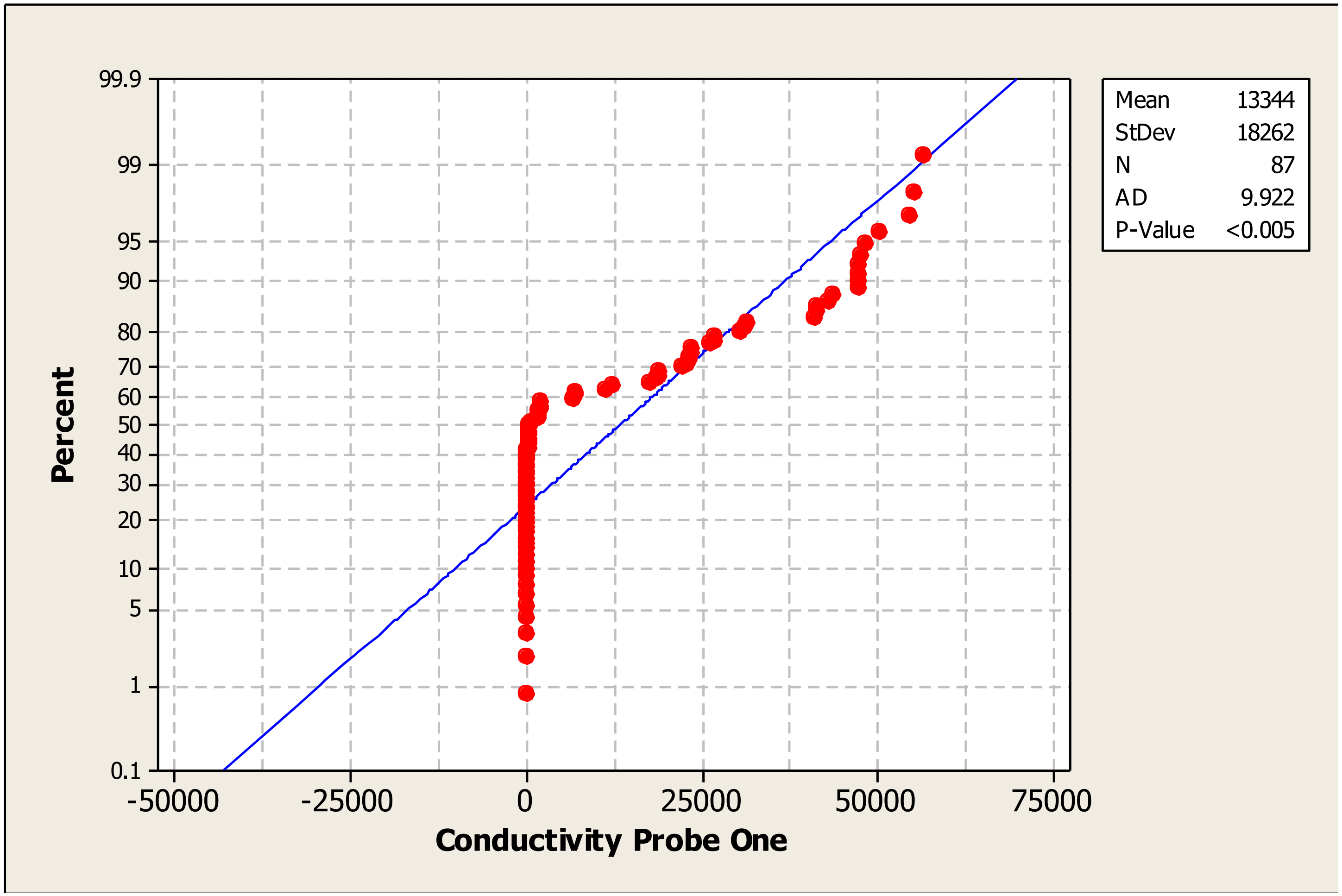


Figure 15. **Anderson-Darling Normality test of probe one for conductivity (µS/cm).**

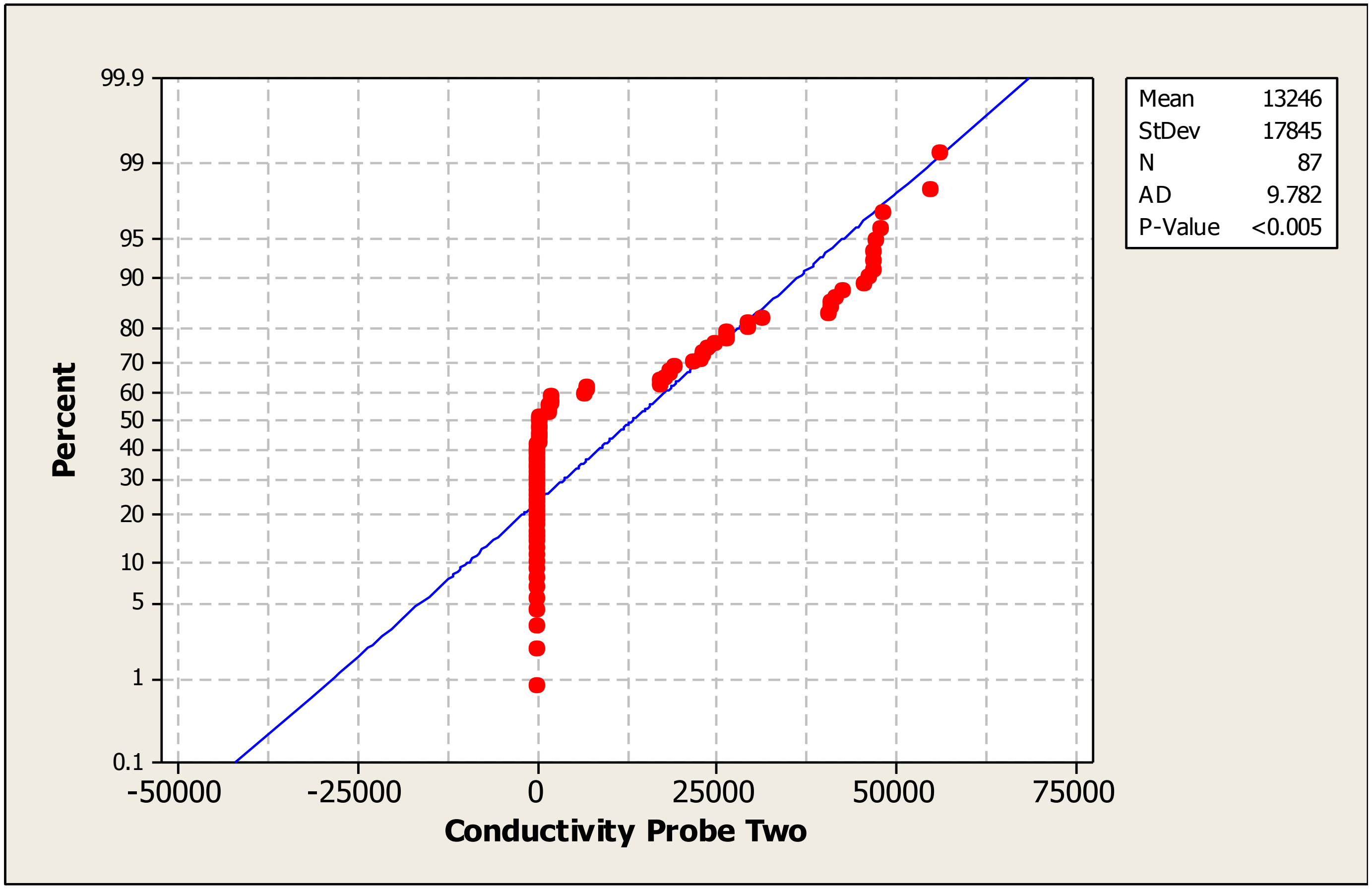


Figure 16. Anderson-Darling Normality test of probe two for conductivity (µS/cm).

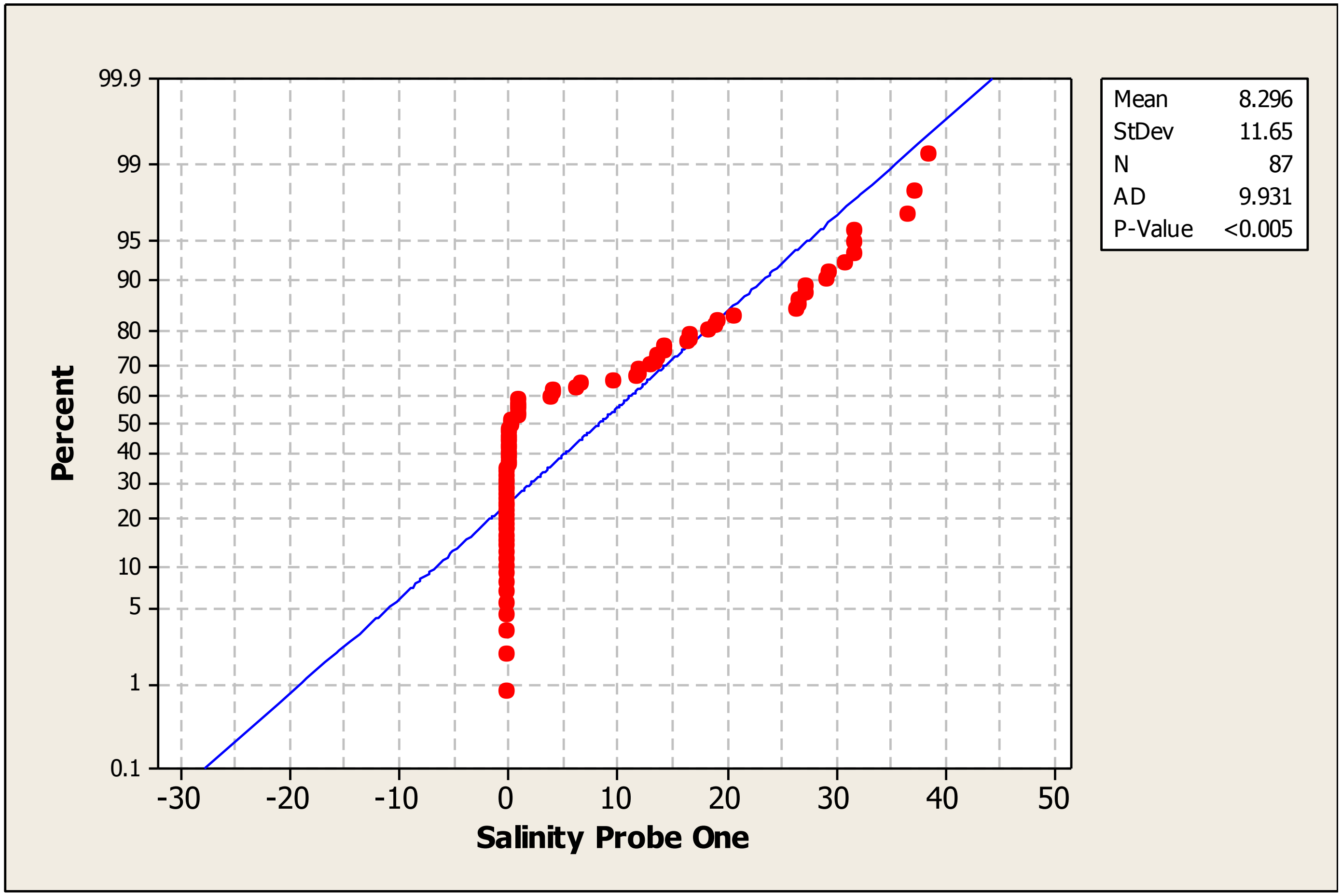


Figure 17. Anderson-Darling Normality test of probe one for salinity (ppt).

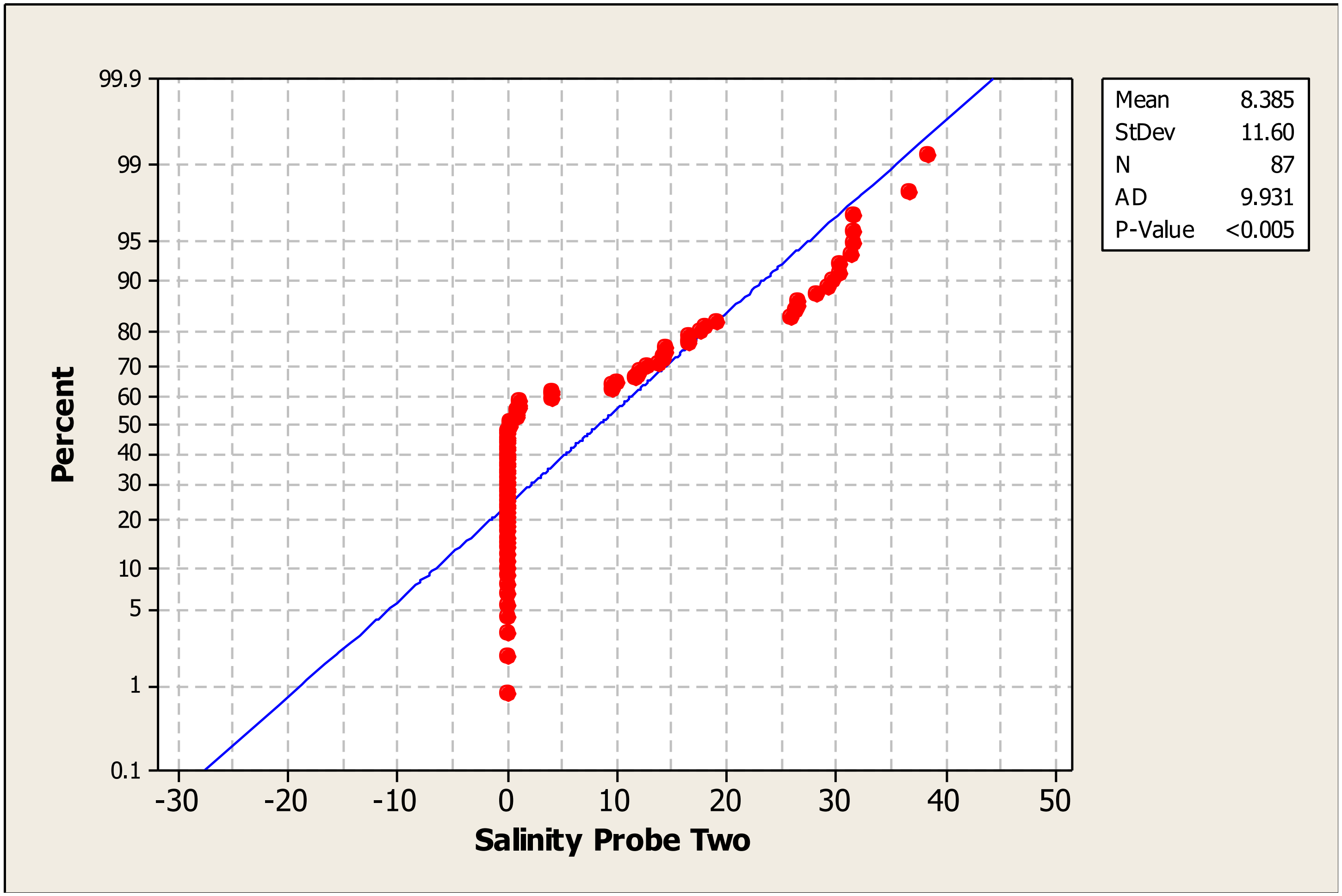


Figure 18. Anderson-Darling Normality test of probe two for salinity (ppt).

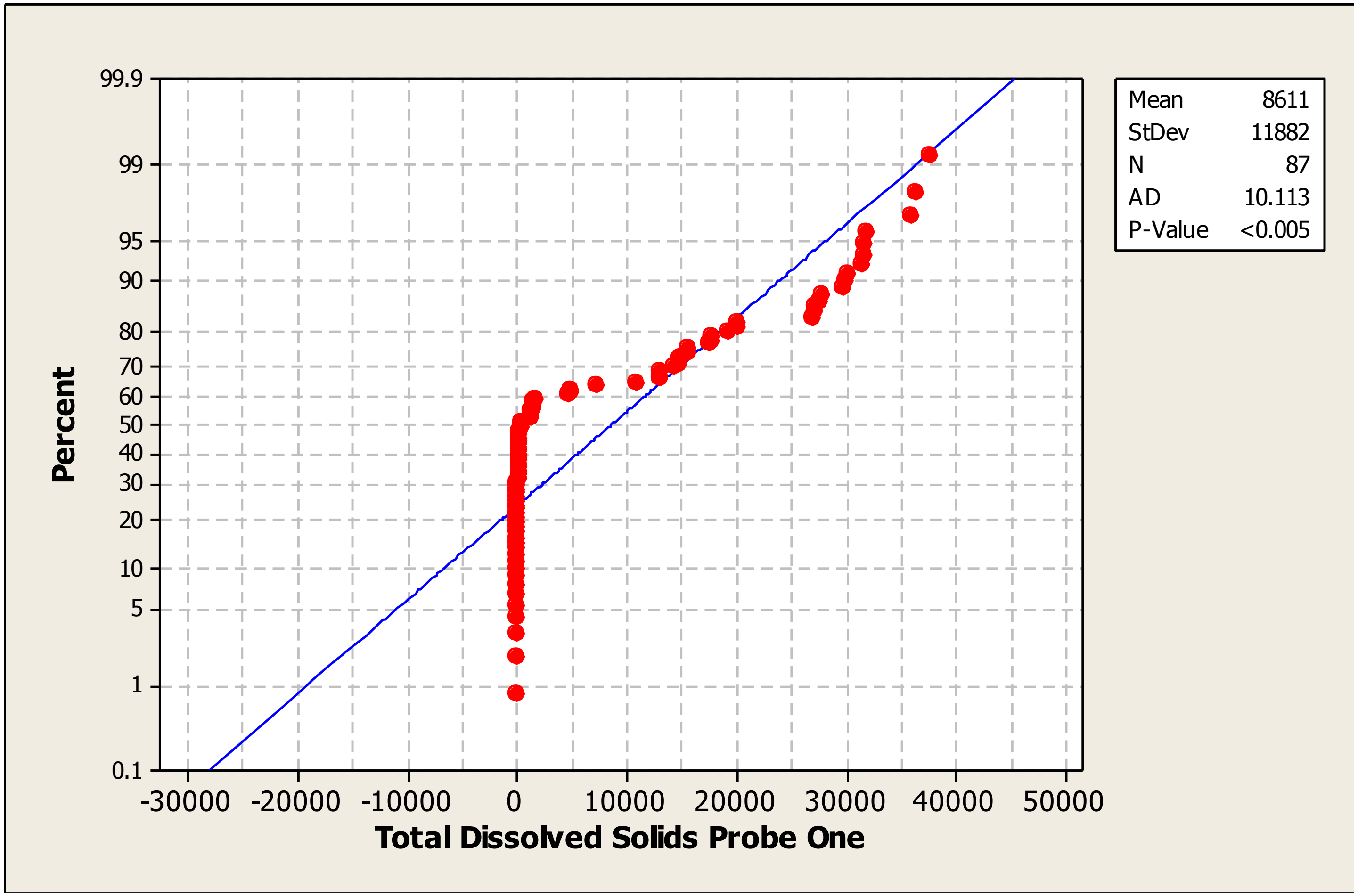


Figure 19. Anderson-Darling Normality test of probe one for total dissolved solids (mg/L).

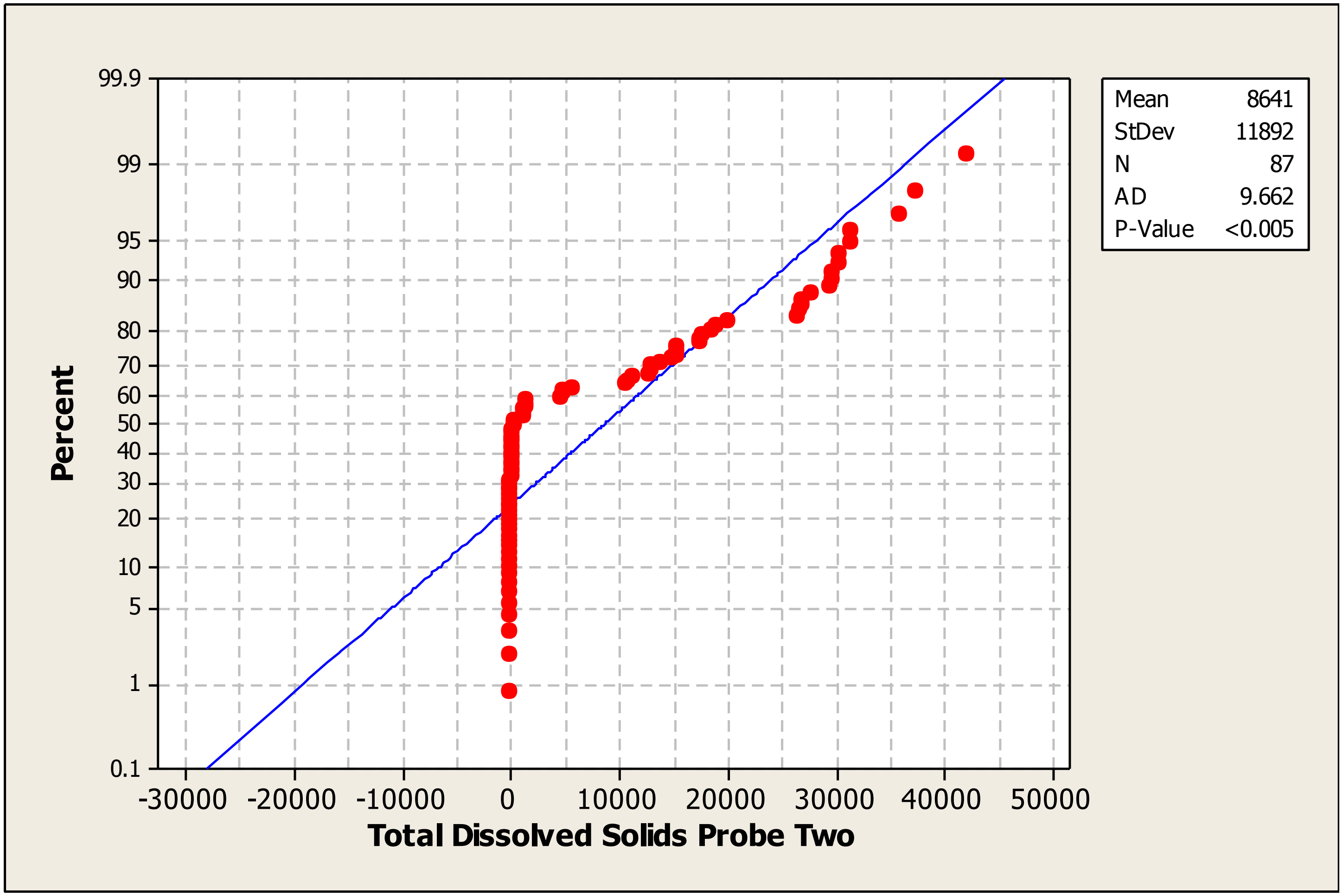


Figure 20. **Anderson-Darling Normality test of probe two for total dissolved solids**.

Table 9. **Volunteer data for site number 1.** (Volunteer measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppm)
1	6:03 PM	4.9	61	52.6	51.6	33.8	26.0	7.56	0.02
2	6:09 PM	5.7	69	54.7	53.5	34.5	26.2	7.62	0.02
3	6:24 PM	6.3	79	51.6	50.4	32.5	26.2	7.73	0.02

Table 10. Professional data for site number 1. (Professional measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	6:03 PM	6.0	75	51.9	50.7	33.2	26.2	7.29	0.02
2	6:10 PM	5.3	64	53.0	52.0	33.8	26.0	7.21	0.02
3	6:24 PM	7.0	87	51.9	50.7	33.2	26.2	7.52	0.02

Table 11. **Volunteer data for site number 2.** (Volunteer measured three transects at each site)

Transect #	**Time**	**DO (mg/L)**	**DO (%)**	**Conductivity (uS/cm)**	**SPC (uS/cm)**	**TDS (mg/L)**	**Water Temp (ºC)**	**pH**	**Salinity (ppt)**
1	5:51 PM	5.6	68	52.2	51.0	33.2	26.2	7.53	0.02
2	5:58 PM	5.3	66	54.5	53.2	39.0	26.3	6.85	0.03
3	6:03 PM	6.0	75	52.2	51.0	33.2	26.2	7.59	0.02

Table 12. **Professional data for site number 2**. (Professional measured three transects at each site)

Transect #	**Time**	**DO (mg/L)**	**DO (%)**	**Conductivity (uS/cm)**	**SPC (uS/cm)**	**TDS (mg/L)**	**Water Temp (ºC)**	**pH**	**Salinity (ppt)**
1	5:51 PM	6.6	84	52.6	51.3	33.2	26.3	7.53	0.02
2	5:58 PM	6.5	81	52.1	50.9	33.2	26.2	7.28	0.02
3	6:03 PM	6.8	85	52.4	51.2	33.2	26.2	7.54	0.02

Table 13. **Volunteer data for site number 3.** (Volunteer measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	12:20pm	6.6	84	52.6	51.3	33.2	26.3	7.53	0.02
2	12:25pm	6.8	85	52.4	51.2	33.2	26.2	7.54	0.02
3	12:30pm	6.5	81	52.1	50.9	33.2	26.2	7.28	0.02

Table 14. **Professional data for site number 3**. (Professional measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	12:20pm	5.6	68	52.2	51.0	33.2	26.2	7.53	0.02
2	12:25pm	6.0	75	52.2	51.0	33.2	26.2	7.59	0.02
3	12:30pm	5.3	66	53.3	52.0	39.0	26.3	6.85	0.03

Table 15. **Volunteer data for site number 4.** (Volunteer measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	12:40pm	6.4	80	52.1	51.1	33.2	26.0	7.58	0.02
2	12:45pm	5.7	71	52.5	51.5	33.2	26.0	7.57	0.02
3	12:47pm	5.0	62	52.0	51.1	33.2	25.9	7.48	0.02

Table 16. Professional data for site number 4. (Professional measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	12:40pm	7.8	60	52.0	51.0	33.2	26	7.55	0.02
2	12:45pm	5.5	68	52.1	51.1	33.2	26	7.58	0.02
3	12:47pm	6.3	79	52.7	51.7	33.8	26	7.46	0.02

Table 17. Volunteer data for site number 5. (Volunteer measured three transects at each site)

Transect #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	5.00pm	5.7	69	160.1	160.1	104.7	25.0	7.33	0.07
2	5:10pm	5.4	66	161.8	161.8	105.3	25.0	7.31	0.08
3	5:05pm	5.6	68	161.3	161.3	104.7	25.0	7.30	0.08

Table 18. **Professional data for site number 5**. (Professional measured three transects at each site)

Event #	Time	DO (mg/L)	DO (%)	Conductivity (uS/cm)	SPC (uS/cm)	TDS (mg/L)	Water Temp (ºC)	pH	Salinity (ppt)
1	5.00pm	6.1	74	160.4	160.4	104	25	7.39	0.07
2	5:10pm	5.9	71	161.8	161.8	105.3	25	7.34	0.08
3	5:05 pm	7.6	6.2	161.3	161.3	104.65	25	7.32	0.08

Table 19. **Volunteer statistical analyses by site.** Data was calculated from raw surface water data (n=6)

Site 1	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.1	7.64	5.6	53.0	0.2	33.6
Standard Deviation	0.115	0.086	0.702	1.582	0.000	1.0149
MIN	26.0	7.56	6.3	51.6	0.2	32.5
MAX	26.2	7.73	4.9	54.7	0.2	34.5

Site 2	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.2	7.32	5.6	53.0	0.2	35.1
Standard Deviation	0.058	0.411	0.351	1.328	0.000	3.349
MIN	26.2	6.85	5.3	52.2	0.2	33.2
MAX	26.3	7.59	6.0	54.5	0.2	39.0

Site 3	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.2	7.45	6.6	52.4	0.2	33.2
Standard Deviation	0.058	0.147	0.153	0.252	0.000	0.000
MIN	26.2	7.28	6.5	52.1	0.2	33.2
MAX	26.3	7.54	6.8	52.6	0.3	33.2

Site 4	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.0	7.54	5.7	52.2	0.2	33.2
Standard Deviation	0.058	0.055	0.700	0.265	0.000	0.000
MIN	25.9	7.48	5.0	52.0	0.2	33.2
MAX	26.0	7.58	6.4	52.5	0.2	33.2

Site 5	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	25.0	7.31	5.6	161.1	0.1	104.9
Standard Deviation	0.00	0.015	0.153	0.874	0.006	0.346
MIN	25.0	7.30	5.4	160.1	0.7	104.7
MAX	25.0	7.33	5.7	161.8	0.8	105.3

Table 20. Professional statistical analyses by site. Data was calculated from raw surface water data (n=6)

Site 1	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.1	7.34	6.1	52.3	0.2	33.4
Standard Deviation	0.115	0.161	0.854	0.635	0.000	0.346
MIN	26.0	7.21	5.3	51.9	0.2	33.2
MAX	26.2	7.52	7.0	53.0	0.2	33.8

Site 2	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.2	7.45	6.6	52.4	0.2	33.2
Standard Deviation	0.058	0.147	0.153	0.252	0.000	0.000
MIN	26.2	7.28	6.5	52.1	0.2	33.2
MAX	26.3	7.54	6.8	52.6	0.2	33.2

Site 3	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	26.0	7.32	5.6	52.6	0.2	35.1
Standard Deviation	0.058	0.411	0.351	0.635	0.000	3.349
MIN	26.2	6.85	5.3	52.2	0.2	33.2
MAX	26.3	7.59	6.0	53.3	0.2	39.0

Site 4	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	25.0	7.53	6.5	52.3	0.2	33.4
Standard Deviation	0	0.062	1.168	0.379	0.000	0.346
MIN	26.0	7.46	5.5	52.0	0.2	33.2
MAX	26.0	7.58	7.8	52.7	0.2	33.8

Site 5	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Salinity (ppm)	Total Dissolved Solids (mg/L)
MEAN	25.0	7.58	6.5	161.2	0.1	104.6
Standard Deviation	0	0.036	0.929	0.709	0.006	0.513
MIN	25.0	7.32	5.9	160.4	0.7	104.0
MAX	25.0	7.39	7.6	161.8	0.8	105.0

Appendix C

Table 21. Maximum difference limits for water quality monitoring sensors. Not including salinity or total dissolved solid values.
Adapted from Nova Scotia Environment, 2010a; Wagner *et al.*, 2006.

Parameter	**Nova Scotia Environment (NSE) & United States Geological Survey (USGS)**	**Environment Canada**
Temperature (°C)	± 2	± 0.2
Specific Conductivity ($\mu S\ cm^{-1}$)	± 50 (or 30%)	± 5 (or 3%)
pH	± 2	± 0.2
Dissolved Oxygen ($mg\ L^{-1}$)	± 2 (or 20%)	± 0.3

Appendix D

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F 902.496.8213

Melissa Healey
Department of Geography
Saint Mary's University

17 December, 2012

I hereby by confirm that the map "Watershed of the Gambia River" was created solely by me and I hereby grant you permission to include said map in your graduate thesis.

This map should be credited thusly:
Cartography by Greg Baker, 2012. Data Sources: Shuttle Radar Topography Mission Level-1 Data, National Aeronautics and Space Administration, 2000; ESRI Data & Maps, Environmental Systems Research Institute / DeLorme, 2012.

Greg Baker,
Research Instrument Technician
Maritime Provinces Spatial Analysis Research Centre
Department of Geography
Saint Mary's University

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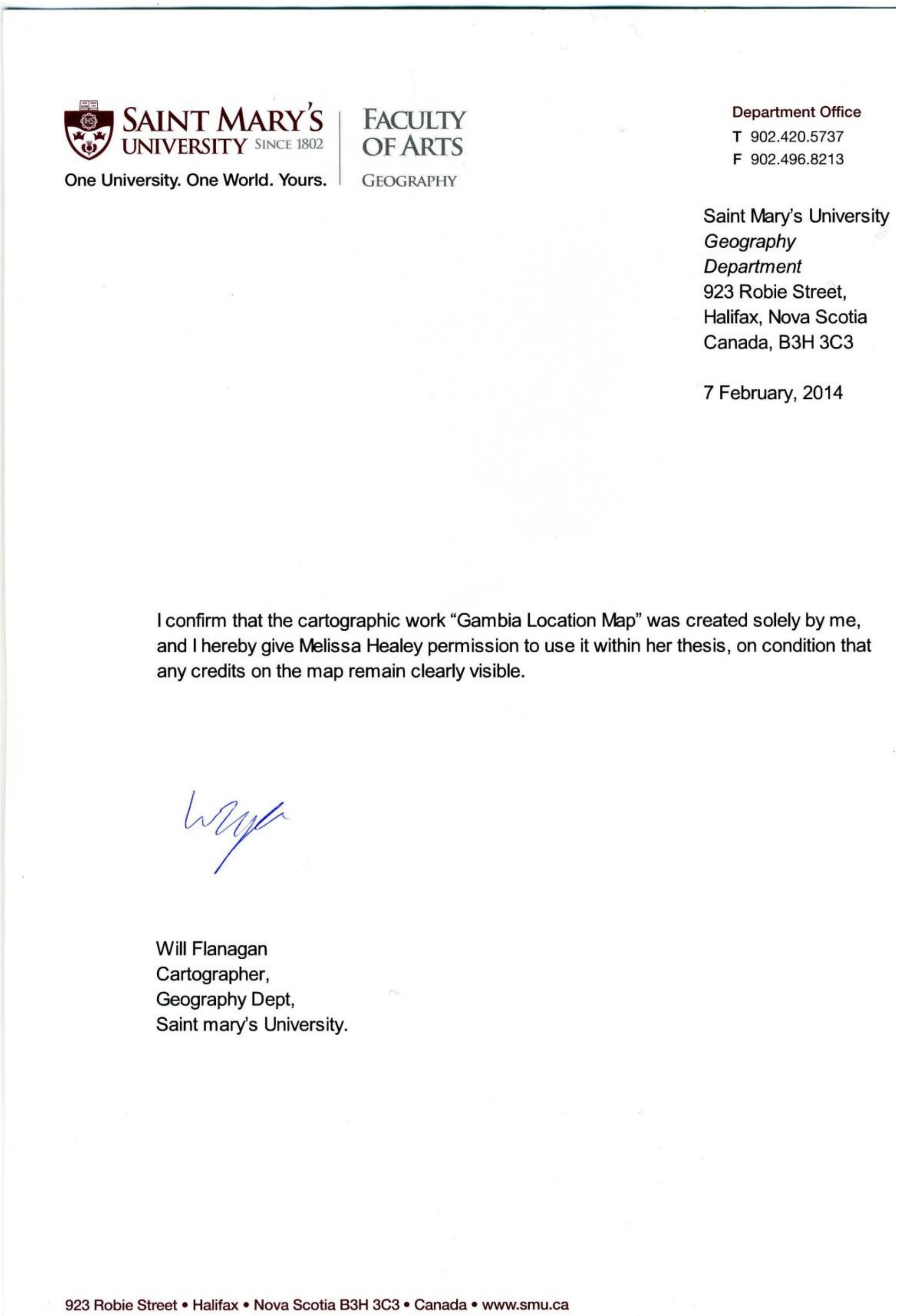
Figure 21. Letter of Permission: Watershed of The Gambia River



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Halifax, Nova Scotia
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7 February, 2014

I confirm that the cartographic work "Gambia Location Map" was created solely by me, and I hereby give Melissa Healey permission to use it within her thesis, on condition that any credits on the map remain clearly visible.

Will Flanagan
Cartographer,
Geography Dept,
Saint mary's University.

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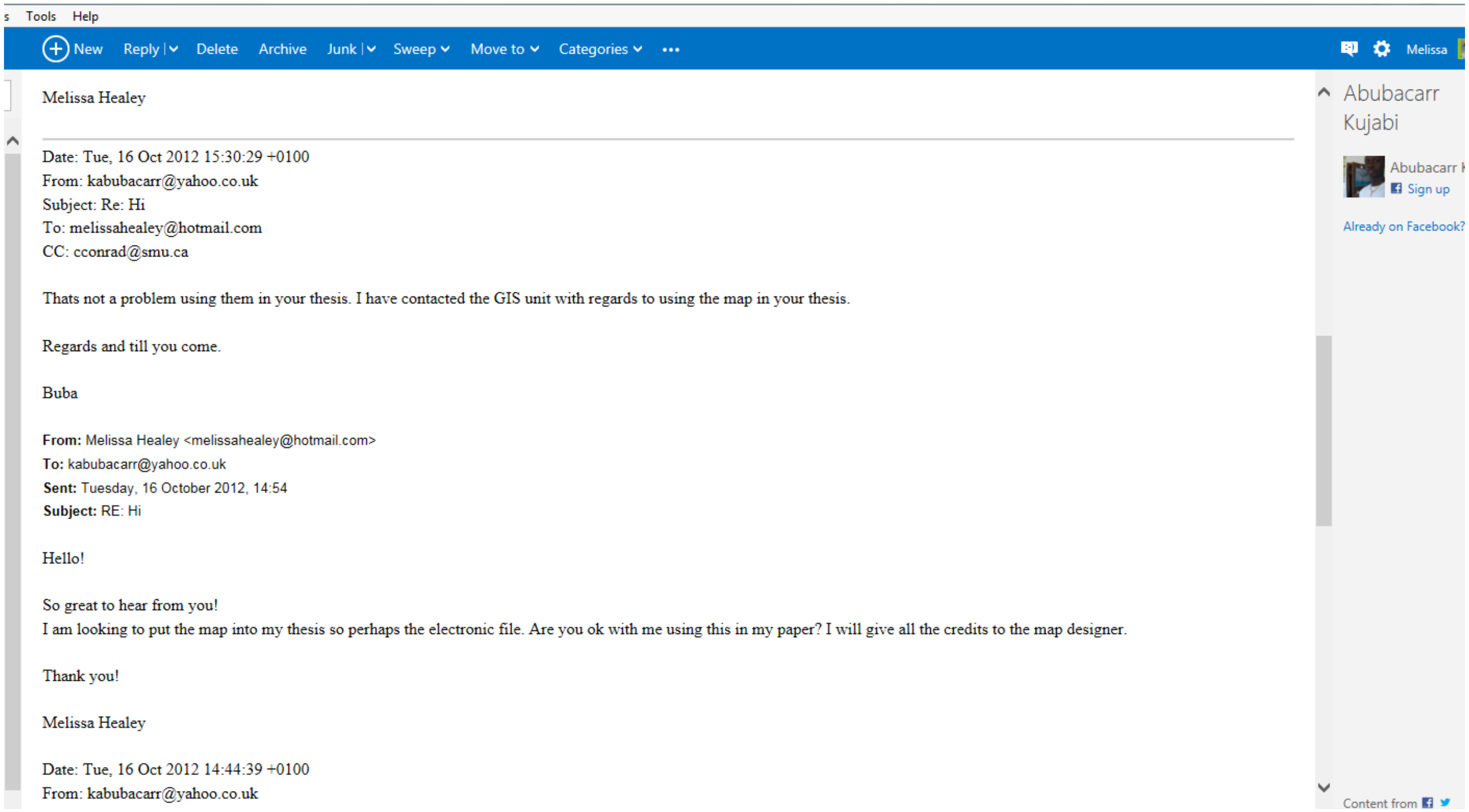
Figure 22. Letter of Permission: Gambia Location Map



Melissa Healey

Date: Tue, 16 Oct 2012 15:30:29 +0100
From: kabubacarr@yahoo.co.uk
Subject: Re: Hi
To: melissahealey@hotmail.com
CC: cconrad@smu.ca

Thats not a problem using them in your thesis. I have contacted the GIS unit with regards to using the map in your thesis.

Regards and till you come.

Buba

From: Melissa Healey <melissahealey@hotmail.com>
To: kabubacarr@yahoo.co.uk
Sent: Tuesday, 16 October 2012, 14:54
Subject: RE: Hi

Hello!

So great to hear from you!
I am looking to put the map into my thesis so perhaps the electronic file. Are you ok with me using this in my paper? I will give all the credits to the map designer.

Thank you!

Melissa Healey

Date: Tue, 16 Oct 2012 14:44:39 +0100
From: kabubacarr@yahoo.co.uk

Figure 23. Email Correspondence of Permission: The Administrative Regions of The Gambia