KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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KUMASI – GHANA

ASSESSING THE WATER SUPPLY POTENTIAL OF BOREHOLES ON KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY CAMPUS

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ASSESSING THE WATER SUPPLY POTENTIAL OF BOREHOLES ON KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY CAMPUS

By

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CERTIFICATION

I hereby declare that this thesis is my own work towards the Master of Science (MSc) degree in Water Supply and Environmental Sanitation and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this work to God, my parents and my grandmother for their continuous support during my study.

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My profound gratitude goes to the Almighty God for the wealth of His grace, mercy, guidance, strength, protection, steadfast love and wisdom throughout the program.

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To my family, thank you for your support and encouragement. Finally to all my friends who contributed in diverse ways to making this project a reality, I say God bless you.

ABSTRACT

There have been major expansions on the Kumasi water supply system all in the bid to meet the demand of its ever-growing population. However, many places in the metropolis still continue to experience interrupted water supply and Kwame Nkrumah University of Science and Technology (KNUST) even though it is a priority area, continues to experience water shortages. In a bid to cover these shortages, colleges, departments, hostels etc. have drilled boreholes to make up for the shortages. As a result, many boreholes are dotted over the university campus serving the needs of individual departments and hostels. This project seeks to assess the groundwater potential of KNUST to see if all the boreholes could be integrated into a system of water supply for the university community. Mapping of all boreholes (with coordinates and some characteristics such as yield and depth) on campus has been done. The daily water demand for the university has been estimated to be 3000m^3.The potential of all the boreholes drilled on campus has been assessed to be 2220 m^3 when pumping for 18 hours a day. The water quality of the water from the boreholes has been analysed and the results show that, there are no major health concerns from the existing boreholes in terms of iron, lead, manganese, arsenic and fluoride. However, total coliform was found to be present and the pH values show the water was slightly acidic and would pose some health risks to consumers. Therefore the water from the boreholes requires a limited amount of treatment in respect of disinfection and pH correction. Since the boreholes on the university campus have the potential of meeting about 74 % of the university's total demand, it is recommended that a conscious effort be made to bring all the borehole water to a point where quality improvement can be done before its distribution to the whole university community.

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1. INTRODUCTION

1.1 Background to Study

The availability of good quality water to most people in developing nations has become a serious social, economic and environmental issue. Increasing demands of growing populations has placed stress on the existing sources of surface water and experts have predicted that this could lead to national and international disputes in the future (Awuah and Anipa, 2002). Therefore there is a paradigm shift towards accessing groundwater. Kumasi as a regional capital is not different since the Ghana Water Company limited (GWCL), the main supplier of potable water to the metropolis has been trying as much as it can to meet the demand of the ever growing population. There have been three major expansions of its treatment facilities since the eighties, all in a bid to meet the demand of the metropolis. Despite all these expansion works, the GWCL has not been able to meet demand. As a result, many areas of the metropolis are not connected to water supply services and in areas where connection exists, supply is intermittent. The Kwame Nkrumah University of Science and Technology (KNUST) is one of such areas. The KNUST, though considered a high priority area (for services such as water, electricity etc.) suffers intermittent supply of water. Due to the unreliability of water supply, many hostels, departments, colleges etc. have drilled boreholes to supplement the GWCL water with groundwater. Boreholes are scattered all over the university campus and the need therefore arises to assess the water supply capacity of KNUST and also to make a conscious effort to bring all the borehole water to a point where quality improvement can be done before its distribution to the whole university community.

1.2 Problem statement

There have been major expansions on the Kumasi water supply system all in the bid to meet the demand of its ever-growing population. However, many places in the metropolis still continue to experience interrupted water supply and Kwame Nkrumah University of Science and Technology (KNUST) even though it is a priority area, continues to experience water shortages. In a bid to cover these shortages, colleges, departments, hostels etc. have drilled boreholes to make up for the shortages. As a result, many boreholes are dotted over the university campus serving the needs of individual departments and hostels.

1.3 Justification

To ensure a reliable water supply, there is the need for KNUST as an institution to manage its own water supply system. This study seeks to ascertain the possibility of KNUST being self-reliant by the use of various boreholes on its campus.

1.4 Objectives

The main objective of this study is to assess the water supply potential of boreholes on Kwame Nkrumah University of Science and Technology campus.

To achieve this main objective, the following specific objectives were investigated:

- Make an inventory and map all existing boreholes on KNUST campus
- Estimate the groundwater supply capacity of KNUST
- Determine the quality of the groundwater
- Propose a treatment scheme

1.5 Scope of Study

The study is limited to the Kwame Nkrumah University of Science and Technology campus in Kumasi and basically considers the water supply potential of the university by depending on already existing boreholes on its campus.

1.6 Structure of the Thesis

This thesis consists of six chapters. Chapter one, comprises of the introduction, problem statement; justification; research objectives; and the scope of study. Chapter Two focuses on review of literature. Chapter Three presents the general background of the study area. Chapter Four, which is the research methodology, explains how the study was carried out. Then Chapter Five presents and discusses the findings from the study. Finally, Chapter Six presents the conclusions and recommendations based on findings from the study.

2. LITERATURE REVIEW

2.1 Groundwater as a Resource

Groundwater is defined as subsurface water that occurs beneath the water table and flows through voids in soils and permeable geologic formations that are fully saturated (Freeze and Cherry, 1979). Groundwater extraction has facilitated significant social development and economic growth, enhanced food security and alleviated drought in many farming regions (Giordano & Villholth, 2007).

Over much of Ghana and Sub-Sahara Africa in general, the existence of readily accessible water has always been a very important criterion for settlement. The seasonality of rainfall, its effect on the presence of water and pasture, has resulted in fixed settlement occurring only close to perennial surface water or shallow groundwater. Across most of the rural communities in Ghana, groundwater use was until more recently, restricted to abstraction from shallow hand-dug wells and open holes on river banks or in dry river beds (Nyako *et al.,* 2006).

Gupta *et al.*, 2009 defines Groundwater as water contained in an aquifer matrix located beneath the surface in the saturated zone, as opposed to free surface water bodies like streams, reservoirs, or lakes. The quality of ground water depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region.

This increased popularity of groundwater has resulted from the fact that this resource is characterized by certain features that make it attractive as a source of potable water supply (Quist *et al*. 1988). Firstly, aquifers underlie geographically large areas of the country, and these can commonly be tapped at shallow depths near the water demand centers, even though rural settlements are widely dispersed. Some of these aquifers in certain geological formations have been assessed and their characteristics are fairly well known. Secondly, water stored in aquifers is, for the most part, protected naturally from evaporation, and well yields are in many cases adequate, offering water-supply security in regions that are prone to protracted droughts, such as in the northern parts of Ghana. Thirdly, with adequate aquifer protection, groundwater has excellent microbiological and chemical quality, and it therefore requires minimal or no treatment. Lastly, the capital cost of groundwater development as opposed to the cost of conventional methods of treating surface waters is relatively modest, and the resource lends itself to flexible development capable of being phased to meet rising demand (Dapaah-Siakwan and Gyau-Boakye, 2000).

2.2 Hydrogeologic Provinces and Borehole Yields

An analysis of boreholes yields has been made for the various geologic formations in Ghana (water resource research institute, 1996).

Two major hydrogeologic provinces exist in Ghana: the Basement Complex composed of Precambrian crystalline igneous and metamorphic rocks, and Paleozoic sedimentary formations.

As shown in Figure 2.1, Minor provinces consist of Cenozoic, Mesozoic, and Paleozoic sedimentary strata along narrow belts on the coast; and Quaternary alluvium along the major stream courses (Dapaah-Siakwan and Gyau-Boakye, 2000).

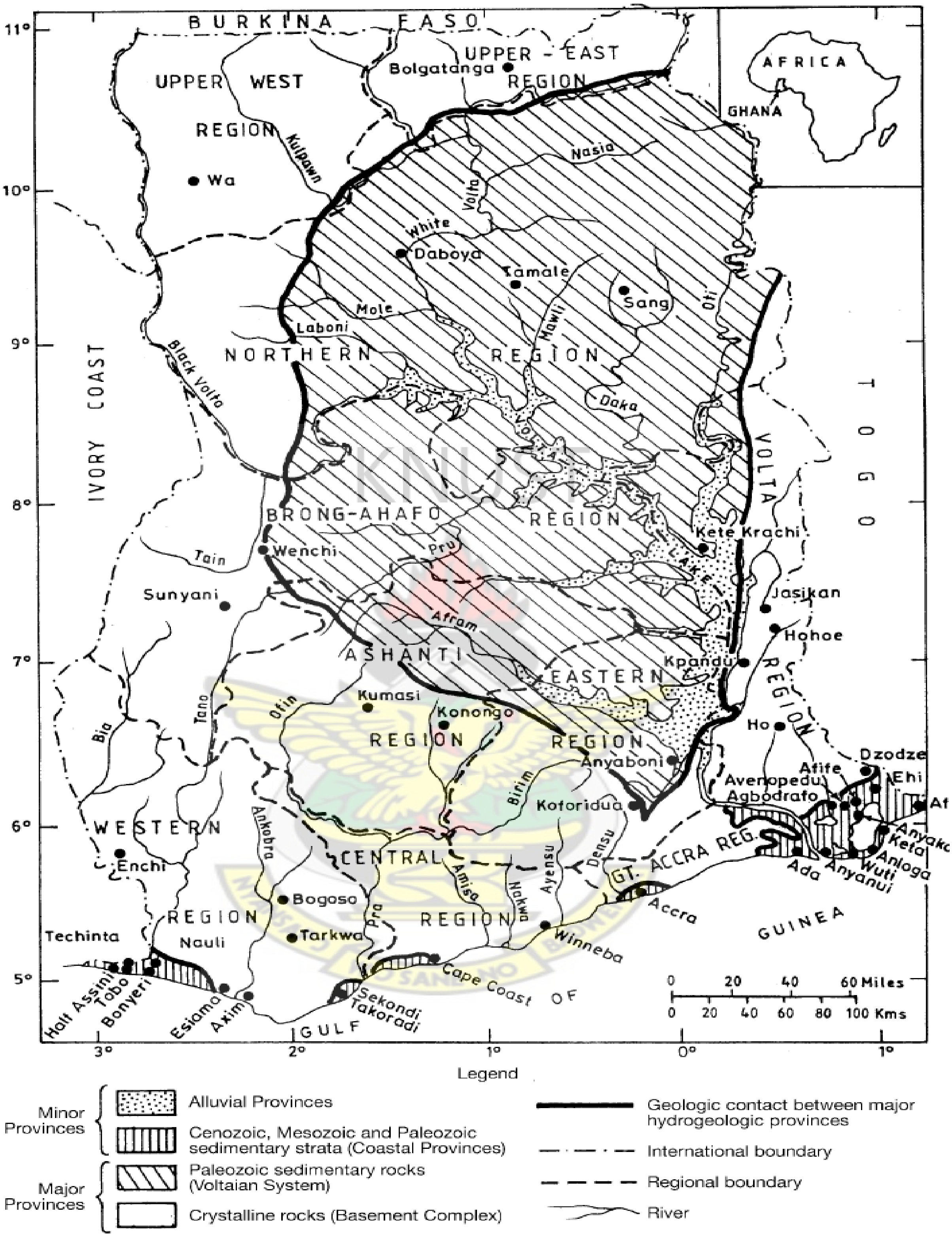

Figure 2.1 Hydrogeological provinces and river systems of Ghana

(Geological Survey of Ghana 1969)

Upper and Lower Birimian System, and associated granite extends from the north through the mid-west to the southwestern parts of the country.It is made up of rocks of the Birimian System and associated intrusives. The Birimian System consists of a great thickness of isoclinally folded, metamorphosed sediments intercalated with metamorphosed tuff and lava. The tuff and lava are predominant in the upper part of the System, whereas the sediments are predominant in the lower part. The entire sequence is intruded by batholithic masses of granite and gneiss. These dominantly argillaceous sediments were metamorphosed to schist, slate, and phyllite, with some interbedded greywacke.

The Basement Complex underlies about 54% of the country and is further divided into subprovinces on the basis of geologic and groundwater conditions (Gill, 1969).

Generally, these subprovinces include the metamorphosed and folded rocks of the Birimian System, Dahomeyan System, Tarkwaian System, Togo Series, and the Buem Formation; the distribution of these units. The Basement Complex consists mainly of gneiss, phyllite, schist, migmatite, granite-gneiss, and quartzite. Large masses of granite have intruded the Birimian rocks (Dapaah-Siakwan and Gyau-Boakye, 2000).

Kwame Nkrumah University of Science and Technology which is in Kumasi, is underlined by the upper and lower Birimian and associated with granite Basement complex hydrogeologic subdivision. The granite and gneiss associated with the Birimian rocks are of considerable importance in the water economy of Ghana because they underlie extensive and usually well populated areas. They are not inherently permeable, but secondary permeability and porosity have developed as a result of fracturing and weathering. Where precipitation is high and weathering processes penetrate deeply along fracture systems, the granite and gneiss commonly have been eroded down to low-lying areas. On the other hand, where the precipitation is relatively low, the granite occurs in massive, poorly jointed inselbergs that rise above the surrounding lowlands. In some areas, weathered granite or gneiss form permeable groundwater reservoirs. Major fault zones also are favorable locations for groundwater storage.

As shown in Figure 2.2, in the mid-sections around Kumasi and surrounding areas, the boreholes have higher yields than in other areas; the average is 9.3 m^3/h (2046 igph).

The rainfall around Kumasi and surrounding areas is greater than around the Wa and Winneba areas; hence the zone of weathering is thicker and well yields are greater (Dapaah-Siakwan and Gyau-Boakye, 2000) as shown in Table 2.1.

Table 2. 1 Summary of borehole yields of hydrogeologic provinces and subprovinces

Hydrogeologic province And Subprovince	**Boreholes-completion success rate (%)**	**Range of yield (m^3/h)**	**Average yield (m^3/h)**
Lower birimian system	75	0.41-29.8	12.7
Upper birimian system	76.5	0.45-23.6	7.4
Dahomeyan system	36	1-3	2.7
Tarkwaian system	83	1-23.2	8.7
Togo series	87.9	0.72-24.3	9.2
Buem formation	87.9	0.72-24.3	9.2

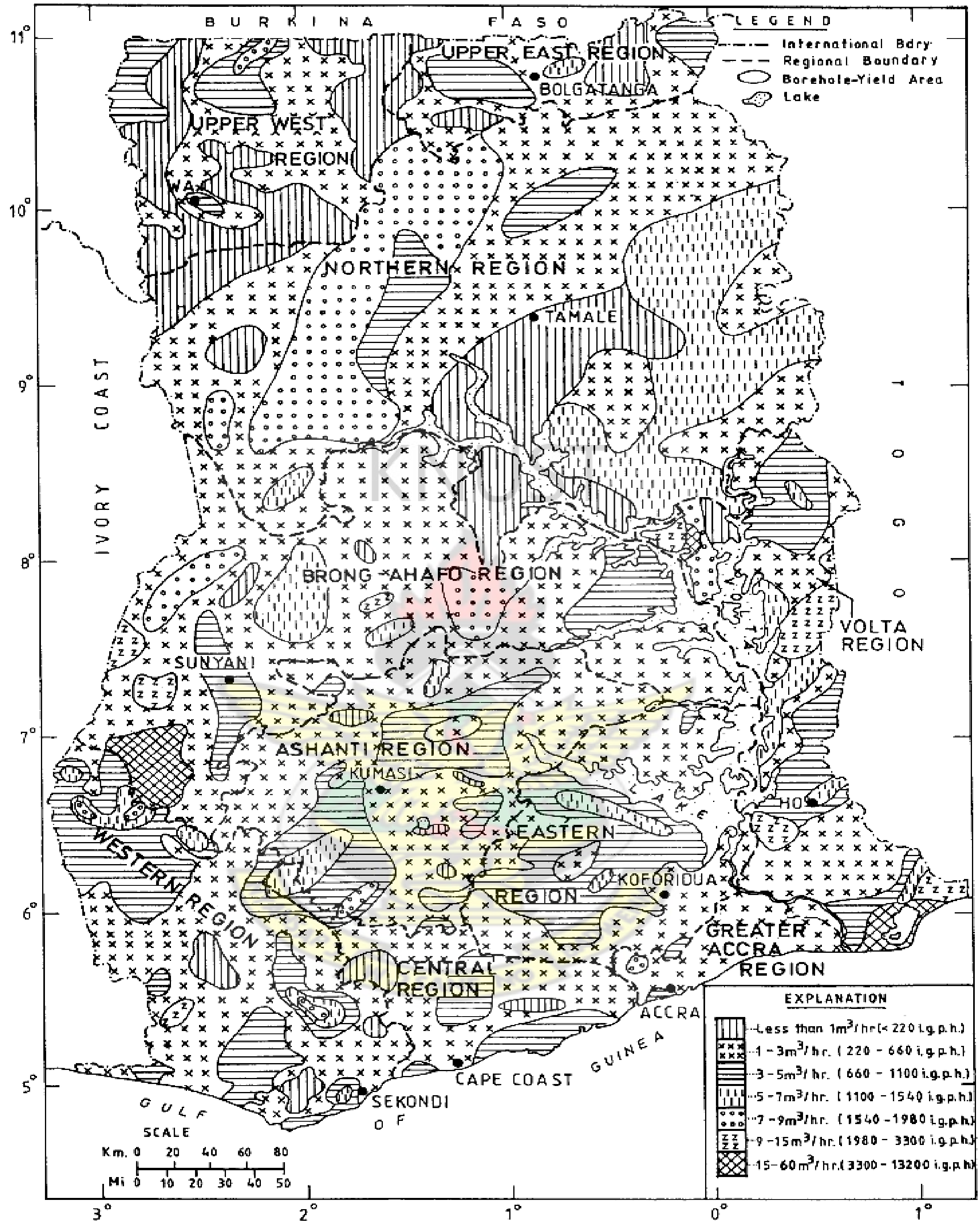

Figure 2.2 Water Resources Research Institute (1994) Borehole yield Map of Ghana

2.3 Groundwater Quality

The primary objective of water treatment is the purity and safety of the finished water (Tillman, 1996). But groundwater development has also depressed water tables (Konikov and Kendy, 2005) degraded ecosystems (Sophocleous, 2002) and led to the deterioration of groundwater quality (Fogg and LaBolle, 2006) and can sometimes affect the groundwater quality.

The quality of groundwater reflects input from the atmosphere, soil and water-rock reaction as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic waste and industrial waste (Appelo and Postma, 1993). The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region (Gupta *et al*, 2009).

2.3.1 Iron

Iron occurs in natural waters in the form of ferrous (Fe^{2+}) iron. Its presence is normally attributed to the dissolution of mafic mineral rocks. When exposed to air it causes staining of clothes. Again it can cause slimy coats on pipes as a result of oxidation. Iron is one of the most abundant metals in the Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/litre. Iron may also be present in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day. As a precaution against storage in the body of excessive iron, in 1983 Joint Expect Committee on Food Additives (JECFA) established a Provisional Maximum Tolerable Daily Intake (PMTDI) of 0.8 mg/kg of body weight, which applies to iron from all sources except for iron oxides used as colouring agents and iron supplements taken during pregnancy and lactation or for specific clinical requirements. An allocation of 10% of this PMTDI to drinking-water gives a value of about 2 mg/litre, which does not present a hazard to health. The taste and appearance of drinking-water will usually be affected below this level (WHO, 2003)

2.3.2 PH

pH is the measure of acid balance of a solution. The WHO recommends a PH range of 6.5-8.5. pH is a measure of the activity of the (solvated) hydrogen ion. p[H], which measures the hydrogen ion concentration is closely related to, and is often written as, pH**.** The EPA Guide specifically mentions pH as something that may necessitate periodic monitoring. The reason for setting a low limit is that low pH water is corrosive and can dissolve plumbing components. This is especially a concern when water contacts brass and copper piping systems where copper, zinc, and lead can dissolve into the drinking water. Reasons for setting a high limit are that high pH can promote hardness scale precipitation and that chlorine disinfection is not as effective at high pH (WHO, 2003).

2.3.3 Turbidity

Turbidity is important because it affects both the acceptability of water to consumers, and the selection and efficiency of treatment processes, particularly the efficiency of disinfection with chlorine since it exerts a chlorine demand and protects microorganisms and may also stimulate the growth of bacteria. In all processes in which disinfection is used, the turbidity must always be low—preferably below 1 NTU or JTU (WHO, 2003).

2.3.4 Total Dissolved Solids or Conductivity.

Total dissolved solids (TDS) and conductivity both indicate the total inorganic mineral content of drinking water. Either of these tests can be used to monitor the consistency of quality from water purification processes (such as reverse osmosis), which remove inorganic contaminants from water. The typical con-ductivity of reverse osmosis (RO) water ranges between 1-100 µS/cm, depending on the conductivity of the supply water (EPA standards, 2003).

2.3.5 Colour

Colour in drinking-water may be due to the presence of coloured organic matter, e.g. humic substances, metals such as iron and manganese, or highly coloured industrial wastes. Drinking-water should be colourless.

2.3.6 Nitrate and Nitrite

The WHO recommends 10mg/l as the maximum guideline value for nitrate. Excessive amounts in drinking water may cause methahemoglobinemia, which causes shortness of breath and blueness of skin (Mashod, 2008).

Nitrate (NO_3) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrite (NO_2) is not usually present in significant concentrations except in a reducing environment, since nitrate is the most stable oxidation state. It can be formed by the microbial reduction of nitrate. Nitrite can also be formed chemically in distribution pipes by Nitrosomonas bacteria during stagnation of nitrate-containing and oxygen-poor drinking-water in galvanized steel pipes or if chloramination is used to provide a residual disinfectant. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes. Some groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation. In general, the most important source of human exposure to nitrate and nitrite is through vegetables (nitrite and nitrate) and through meat in the diet (nitrite is used as a preservative in many cured meats). In some circumstances, however, drinking water can make a significant contribution to nitrate and, occasionally, nitrite intake. In the case of bottle-fed infants, drinking-water can be the major external source of exposure to nitrate and nitrite (WHO, 2008)

2.3.7 Hardness.

The reason for setting an upper limit on hardness is that hard water can cause calcium carbonate scale deposits in automated watering systems, which can lead to drinking valve leaks and other operational problems. According to the Water Quality Association, water is considered "hard" when the measured hardness exceeds 120 mg/L. Just knowing the hardness level of water is not enough to predict if it will cause scaling problems. A better predictor is the Langelier Saturation Index (LSI). When the LSI (which is calculated from pH, total dissolved solids, calcium hardness, and alkalinity) is greater than zero, water will have a tendency to scale (WHO, 2003).

2.3.8 Coliform Bacteria.

The coliform test is a reliable indicator of the possible presence of fecal contamination and is, consequently, correlated with pathogens. The EPA Maximum Contaminant Level (MCL) is less than one coliform per 100 ml. Many animal facilities periodically test animal drinking water for coliforms and use this limit. Recommendation: potable water. (<1 coliform/100mL), (WHO, 2003).

The Heterotrophic Plate Count (HPC) test, also called “total count “or “plate count”, provides an estimate of the total number of bacteria in a sample that will develop into colonies during a period of incubation in a nutrient. This test detects a broad group of bacteria including nonpathogens, pathogens, and opportunistic pathogens, but it does not pretend to report all of the bacteria in the water sample examined. HPC may be an indicator of poor general biological quality of drinking water.

Health agencies like the EPA and World Health Organization (WHO) “have avoided setting standards for plate counts, possibly for lack of pathogenicity and great variation in density encountered (DeZuane, 1990).” A recommended MCL for human drinking water has not yet been proposed, but the EPA does recognize the water quality deterioration implied by high plate counts. The upper limit for potable water is usually 500 colony-forming units or cfu/mL. According to (DeZuane, 1990) , water with counts under 100 cfu/mL should be considered “potable” and values 100-500/mL “questionable” (WHO,2003).

2.3.9 Chloride

Chloride in drinking-water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. The main source of human exposure to chloride is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking-water. Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/litre can give rise to detectable taste in water (WHO standards, 2008).

2.4 Kumasi Water Supply System

Kumasi is the second largest city in Ghana and the capital of Ashanti region. Millenium Cities Initiatives estimates the 2010 population at 1.6 million, with a daytime population estimated at roughly 2 million.

Kumasi, Ghana’s second largest city, is located in south-central Ghana and is a commercial, industrial and cultural center with a rapidly increasing population (Moumié, 2010)

Access to piped water in Kumasi has increased from 66.2 percent in 2000 to 80 percent in 2008 (Moumié, 2010).

Water production in Kumasi has been expanding in recent years, with an increase from 21 to 27 million gallons per day between 2005 and 2010 (Blokhuis et al., 2005)

Irregular, and hence, unreliable water supply is mainly the result of frequent power outages, a chronic problem afflicting all of Ghana in recent years. Water loss from leakages, though, is expected to decline, given the ongoing effort of Ghana Water Company Limited (GWCL), to replace the old pipes and extend the water main (Moumié, 2010).

Rainwater harvesting used to be widely practiced in Kumasi, but urbanization and pollution have made it impractical. Emissions from a growing number of industries and vehicular fumes have increased the range and levels of pollutants in the city, including such toxic chemicals as platinum, palladium and lead.(Moumié , 2010)

There are two water intake points: one at Owabi (located 10 km from the city); the other at

Barekese (located 19 km from the city).The abstracted water is treated at the Owabi and Barekese Water Treatment Plants. The water is stored at the Owabi reservoir, a stone masonry gravity dam constructed in 1928 that is 135 meters long and 11 meters high, and at the Barekese reservoir, a 15 meters high and 600 meters long earth-filled dam built between 1967 and 1971 and rehabilitated in 1998.

Kuma et al., (2010) estimate that, in 1996, daily per capita water consumption was 24.2 m3/year (0.066 m3/day or 66 liters/day) and argue that in 2009, it should have been 0.094 m3/day or 94liters/day. GWCL, on the other hand, notes that current per capita daily water consumption varies depending on socio-economic status. Low-income residents, for example, consume 0.025-0.035 m3/day, while middle-income residents consume 0.060-0.075 m^3/day and upper-income residents consume over 0.120 m^3/day. Average water consumption also varies, depending on the number of people per household and each household's location.

Water produced in Kumasi is generally of acceptable quality, but the use of chemicals near river bodies is threatening the quality of the water supply. According to the Kumasi Metropolitan Assembly, chemicals used by farmers and fishermen have been polluting streamlets that feed streams, which, in turn, supply water to the Bakerese and Owabi dams. The discharge of liquid waste from sewers and drains into rivers also threatens water quality.

According to the GWCL, another issue has been the infestation of bloodworms in the Owabi River, which dramatically diminishes the quality of the water from that source. These organisms contaminate the water by invading the filtration system and breeding in distribution tanks

Table 2.2 Water Demand and Coverage projections (Moumié, 2010)

Year	Demand L/Day	Production L/Day	Coverage %
1990	68678000	68200000	98
2010	242735348	122727273	51
2011	256382827	150021032	59
2012	270797618	177297600	65
2013	286022863	204574100	72
2014	302104126	231818182	77
2015	319089538	231818182	73

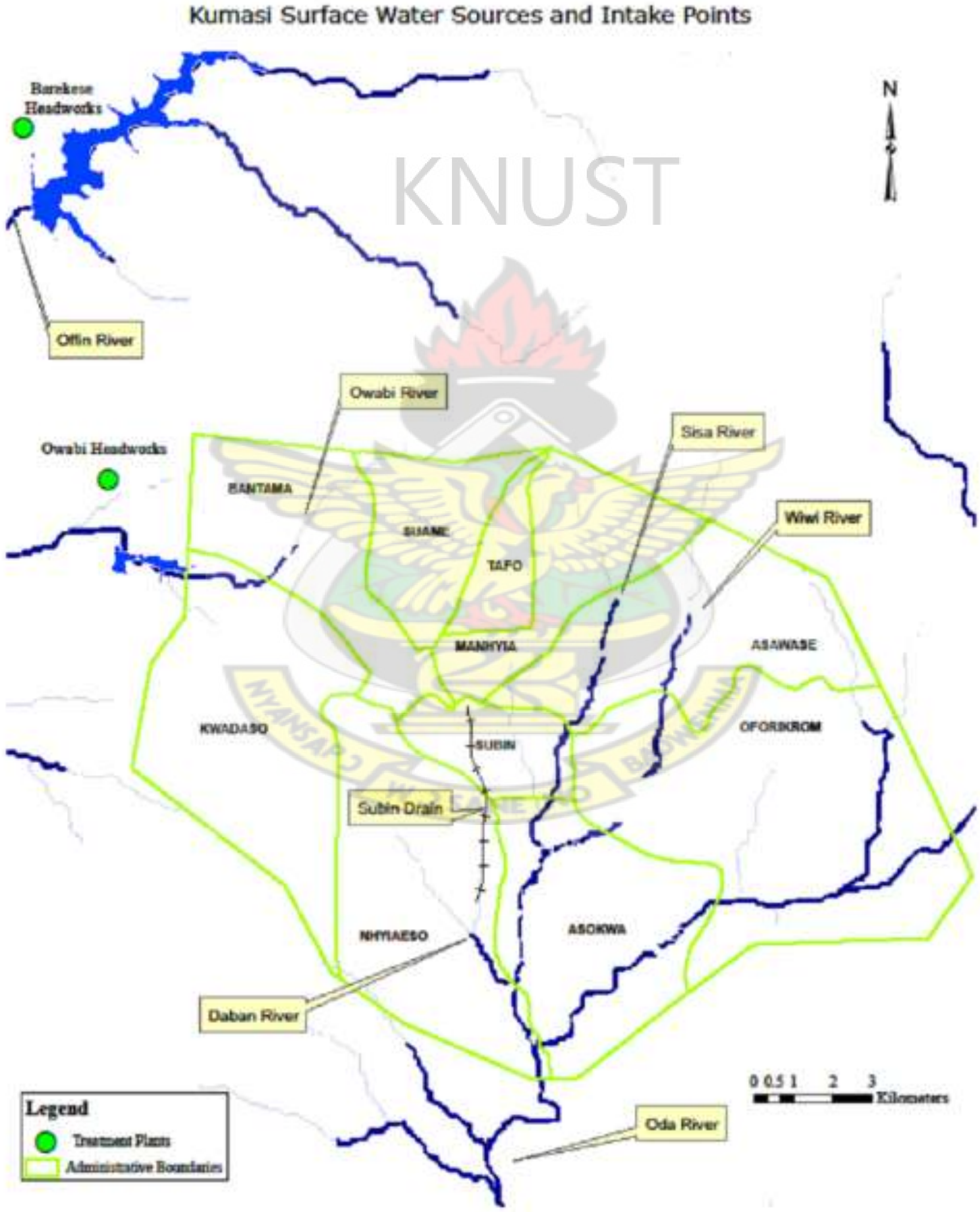

Figure 2.3 Kumasi surface water sources and intake points

3. GENERAL BACKGROUND OF THE STUDY AREA

3.1 Introduction

Kwame Nkrumah University of Science and Technology is located within the Kumasi Metropolitan area as shown in Figure 3.1. The Kumasi Metropolitan area has an approximate area of 254 square kilometres and it is located between latitudes $6^0 35'$ and $6^0 4'$ N and longitudes $1^0 30'$ and $1^0 35'$ E. The Metropolitan area is dominated by the middle Precambrian Rock. It is within the plateau of the South-West physical region which ranges between 250-300 metres above sea level. The topography is generally undulating.

The KNUST campus is on the South-Eastern part of the city of Kumasi and situated about 8 km from the city center. The campus covers an area of about 18 square kilometers of undulating land. It is bounded to the west by Ahinsan and Bomso suburbs, on the East by Ayeduase, the North bounded by Bomso and Ayigya and on the south by Ahinsan.

The university campus has facilities which includes staff bungalows, a hospital, maintenance and estate department, basic schools (i.e. a nursery, primary and junior high school), a senior high school, , transport department, photocopy unit, printing press, bookshop, senior staff club, sports stadium, an Olympic size swimming pool, commercial and banking facilities, post office, places of worship and guest houses and restaurants .

There are seven halls of residence and five hostels on the university campus. Four of the halls are for male and female students, two for males only and one for females only. In addition there are three other hostels that are owned and managed by the management boards of specialized postgraduate programmes including the Water Resources and Environmental Sanitation (WREPS) and Road and Transportation Engineering Programmes (RTEP) post-graduate programmes of Civil Engineering Department and the Spring postgraduate programme of the Planning Department.

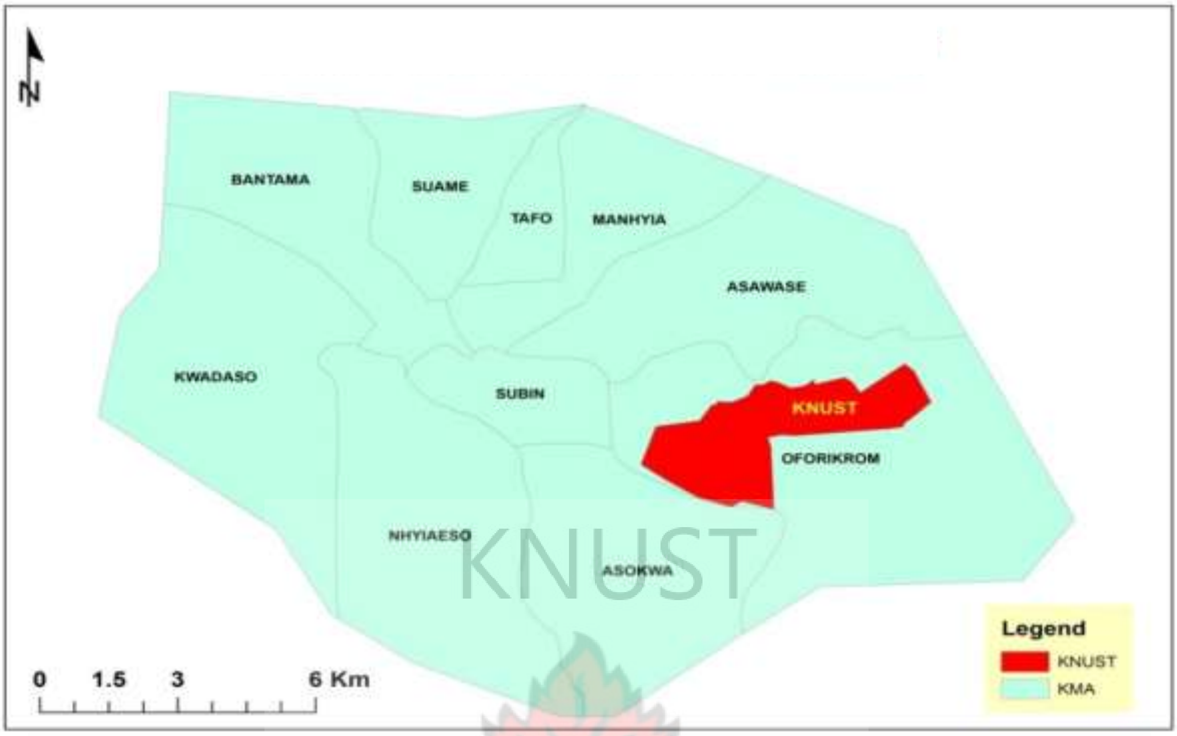

Figure 3.1 A map of Kumasi Metropolitan Assembly showing KNUST, the study area

According to the Ghana Meteorological Agency office in Kumasi, the climate of the study area is wet sub-equatorial type with two rainfall seasons. The major rainfall season starts from May to June while the minor starts from September to October. The mean monthly rainfall ranges from 15 mm in January, to 214 mm in June. The minimum daily temperature ranges from $20.1^{O}C$ in January to $34^{O}C$ in February. The evapo-transpiration is between 86 mm in October and 157 mm in January while the mean annual evapo-transpiration is 1412 mm

3.2 Water supply situation

The main sources of water for the KNUST community are from

- Surface water sources (GWCL system)
- Groundwater sources (Boreholes)

The water supplied by GWCL is produced at the Barekese treatment plant and is transported over some 25km (Google map) through Suame to the KNUST campus. The water pressure within the network drops below required levels just before the project area and is therefore improved by the booster station. On the average GWCL supplies 45,500 cubic meters of water directly into the distribution network every month through a nine inches diameter pipe. Additional 15,984 cubic meters of water is pumped into double chambered underground clear water reservoir with a capacity of 4,500 cubic meters (1 million gallons) where it is dosed with chlorine to boost the residual chlorine content. The water is then pumped into two overhead tanks each with a capacity of 250 cubic meters which then flows under gravity into the distribution system. In all, on the average GWCL supplies a total of 61, 484 cubic meters of water monthly to the community.

Figure 3.2 KNUST overhead tanks (250 cubic metres each)

4. RESEARCH METHODOLOGY

The following methods were used to achieve the objectives of the study.

4.1 Desk Study

Reports and data on boreholes, topographical and hydrogeological maps were collected from the geomatic and geological departments of KNUST for review. Also data on population and their categories were collected from the KNUST development office and the halls. The summary of Data and their sources were compiled as shown in table 4.1 below.

Table 4.1 Summary of Data Sources

TYPE OF DATA	SOURCE OF DATA
Hydrogeological reports	Geomatic Department, KNUST
Topographical maps	Survey Department, Kumasi
Geological maps	Geological Survey Department, Kumasi
Shape file of KNUST	GIS section of Geomatic Department, KNUST
Housing population	Development office, KNUST
Water consumption bills	Ghana water company limited Kumasi
Publications and journals	Internet and KNUST library
Master of science(MSc.) Thesis	Water Resources and Sanitation library, KNUST,

4.2 Field Study

The field was visited several times for these two reasons: the first was to map and take water samples from boreholes in the study area and it was followed by the water needs assessment.

4.2.1 Mapping of Borehole points.

For the mapping of boreholes, the exact location of the boreholes were found by using Garmin GPS 76 Global Position Satellite (GPS) .The instrument was positioned on the borehole till the accuracy was improved to about 10m error margin (error margin of GPS). Data on the depth and yield of all the boreholes were later collected from the drilling services. The sampling was done for both biological and physiochemical analysis. Ethanol was used to sterilize the opening of the pipe so as to avoid contamination of the sample.

The second phase of the field work entailed the collection of information on the population of the selected halls as well as their water usage information.

4.2.2 Water Sampling

Ten (10) Water samples were collected at random from the 27 boreholes on campus. These boreholes were chosen due to accessibility to the borehole and its position on campus. It was realized from the field study that most of the boreholes cluster at specific places. Therefore the sampling was done to have a balance and capture as many different aquifers (if they are different) as possible. The purpose for sampling the water was to ensure the potability of the groundwater. Three samples were taken from each borehole point and they were labeled according to the codes of the boreholes.

The first sample was the bacteriological test sample which was collected in a sterilized bottle originally containing distilled water. Sulphiric acid was used to wipe the tip of the pipes to avoid contamination and the water is made to run for about 2 minutes to avoid stagnant water. The samples were then kept in an ice chest and the process was repeated at all the borehole points before they were transported to the Environmental Quality Laboratory for storage.

The second sample was taken for heavy metal test. These bottles were 100 ml bottles which were used to take samples and because the distance from the laboratory to the places of sampling were not far, they were not iced but rather transferred swiftly to the laboratory for proper storage.

The third sample was taken for the physiochemical test. These samples were collected and kept in new bottled water bottles.

4.2.3 In Situ Test

In-situ analyses of pH, electrical conductivity, total dissolved solids and dissolved oxygen were conducted by using hand held Horiba Multi-Probe equipment because groundwater outside its natural environment quickly undergoes several changes and would have impact on the mentioned parameters. The probes of the Horiba Multi-Probe equipment were immersed into a bucket of water after which the instrument was switched on to record all readings while keeping the probes immersed

4.2.4 Laboratory Analysis

Chemical analyses of the samples were carried out using appropriate certified and acceptable international procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA-WWA-WPCF,1994); calcium (Ca) by EDTA titration; Magnesium (Mg) by calculation after EDTA titration of calcium and total hardness; chloride (Cl) by argentometric titration; Nitrate-nitrogen was analyzed by hydrazine reduction and spectrophotometric determination at 520 nm; heavy metals were analyzed using UNICAM 969 atomic absorption spectrophotometer. An ionic error balance was computed for each chemical sample and used as a basis for checking analytical results. In accordance with international standards, results with ionic balance error greater that 5% were rejected.

The physicochemical parameters were analyzed and compared to world Health Organization (WHO) standards.

5. RESULTS AND DISCUSSIONS

5.1 Inventory and Mapping

The boreholes on campus were all mapped with Global Position Satellite (GPS) and the exact positions of the boreholes were known. This was done by assigning codes to various Boreholes so they could be captured and stored in the GPS. This included descriptive information as well as remarks concerning each particular borehole, as shown in Appendix 3. These coordinates generated from the GPS are shown in Appendix 4. These coordinates were exported and superimposed on the shapefiles of KNUST and the map showing all the boreholes on campus was generated. This map is as shown in Appendix 5.

Table 5.1 below shows the inventory of the boreholes on campus. In all, 27 boreholes were mapped. The highest yield was 450 litres per minute and the lowest yield was found to be 9 litres per minute, beside Paa Joe stadium and GUSSS house respectively. The average yield across campus from the available data was 72.64 l/min. This is not however to suggest that this is the average yield expected across campus since the yield depends largely on the aquifer characteristics.

The depth of the boreholes on campus ranged from 21metres at both BH021 and BH022 to 69metres at BH020. At SRC Hostel (BH021 and BH022), the boreholes were drilled in a waterlog area and has accounted for the short depth at which a yield of 90 l/min and 60 l/min were realized at BH021 and BH022 respectively. The highest depth of 69 which was at Republic hall has a yield of 21 l/min which is one of the lowest yields on campus.

The minimum borehole yield of 50 L/min can provide water for urban water supply (Kortatsi and Quansah, 2004). The borehole yields shown in Table 5.1 has 15 boreholes which represent 60 % with yields less than 50 L/min and 10 boreholes representing 40 % with yields greater than 50 L/min as shown in Table 5.2.

Table 5. 1 Borehole Inventory

Id	Description	Yield (L/Min)	Depth (M)
BH001	Gusss house behind i-block	25	30
BH002	Gusss house behind j-block	18	30
BH003	Gusss house behind k-block	9	25
BH004	Graduate hostel	40	
BH005	Tech credit hostel	40	
BH006	Behind steven paris hostel	150	38
BH007	New one closer to steven paris		
BH008	New one further from steven paris		
BH009	University hall (katanga)	30	
BH010	Beside paa joe stadium	450	
BH011	Hall 7 close to indece road	60	45
BH012	Behind steven paris hostel (covered)	120	35
BH013	Queens hall	50	61
BH014	Beside hall 7 (facing africa)	18	40
BH015	Africa hall	25	
BH016	Chemistry department	30	58
BH017	Pharmacy	40	40
BH018	Engineering (closer to auditorium)	63	34
BH019	Engineering (behind the lab)	117	27
BH020	Republic hall	21	69
BH021	Src hostel 1	90	21
BH022	Src hostel 2	60	21
BH023	School of medical sciences	60	53
BH024	College of science	50	55
BH025	Natural resources department	50	63
BH026	Business school	90	55
BH027	Agriculture department	150	53

Table 5.2 Borehole yields

Yield, l/min	Number of boreholes	Percentage
Less than 50	15	60
Greater than 50	10	40

There were 27 borehole points which were identified, out of these, 2 are new and yet to be fitted with pumps. The research conducted showed that, out of the 25 already mechanized borehole points, 5 are not working due to faulty pumps. The remaining 20 which forms 80 % of those fitted with pumps are in good working conditions as shown in Figure 5.1

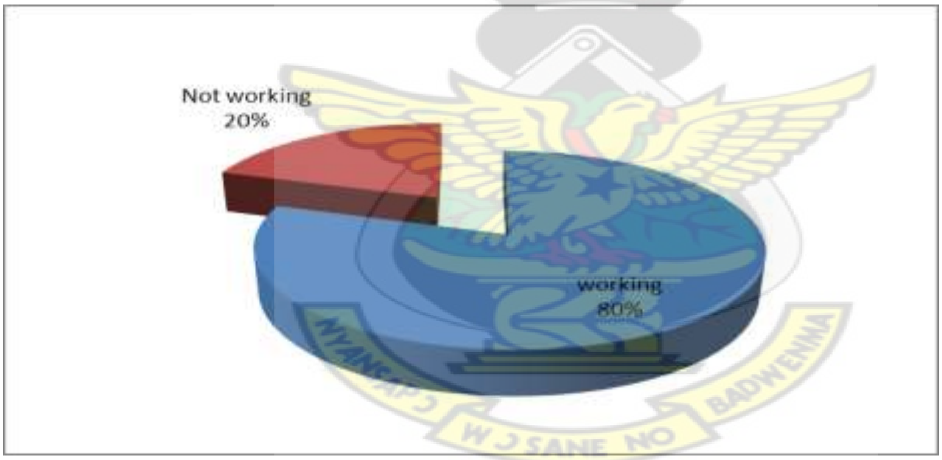

Figure 5.1 Conditions of Boreholes

5.1.1 Available Water Resource

The summation of all the borehole yields, gives the volume of water available every minute. The total water available hourly from the entire mechanized borehole was 2.056 m^3 .The hours of pumping is determined by the knowledge of the borehole recovery. Though data on the various borehole recoveries was not accessible, the maximum recovery on campus was known. From data available to the senior hydrogeologist, it takes maximum 20 minutes for the borehole to recover up to 85 percent and a maximum of an hour to reach 95 percent recovery. 100 percent recovery however takes an infinite time to achieve .There was therefore the need to allow for at least an hour in-between a six hour pumping period. Two hours left between each pumping so that there can be enough recharge and also ample time to start and stop pumping hence pumping for 6 hours three times a day (18 hours a day) will yield a resource of 2220 m^3 of water daily. Table 5.3 shows the various pumping hours and the resource which will be available if pumping is done for that number of hours in a day.

Table 5.3 Pumping hours

PUMPINGS	Yields (L/day)	yield (m3/day)
1 hour	123360	123.36
8 hours	986880	986.88
10 hours	1233600	1233.6
12 hours	1480320	1480.32
14 hours	1727040	1727.04
16 hours	1973760	1973.76
18 hours	2220480	2220.48

The available groundwater that can be realized from pumping all the boreholes for 18 hours a day is 2220 m^3 of water. This resource is however distributed through campus as shown in Figure 5.2.

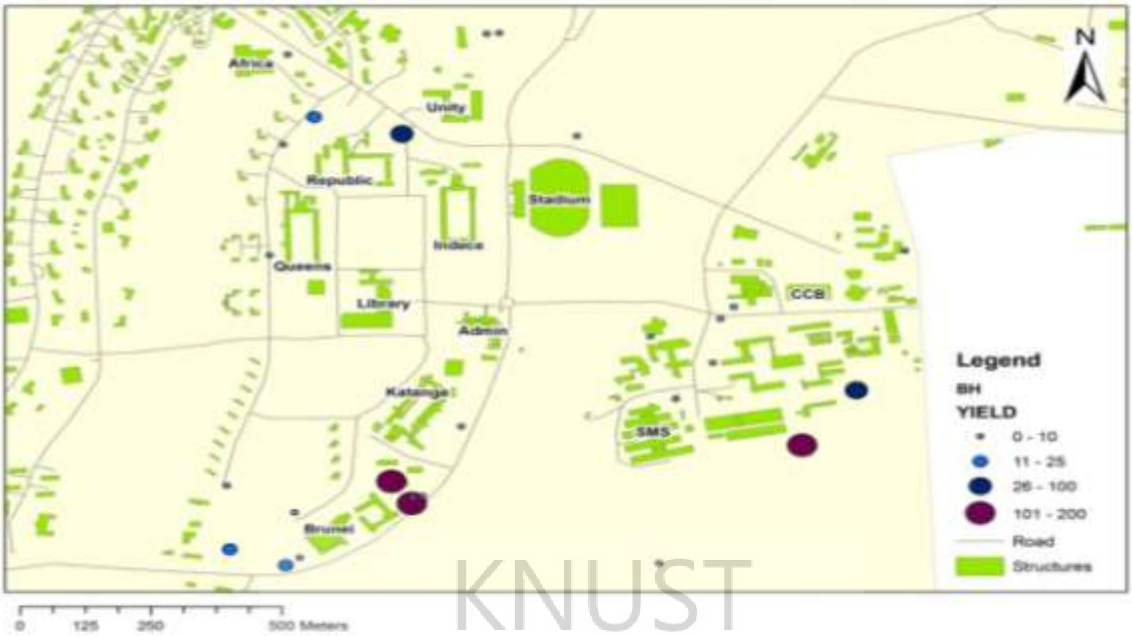

Figure 5.2 Map of KNUST showing the borehole yields

5.2 Needs Assessment

Inventory was made of all places on campus and the populations at various places were noted. There are 578 housing units on campus, as shown in Appendix 1. An average number of persons to a house used was 5.This made the population of staff and their family resident on campus to amount to 2890 people and with a 90 litres per person per day consumption used, the demand was 260100 litres per day.

The security barracks was however not factored in the above demand hence a water demand of 45000 litres per day was arrived at after a population of 500 people were giving a consumption of 90 litres per person per day. This brings the demand of staff resident on campus to 305.1 cubic metres.

The population of students resident on campus was 13698 and with a 90 litres per capita water consumption, the demand was 1232820l/min .These residence included halls and hostels on campus premises. These facilities are managed by 370 workers and with a per capita consumption of 15 litres; the daily demand was 5670 litres. The total demand for student residence was therefore 1,238,445 litres per day as shown in Table 5.4

Table 5.4 Water demand breakdown

Places On Campus	**Demand (l/day)**	**Demand (m^3/day)**
Staff Residence	305100	305.1
Students Residence	1238445	1238.445
Laboratories	100000	100
Restaurants	120000	130
Colleges	43600	43.6
Health Facility	10800	10.8
Leakages And Wastages	600000	600
Fire Fighting	400000	400
Schools	35000	35
Other Places	146000	146
Total		2998.945

The laboratories on campus due to their constant usage use a lot of water as most of the experiments involve the use of water as well the production of Distilled water. The demand allocated to the laboratories was 100 cubic meters of water daily, and this formed 3 % of the total demand on campus as shown in Figure 5.3 below.

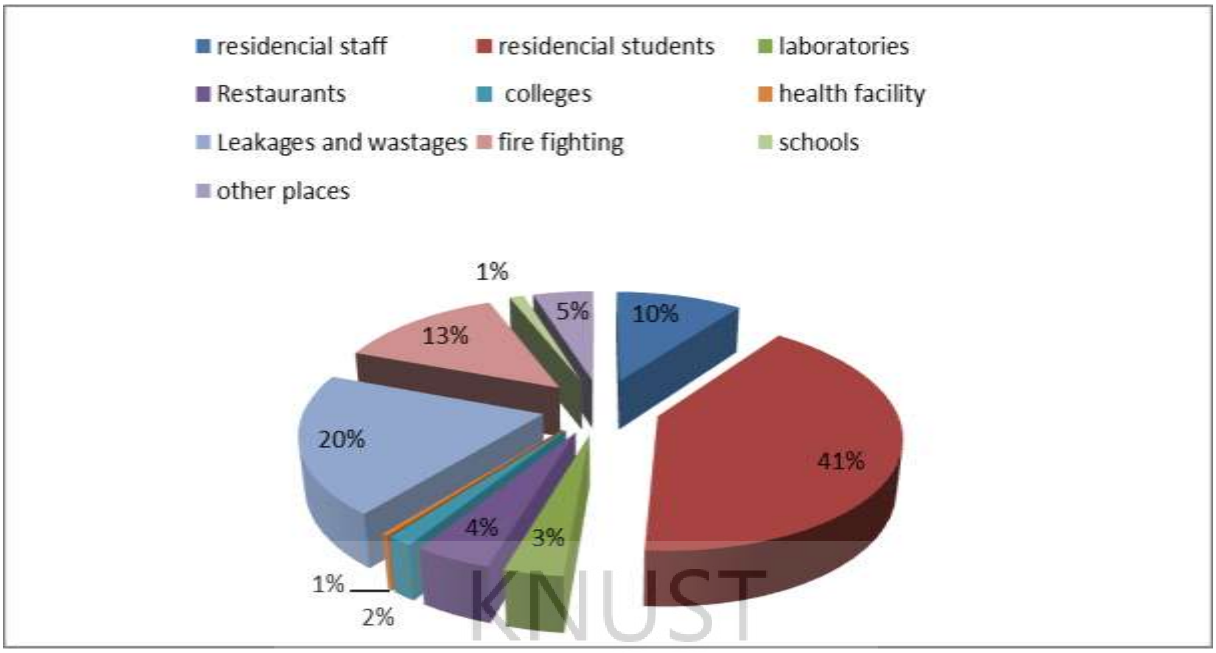

Figure 5.3 Breakdown of water demand

Restaurants and guest houses on campus are also places where water was considered important. Some of the eateries included Kumasi centre for collaborative Research (KCCR) engineering and school of medical sciences Guest houses. In a day, the average patronage in all these restaurants was known to be 1000 people per day. The water demand of these places was estimated to be 120 cubic meters as a per capita water consumption of 120l/c/d was used for the 1000 people who patronize these places on campus As shown in Figure 5.3 above, the daily demand of the restaurants formed 4 % of the total daily water demand of KNUST.

There are six colleges in this study area and these are places where most lecturers have their offices and academic work takes place. Water is needed daily for cleaning and the lavatories. The various colleges were assessed based on their lavatories and staff size as well as offices. The six colleges had different estimates which totals to a demand of 43.6 cubic metre of water are daily. At Business School, an estimated 3.6 cubic metres of water will be needed daily whiles at school of medical sciences a demand of 10 cubic metres was estimated as their daily demand. The estimate was done for college of science, college of Engineering, college of art and Sciences, College of Architecture college of Agriculture & Natural Resources as shown in Appendix 2

For health reasons, KNUST has a student's clinic and a hospital. The hospital is open to people within campus and its environs. The hospital has 360 beds and an average daily out patience of 120.The demand for water is estimated at 93600 litres daily. The clinic also will need 14400 litres of water daily and hence the health facilities on campus need 10.8 cubic metres of water daily

Due to the ageing nature of the pipes in the distribution network of KNUST, there are bound to be a lot of losses during distribution. This coupled with wastages of water as students are most often in a hurry and leaves tap not firmly closed. Leakages and wastages demand 600 cubic metres daily and this represents 20 % of the total demand on campus.

The two main schools within KNUST are the KNUST Senior High and the Primary and Junior High school. There is the need for water in these places. They will need 35 cubic meters every day. This water will be used for washing of hands, drinking, flushing of toilets and gardening.

Maintenance department, University Printing Press and KNUST museum will need water of 146 cubic meters as shown in Table 5.4. This daily supply also includes that of Commercial area and the new jubilee mall.

Also, appendix 2 has the various breakdowns of all the places on campus with their various water consumptions. A total demand of 3000 cubic meters per day was arrived at.

The total water needs of KNUST were estimated to be 3000 cubic meters per day.

5.3 Water Quality

The total number of boreholes on campus was grouped into ten (10) and samples were collected at random from each zone. This was done because most of the boreholes were very close together and there is therefore the tendency of them being within the same aquifer hence their qualities are likely to give the same parameters.

5.3.1 Heavy metals and Ions

The arsenic values recorded during the laboratory test were found to be below 0.01 mg/l and this means that they are below the WHO standards. This means that, all the boreholes tested on campus do not pose any health threat in terms of arsenic concentration.

The iron concentrations in the groundwater were also measured. The maximum iron concentration was found to be 0.175 mg/l at BH 016 (chemistry department) as shown in Table 5.5. The world health organization has set the guideline value of iron in portable water as 0.3mg/l and from the results obtained from the boreholes; KNUST has no iron concerns in its groundwater.

Table 5.5 Heavy metals and ions

No	Sample Code	As	Fe	Mn	Pb	F
1	**BH 001**	<0.01	0.050	0.018	<0.01	<0.1
2	**BH 003**	<0.01	0.023	0.014	<0.01	<0.1
3	**BH 006**	<0.01	<0.01	0.006	<0.01	<0.1
4	**BH 011**	<0.01	<0.01	0.008	<0.01	<0.1
5	**BH 012**	<0.01	<0.01	0.004	<0.01	<0.1
6	**BH 016**	<0.01	0.175	0.028	<0.01	<0.1
7	**BH 020**	<0.01	0.060	0.016	<0.01	<0.1
8	**BH 021**	<0.01	<0.01	0.004	<0.01	<0.1
9	**BH 022**	<0.01	<0.01	0.004	<0.01	<0.1
10	**BH 026**	<0.01	0.165	0.025	<0.01	<0.1

The manganese levels recorded were all found to be below the guideline values of 0.05mg/l set by World Health Organization. The maximum and minimum values were found to be 0.028mg/l and 0.004mg/l respectively. The maximum and the minimum were recorded at the chemistry department (BH016) and the SRC hostel 1 (BH021) respectively. The average manganese level was 0.0127mg/l. The maximum concentration was even lower than the 0.05mg/l hence the boreholes tested were found to have no manganese concerns.

The sampled water from the ten boreholes was tested to see if there could be any health hazards posed by fluoride. From the laboratory results, all the values were below 0.1mg/l and there are therefore no fluoride health concerns. There was no lead hazards anticipated from the laboratory results obtained as they were within the allowable range of 0.01 mg/l set by the WHO for drinking water.

The nitrite levels were tested and it was realized that the maximum and minimum concentrations were found at to be 0.089mg/l at Republic hall (BH020) and 0.021 mg/l at the covered borehole behind Steven Paris hostel (BH012) respectively. As shown in Figure 5.4 below, all the water tested was within the WHO Guideline Value (GLV) and it has an average concentration of 0.0351mg/l.

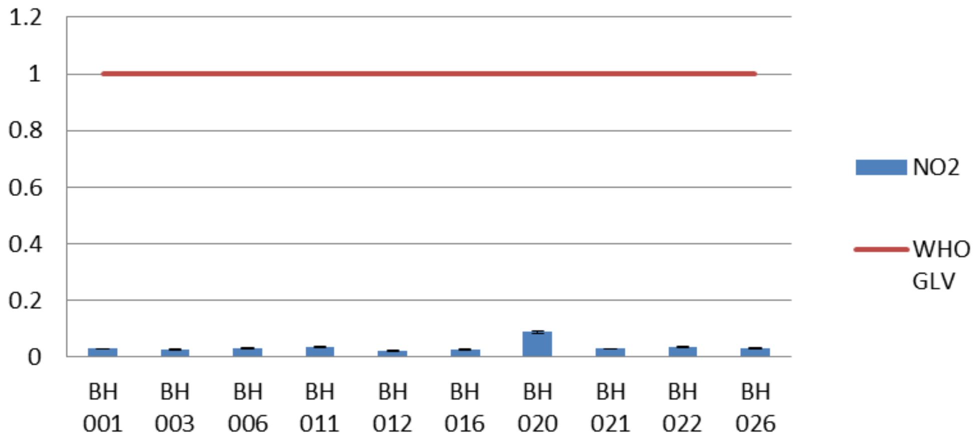

Figure 5.4 Nitrites levels in the water

Due to its high mobility, nitrate also can leach into groundwater. If people or animals drink water high in nitrate, it may cause methemoglobinemia, an illness found especially in infants (Watson, 2008).This therefore gave the need for the nitrates levels in the water to be tested.as shown in Figure 5.5, the maximum concentration occurred at SRC 1 (BHO21) which was found to be 0.038mg/l whiles at GUSSS behind i-block (BH001), a minimum concentration of 0.05mg/l was recorded. The average nitrate value was found to be 0.151mg/l and with the World health Organization's guideline value set at 10mg/l, there are no health concern scares.

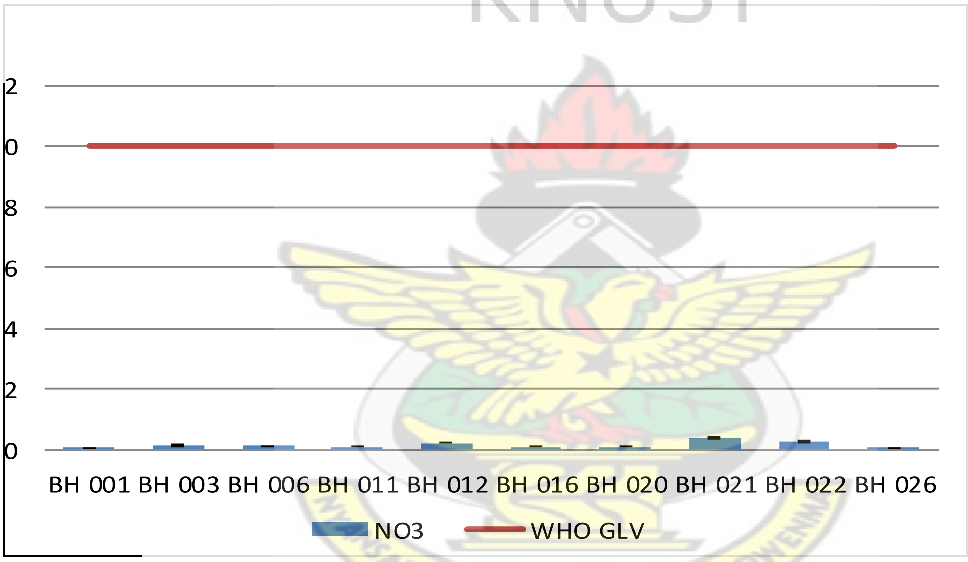

Figure 5.5 Nitrate concentration levels

5.3.2 Physical properties

Physical properties of the water were tested to ascertain the potability of the water. The physical properties which were tested included pH, turbidity pH, total dissolved solids (TDS), electronic conductivity, colour, total suspended solids (TSS), hardness, alkalinity and chloride.

The pH values were tested .This was to ascertain the acidity or basicity of the water.

The pH values ranged from 4.61 to 6.01 as shown in figure 5.6. All the pH values recorded were lower than the minimum GLV value (6.5) given by WHO. The average pH is 5.3 which is also low. Low pH or acidity gives sour taste to water (Kortatsi and Quansah, 2004). From boreholes tested in the Ashanti region, the pH of a groundwater ranged from 6 to 8 (Buamah *et al*, 2008).

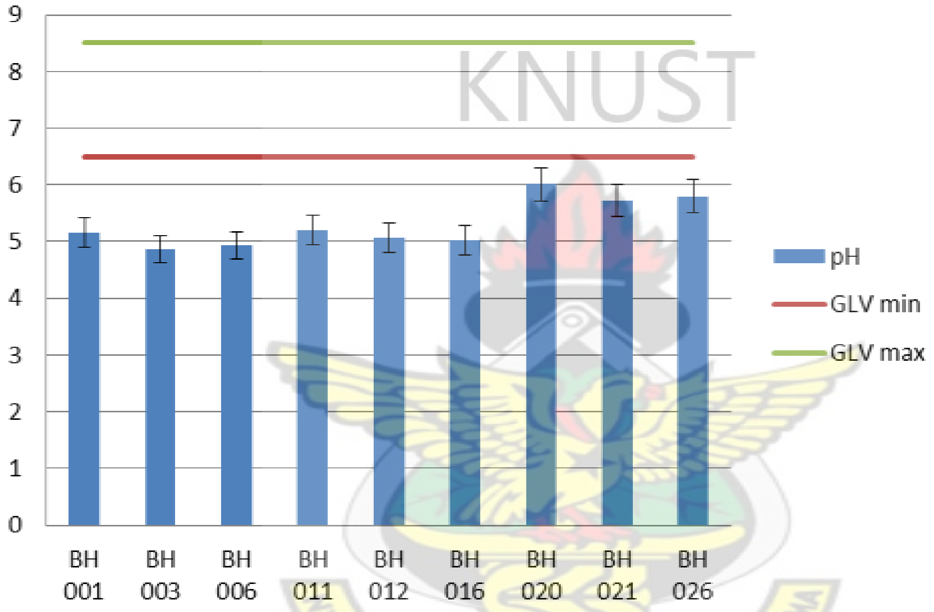

Figure 5.6 pH of the sampled water

Since the water tested, generally had a pH less than 6.5, then the water could be acidic, soft, and corrosive. The pH is of major importance in determining the corrosivity of water. In general, a lower pH corresponds to a higher the level of corrosion. However, pH is only one of a variety of factors affecting corrosion (WHO, 1996). At a pH of less than 4, corrosion increases rapidly with decrease in pH and from a pH range of 4 to 9, changes in pH have minor effects on corrosivity (Baboian, 2004).

Alkalinity is a measure of the capacity of the water to resist a change in pH that would tend to make the water more acidic (Bates & Vijh, 1973). The alkalinity values recorded ranged from 12.2 mg/l to 39 mg/l. The maximum occurred at Business school (BH026) whiles the minimum occurred at SRC1 (BH021).

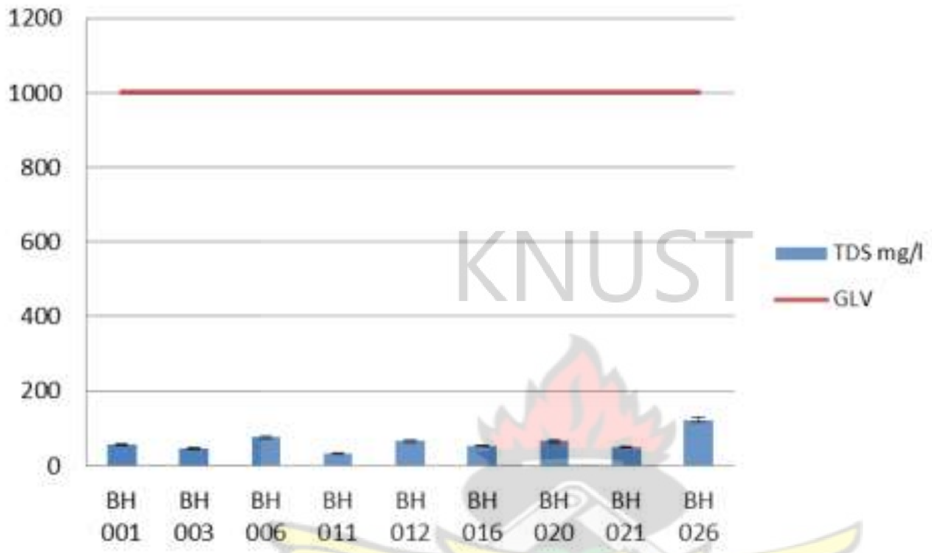

Figure 5.7 Total dissolved solids

Total dissolved solids were measured and compared to the WHO standards for drinking water. The results as shown in Figure 5.7 above, has a maximum level of 123mg/l at BH026.thiss maximum value is however lower than the WHO guideline value of 1000mg/l.

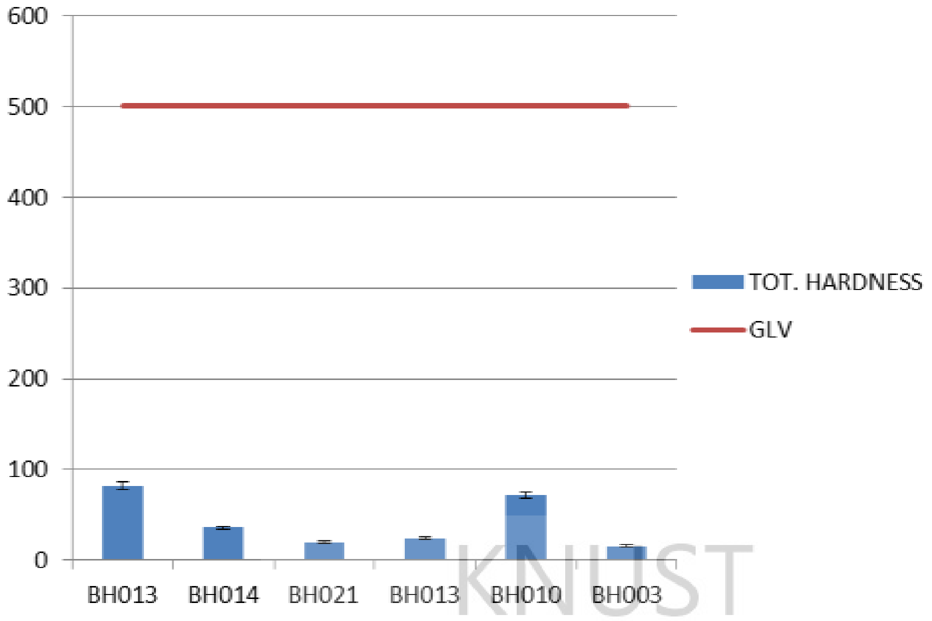

Figure 5.8 Total hardness

The Total hardness levels determined were found to be within the WHO standards range. The highest level was 82 mg/L found at BH013 and the lowest was 16 mg/L found at BH003 as shown in Figure 5.8.

The turbidity of the water points was determined. As shown in Figure 5.9 below, the WHO guideline value of 5 NTU was not exceeded as the maximum recorded was 3.57 NTU at BH021.

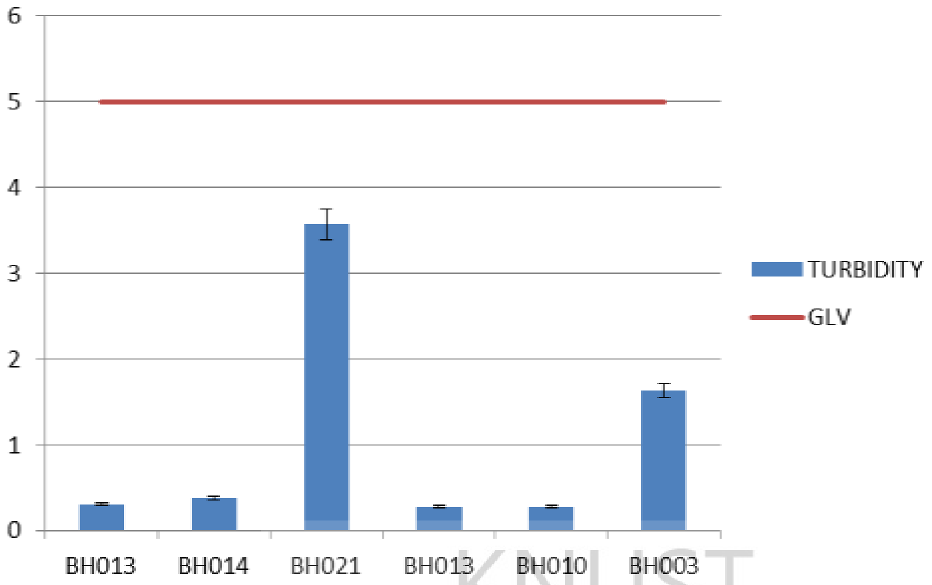

Figure 5.9 Turbidity

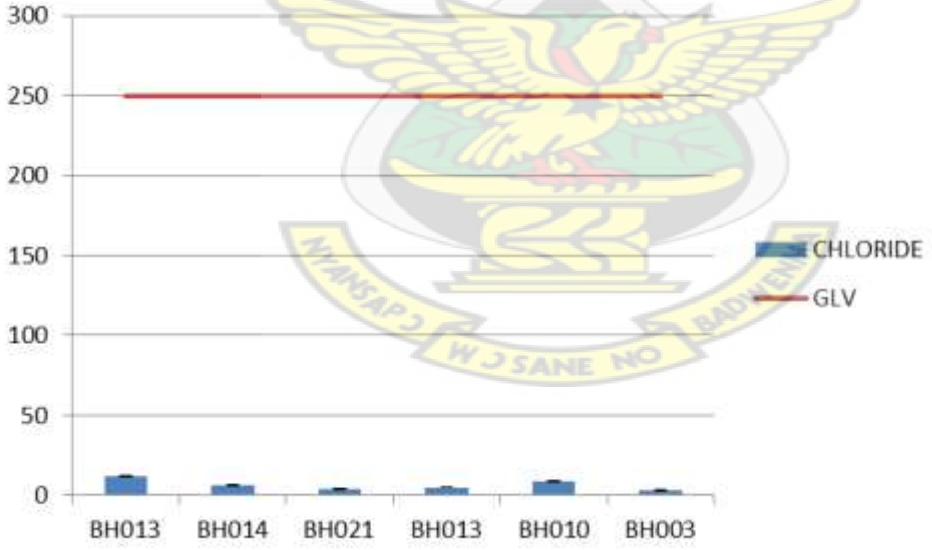

Figure 5.10 Chloride levels

The chloride levels in the water are well within the WHO guidelines as shown in figure 5.10 above. The highest value is 12mg/l which was recorded for the sample from (Queens Hall) BH013 whiles the minimum value of 3 mg/l was measured from BH003 (GUSSS House K-block). The average chloride level in the water was found to be 6.16 mg/l. There are therefore no health concerns from chloride as per the portability of this water since all the levels recorded were within the World Health Organization guideline values.

The physical properties are all within the WHO standards except pH and hence will not pose any health concerns if the boreholes are supplied as portable water

5.3.3 Bacteriological properties.

This is a very important aspect of water quality analysis. Bacteriological species are microscopic hence they cannot be seen in the drinking water. They do not have direct bearing on taste so there is therefore the need for this to be investigated to prevent consumers from acquiring any diseases. The major parameters tested included: total coliform, feacal coliform, E. coli and Enterococci coliform.

The tested water sample did not have E. coli in them. There was not any sample that contained E. coli.

Total coliform levels recorded in the water were above zero, which happens to be the guideline value given by WHO. Any value exceeding this GLV poses a health threat to the consumer. All the values in the samples taken were exceeding this value with an average of 9.4×10^6 cfu/100ml. The maximum Total coliform of 43×10^6 cfu/100ml was recorded at BH022 followed by 24×10^6 cfu/100ml which was recorded at BH021 and BH026. The minimum value was however recorded for the samples from BH006 and BH011 which was 4×10^5 cfu/100ml.

The maximum faecal coliform of 9.3 ×10^6 cfu/100ml was recorded at BH011. The minimum value was however recorded for the samples from BH00, BH012 and BH026 which was 2.3×10^5 cfu/100ml as shown in Figure 5.11.

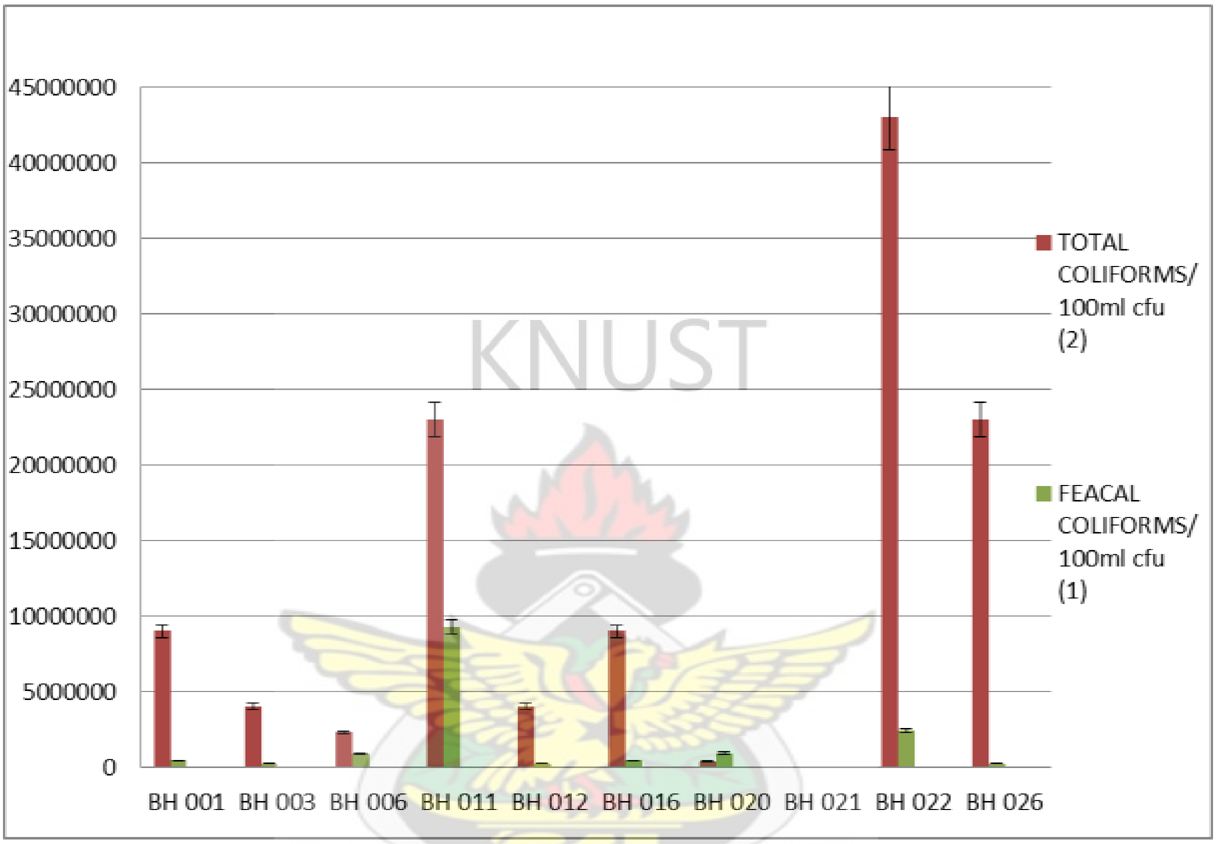

Figure 5.11 Total coliform levels in the water sample

6. CONCLUSIONS AND RECOMMENDATIONS

This chapter of the thesis presents the conclusions drawn from the study and the recommendations proposed.

6.1 Conclusions

Based on the research findings the following conclusions have been made.

- All the known boreholes (27) have been mapped on the KNUST campus map with all their characteristics.
- The internal water supply capacity of KNUST is 74 %. The volume of water available after 18 hours of pumping the boreholes is 2220 cubic metre per day whiles the University needs 3000 cubic metre per day. This leaves the GWCL to supply 780 cubic metres (26 %) of the needed water to KNUST.
- From the research, it was realized that, there are no health concerns from the existing boreholes in terms of Iron, lead, manganese, Arsenic and fluoride since all the water from the borehole points fell within the WHO limits for drinking water.
- The water from the boreholes contained total coliform but however, there were no levels of *E. coli* and pH levels were below 6.5 and this makes the water corrosive for drinking water. This could pose health risks to consumers and therefore disinfection and pH correction is needed to treat the water.

6.2 Recommendation

- There should be a collective effort by the university to chlorinate and distribute the water from the already existing boreholes since it will go a long way to solve the unreliable water supply problem currently in place

- The water quality parameters tested for in this work should be monitored periodically (every 3 to 6 months) by the university development office or those who will be in charge of the water supply so as to ensure that the quality is preserved.
- Since the groundwater will be used for water supply, there should be constant monitoring of the groundwater levels as well as good practices towards groundwater recharge to ensure sustainable abstraction.
- Instead of looking at drilling more boreholes on campus, water reduction measures should be put in place. According to a study by (Odoru-kwarteng *et al*.,2009), there is a potential for reducing the annual water demand by 30.85% through water conservation measures such as retrofitting with water-efficient showerheads and water closets. The payback period for the cost of retrofitting in the study was found to be 6.5 years

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APPENDICES

Appendix 1 Staff residence on campus

SENIOR MEMBERS	**HOUSES**	**PEOPLE**	**TOTAL**
Okodee Road	67	5	335
Buroburo Road	28	5	140
Ridge Road Ext	4	5	20
New Ridge Road	11	5	55
Ridge Road	35	5	175
Allotei Konuah	22	5	110
Link Road	12	5	60
Beposo Flats	6	5	30
Beposo Road	4	5	20
Akurosu Road	11	5	55
Asuogya Road	23	5	115
Ayeduase Road	5	5	25
Warden Close	2	5	10
Indece Hall Road	2	5	10
University Hall Road	4	5	20
Frnr Bungalows	10	5	50
4-Star Bungalows	12	5	60
Guest Flats	16	5	80
Senior Staff			
Primary School Road	12	5	60
A-Line	5	5	25
C-Line	7	5	35
D-Line	5	5	25
Ghana Foreign	20	5	100
Farm Road	16	5	80
Farms Hostel	3	5	15
Terrace	12	5	60
Converted Houses	8	5	40
In-Filling	4	5	20
JUNIOR STAFF			
B- Line	4	5	20
D-Line	25	5	125
D-Line S/D	28	5	140
E-Line	20	5	100
F-Line	79	5	395
F-Line S/D	16	5	80
G- Line S/D	40	5	200
	578		
Total persons			2890

Appendix 2 Water demand

	Population 1	Workers	Consumption (L/C/day	Total (L/day)
Independence hall	1200	21	90	108472.5
Republic hall	1200	25	90	108562.5
Unity hall	1792	20	90	161730
University hall	1200	20	90	108450
Queens hall	1200	20	90	108450
Africa hall	768	20	90	69570
Hall 7	1000	8	90	90180
Gusss hostel	2000	14	90	180315
Credit union	140	12	90	12870
Postgraduate hostel	72	4	90	6570
Spring hostel	20	4	90	1890
RTEP hostel	36	6	90	3375
Steven paris	62	8	90	5760
Great hall	1000		10	10000
Library	200		20	4000
Paa joe	900		30	27000
Knust clinic	60		240	14400
Gaza hostel	432	25	90	39442.5
SRC hostel	1000	8	90	90180
Catholic hostel	200	6	90	18135
Georgia hostel	400	4	90	36090
Crystal rose Hostel	300	5	90	27112.5
Wilkado hostel	116	6	90	10575
Anglican hostel	100	4	90	9090
Royal basin hostel	100	5	90	9112.5
Sun city hostel	360	5	90	32512.5
Knust hospital	360	120	240	93600
Commercial area	400		20	8000
Maintenance department	500		40	20000
Knust printing press	50		40	2000
Knust museum	50		20	1000
Engineering guest house	300		200	60000
Senior staff club	100		90	9000
Sms guest house	250		200	50000
KCCR	20		200	4000
Knust JSS	1000		20	20000
Knust senior high	500		30	15000

Administration	100		40	4000
Knust pool	1000		70	70000
Knust security barracks	500		90	45000
Business School				3600
School of Medical Sciences				10000
College of science				9000
College of Engineering				8000
College of art and sciences				4000
College of architecture				2000
College of Agric. & Natu.				7000
Restaurants	100		120	120000
Laboratories				100000
		370	total daily	1959045
			total daily	1959.045

Appendix 3 Borehole inventory sheet

MSC WATER SUPPLY AND ENVIRONMENTAL SANITATION (2012/2013)

Borehole Data on KNUST Campus

Description
Location
Yield
Depth
Other info

Description
Location
Yield
Depth
Other info

Description
Location
Yield
Depth
Other info

Description
Location
Yield
Depth
Other info

Appendix 4 Coordinates of borehole points

Identity	Latitude	Longitude	Y_Projection	X_Projection
BH001	6.66958898000	-1.57572261000	737450.63120300000	657436.83872600000
BH002	6.66922923000	-1.57475693000	737411.15899400000	657543.71962100000
BH003	6.66939821000	-1.57451369000	737429.92227100000	657570.55835100000
BH004	6.67041519000	-1.57459784000	737542.35154600000	657560.92967200000
BH005	6.67102246000	-1.57576779000	737609.12882700000	657431.38583300000
BH006	6.67061032000	-1.57257470000	737564.57573100000	657784.54611800000
BH007	6.67074954000	-1.57255928000	737579.97542400000	657786.20639500000
BH008	6.67078382000	-1.57238686000	737583.82124400000	657805.25821900000
BH009	6.67233682000	-1.57171564000	737755.76482800000	657878.97102500000
BH010	6.67885199000	-1.56969770000	738476.85127200000	658099.98329500000
BH011	6.67890346000	-1.57271896000	738481.57377800000	657765.94087200000
BH012	6.67110519000	-1.57292683000	737619.18509800000	657745.45616900000
BH013	6.67619057000	-1.57501786000	738180.85039700000	657512.64602900000
BH014	6.67928735000	-1.57423340000	738523.53885300000	657598.38397200000
BH015	6.68069392000	-1.57469055000	738678.92907100000	657547.39210200000
BH016	6.67434680000	-1.56844452000	737979.07502900000	658239.98058400000
BH017	6.67473698000	-1.56722546000	738022.61234700000	658374.63400900000
BH018	6.67313193000	-1.56488221000	737845.88128300000	658634.21968500000
BH019	6.67190013000	-1.56582291000	737709.36743100000	658530.61209900000
BH020	6.67867488000	-1.57477194000	738455.64046400000	657539.03992200000
BH021	6.68114771000	-1.57124961000	738730.21111200000	657927.66990100000
BH022	6.68116649000	-1.57103679000	738732.35606200000	657951.19282100000
BH023	6.67294233000	-1.56800715000	737823.91080200000	658288.78723600000
BH024	6.67375462000	-1.56736108000	737913.94047100000	658359.95566900000
BH025	6.67626240000	-1.56403463000	738192.31859900000	658726.91959700000
BH026	6.66926242000	-1.56830077000	737416.89632800000	658257.50609400000
BH027	6.67500956000	-1.56699386000	738052.82839600000	658400.15196900000

Appendix 5 KNUST Borehole points.