EVALUATION OF BOREHOLE WATER QUALITY IN GASHUA, YOBE STATE, NIGERIA

BY

JOSEPH, Junias Samali
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DEPARTMENT OF CIVIL ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

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ABSTRACT

Water is one of the valuable natural resources whose quality and quantity has vital concern for the human welfare. The study evaluated the water quality (bacteriological and physicochemical parameters) of twenty (20) selected boreholes in Gashua, Yobe State. The percentage (%) efficiency of yield for the twenty (20) boreholes analysed ranges from 16.1% to 99.5%, the least being observed at Takari location (GB19), while the highest at Kabalankara location (GB8); within this range, 85% of the boreholes were producing below 50% efficiency and 15% produce above. The results of the pH values of 20% of the water samples from the boreholes studied ranges from pH 6.50 to 6.82 which are within the NSDWQ maximum permissible limit, while the pH of 80% of the water samples ranges from pH 5.84 to 6.42 which were more acidic and below NSDWQ permissible limit. The heavy metal contamination of water samples shows 100% of the samples contained As, Cd, Hg above, Fe within NSDWQ maximum permissible limits, while Pb was not detected in all the samples analysed. The result of total coliform tests ranges from 0.00 to 4.0 CFU/100ml, which indicated 100% the samples passed NSDWQ maximum permissible limit, while E. coli test result range from 0.00 to 3.0 CFU/100ml from which only 20% of the samples (Takari, Fada, Karamintanda and Yusufari Road) passed the NSDWQ maximum permissible limit. Other physicochemical parameters such as electrical conductivity (EC), total dissolve solids (TDS), total hardness (TH), nitrate (NO_3^-), sulphate (SO_4^-), chloride (Cl^-), Magnesium (Mg) and calcium (Ca) ranges as 0.06 – 0.25 µs/cm; 0.04-0.13 mg/L; 0.72-1.01 mg/L; 1.99-31.55 mg/L; 13.98-37.61 mg/L; 2.07-24.07 mg/L; 0.13-1.06 mg/L and 0.65-2.59 mg/L respectively, all passed the NSDWQ maximum permissible limit. The observed causes of low yield could be due to Hydrogeological, technical/constructional and operations/maintenance factors. Presence of heavy metals and bacteriological contamination could be attributed to the agricultural activities such as irrigation farming which involve use of waste water, chemical fertilizer and other agrochemicals. Traditional potash mining activities which warranted for littered faecal deposits in the area by the miners and the irrigation farmers could be linked to the bacteriological contamination of some of the water samples. The need to deploy expertise by State and local government council in the affected areas will alleviate the situation and adequately supply portable water that can meet the demand of the increasing population of the area.

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ABBREVIATIONS

Abbreviations	**Full Meaning**
WHO	World Health Organization
NAFDAC	National Agency for Food and Drug Administration and Control
NSDWQ	Nigerian Standard for Drinking Water Quality
NGO	Non-Governmental Organization
TSS	Total Suspended Solids
TDS	Total Dissolved Solids

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Water may be found practically everywhere beneath the earth's surface, including hills, mountains, plains, and deserts. It's not always available or fresh enough to use without treatment, and it might be difficult to find, quantify or explain. This water may exist close to the land surface as in a marsh or it may lay several hundreds of feet beneath the ground surface as in some desert parts. Water at a modest depth may be just a few hours old; at moderate depth it may 100 years old; and at extreme depth or after having flowed considerable distances from entry, water may be several thousands of years old.

Groundwater is held in aquifers, which move slowly through moderately permeable rocks. The word aquifer is derived from the Latin words aqua, which means water, and ferre, which means to bear or carry. Aquifers are subsurface reservoirs that carry water. Aquifers can be a layer of gravel or sand, a sandstone or cavernous limestone layer, a ruby top or base of lava flows, or even a vast body of huge rock like granite. (USGS, 2018). Water is one of the most valuable natural resources, and its quality and quantity are critical to human well-being. Groundwater is the primary supply of water for agricultural, industrial, and domestic use. Groundwater availability is determined by the nature of rocks and their water-bearing properties. Ground water is a vital natural resource that contributes to human health, economic development, and ecological function. Many African people are heavily reliant on groundwater. Surface water exploitation has decreased, resulting in a greater reliance on groundwater abstraction as a result of rising pollution and rising water treatment costs (Kortatsi, 2007). About 65 percent of Nigeria's overall population relies largely on groundwater for drinking (Edmunds *et al.*, 1987).

Quality should be defined as how well a water supply meets the needs of the intended user, and it must be evaluated based on its suitability for the intended application (Ayers and Wertscot,1985). The suitability of water for usage is the focus of its quality. If the water quality is good and the soil and management conditions are right, maximum yields can be achieved.

The kind and concentration of dissolved minerals determine the suitability of water for diverse purposes, and groundwater has a higher mineral content than surface water (Mirribasi *et al.,* 2008). Groundwater assessment for drinking and irrigation has become necessary and important task for present and future groundwater quality management. Nowadays, a lot of studies have focused on groundwater quality monitoring and evaluation for domestic and agricultural activities around the world (Mitra *et al.*, 2007; Hakim *et al.*, 2009). The water is deemed to be contaminated when the heavy metals surpass the maximum permitted concentration for drinkable water (Izah and Ineyougha, 2015). Water is life, and it is necessary for all forms of life on the planet. Drinking water as well as water for industry, agriculture and a variety of other uses is a requirement (UNESCO, 2012)

Water supply of sufficient quality has been a source of concern since the dawn of civilization. Groundwater withdrawal in the Lake Chad Basin of Nigeria was only possible until the 1920s using traditional methods such as unlined wells dug by the locals. However, because practically all unlined wells dried up due to water table depletion, this source was insufficient to meet the needs of the study area's population. Groundwater development began in the 1920s as a result of the unreliability and challenges of the conventional sources experienced by the residents of the area, inside the underlying aquifers, boreholes were bored to varying depths (Ndubuisi, 1990).

With the founding of the Chad Basin Development Authority (CBDA) in the 1970s, more mining of these aquifers has continued. Boreholes are currently being sunk by a number of additional entities, including the Agricultural Development Programme, local governments, individuals, NGOs, and private corporations (Ndubuisi, 1990). Groundwater development looks to be the most important water resource development technique in Nigeria's arid zone. This is due to the apparent lack of perennial streams and the hot heat that characterizes the area, both of which may have a negative impact on other water resource development efforts. Hundreds of boreholes and wells have been sunk to tremendous depths to tap groundwater as a result of this. Groundwater development in Nigeria's Arid Zone has created certain environmental issues throughout the years, similar to surface water development. Groundwater development in this area has resulted in groundwater abstraction exceeding recharge. Continued abstraction through recharge boreholes may result in the complete depletion of groundwater resources, putting people in the Arid Zone who rely on groundwater in jeopardy. Aquifer capacity may be reduced as a result of ongoing abstraction over a lengthy period of time, in addition to the apparent fall in the groundwater table. Thus, studies on the qualitative and quantitative evaluation of boreholes performance is necessary if the water supply demand is to be met sufficiently.

1.2 Statement of the Research Problem

Groundwater development looks to be the most important water resource development technique in Nigeria's arid zone, particularly in Yobe State. Groundwater is mostly used for home and agricultural purposes, and is accessed by boreholes and hand dug wells, which are usually drilled in villages and around oases. This is due to the apparent lack of perennial streams and the hot heat that characterizes the area, both of which may have a negative impact on other water resource development efforts. Hundreds of boreholes and wells have been sunk to tremendous depths to tap groundwater as a result of this. Abubakar *et al.* (2014) evaluated the performance of boreholes within Maiduguri metropolis observed the increase in boreholes sinking with observed failures due hydrogeological, technical/constructional and operational/maintenance factors as causes of the failures, (Sobowale, 2003) evaluated the performance of water supply boreholes in Nguru, Nigeria, the study revealed that the boreholes could guarantee future supply of water; however urgent steps that need to be taken to stem the increasing reduction in groundwater levels which could be attributed to reduction in groundwater recharge. Within the states of Borno and Yobe, almost 2,000 boreholes have been sunk and operated (Bunu, 1990). Many agencies are still drilling and operating many more. In general, there is a high rate of abstraction without corresponding recharge. Due to a general decrease in rainfall in the area, groundwater has been over-exploited, and the accessible groundwater resource is diminishing. Borehole water levels have dropped, and borehole yields have plummeted in recent years. The management of groundwater must be done in a methodical manner. Any physical, chemical, or bacteriological contaminants should be removed from the water. However, regardless of the yield accessible for usage, water is not always determined to be pure. Drinking water quality standards were established for this reason, to assure the safety of drinking water sources and the protection of public health. This is especially relevant currently, because the chemical quality of drinking water has worsened significantly in recent years due to the presence of hazardous substances, which can cause substantial health problems even in trace amounts (Ikem *et al.,* 2002). Results showed non-compliance of the bacteriological parameters to WHO and NSDWQ. This could be attributed to the activities going on in this area with respect to the presence of large-scale upland and irrigated farm land which may introduce leaching fertilizer into the river, as well as presence of traditional potash mining sites. As a result, it is critical to guarantee that people have access to portable water for domestic and agricultural use. The word "water quality" has often been used interchangeably with "quantity." For the demand for water for drinking, irrigation, and other domestic purposes to be met adequately, water quality (free of contamination) is critical. The water demand would have been fulfilled significantly if the source of groundwater matched the standard recommendations in terms of quality and provided the yield for which it was planned. As a result, the purpose of this study is to examine the groundwater water quality and yield from a few selected boreholes inside the study region, as well as to determine the area's water demand.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the study

The aim of the study is to evaluate borehole water quality within Gashua, Yobe State Nigeria.

1.3.2 Objectives of the study

In order to achieve the aim highlighted above the following objectives have been set out

I. To examine the physico-chemical and bacteriological parameters of selected boreholes in Gashua and compare them with NSDWQ standard limit.

AI. To deduce the water yield of the selected boreholes and estimate the efficiency of the boreholes from their design yield.

1.4 Justification of the Study

The research will aid in the development of more boreholes for household and agricultural production. Options for beneficial use to accelerate returns on investment would be provided if justified, in order to create opportunities. This information will also be useful to policymakers, scientists, and environmentalists in Nigeria's North East region, notably in Gashua, Yobe State. The study's findings can also be used as a guide for future borehole testing and water quality assessments in the area.

1.5 Scope of the Study

The study shall be limited to selected boreholes in Gashua Yobe State Nigeria. Prior to in situ data collection and experimental assessment, primary data will be collected from the Yobe State Water Corporation and interview of managers/operators of the selected boreholes.

CHAPTER TWO

2.0 LITERATURE REVIEW

Water is life, as the adage goes, and it is widely acknowledged as the most vital natural resource on the planet. The significance of water is so high that the following statements have been made in support of it:

i. Living things depend on water but water does not depend on living things; it has a life of its own (Pielou, 1998).

ii. Water is an integral part of the natural environment and the habitat for many forms of life, be it human, animal and plant (Opoku-Agyemang, 2005).

iii Water is earth's eye, looking into which the beholder measures the depth of his own nature (Thoreau, 1854).

As a result, the value of water on Earth is undeniable for humans, and its demand is growing every day, water is becoming increasingly scarce in many places of the world (Sandwidi, 2007). Water is the second most important essential for human life, behind air. Water is so important in human life that the establishment of any city in the world has almost always occurred near a source of water (Rangwala, 2011). He goes on to say that water is nature's free gift to humanity, and its availability in many forms such as rivers, lakes, streams, solid, liquid, and gas is essential for human comfort, luxury, and other life essentials.

2.1 Boreholes

A borehole is a narrow shaft drilled vertically or horizontally into the ground. A borehole can be dug for a variety of reasons, including the extraction of water, other liquids (like petroleum), or gases (like natural gas), as part of a geotechnical investigation, environmental site assessment, mineral prospecting, temperature measurement, as a pilot hole for laying piers or underground utilities, for geothermal projects, or for storing undesired substances underground, such as carbon and storage. A borehole is a hole made in the earth, usually vertically, to deliver groundwater to the surface, according to a Groundwater Engineer (Todd, 1923). Pumps are required in boreholes until the water pressure is sufficient to propel it to the surface, resulting in a flowing artesian (Todd, 1923; Bunu 1990) defined a borehole as a hole drilled with mechanically operated percussive or rotary tools for the aim of exploring groundwater. Borehole is also defined as a hydraulic structure that, when properly designed and constructed, allows for the cost-effective drawing of water from an aquifer; it is a narrow well drilled with a machine, more expensive than hand-dug wells, but deeper and more reliable (Nazir,1979; Sanyaolu,1991).

Borehole is a word used by engineers and environmental consultants to denote all of the different types of holes dug as part of a geotechnical investigation or environmental site evaluation (or so-called Phase II ESA). This comprises advanced sampling equipment, water samples, and rock Borehole samples are frequently analysed in the lab to identify their physical qualities or to evaluate quantities of various chemical elements or pollutants.

A vertical pipe casing and well screen are typically installed to keep a borehole from caving when it is used as a water well. This also helps to prevent surface contaminants from entering the borehole and protects any installed pump from drawing in sand and sediments.

2.2 Borehole Yield

The problem of water shortages in north-eastern Nigeria has created severe concerns about the resource's long-term viability. Uncoordinated large-scale surface water development upstream of the area has been widely reported, with far-reaching implications for groundwater recharge.

Sobowole (2003) used the Step Draw down test method to examine the performance of ten (10) water supply boreholes dug in the quaternary strata of the Chad Formation at Nguru, Nigeria. Regression approaches were used to determine specific capacity, aquifer loss and well loss, well efficiency, and transmissivity. The results of the testing revealed that the wells' efficiency ranged from 51.1 percent to 89.1 percent when utilized as performance criteria, demonstrating that the boreholes are productive and perform well. The borehole with the lowest transmissivity of 13 m^2/day had the maximum drawdown of 24.56 m. The study found that boreholes could ensure future water supply; however, immediate action is required to prevent the further decline in groundwater levels, which could be attributable to a decrease in groundwater recharge.

Ale *et al.* (2015) conducted pumping experiments on twenty selected boreholes and five hand-dug wells cut across the Ado Ekiti Metropolitan (AEM) area in order to determine the wells' production. A constant rate pumping test was performed, as well as a recovery method test. Borehole depths range from 40 to 120 meters, while hand-dug well depths range from 3 to 15 meters. Borehole yields in the AEM region ranged from 0.267 to 2.0 litres per second. The yield was influenced not only by the depths, but also by factors like porosity and permeability.

Abubakar *et al.* (2012) conducted research aiming at evaluating the performance (yield) of a few selected boreholes in the Maiduguri metropolitan area, as well as analysing (identifying) the factors that contribute to poor yield and borehole failures. In the study region, a total of fifty (50) boreholes were chosen. The research comprises determining the general performance of the selected boreholes, as well as assessing and studying the possible causes of their abandonment and/or poor performance at various sites. The results showed that 64% of the boreholes were productive, whereas 36% were abandoned. It was also discovered that the productive ones performed at a rate of more than 50%.

Hydrogeological, technical/constructional, and operations/maintenance issues all contributed to the recorded failures. Suggestions were made based on the findings in order to give long-term remedies to the problems so that supply can meet the demand of an expanding population as well as industrial and agricultural expansion.

2.3 Water Quality

Water consumers expect it to be both visually appealing and safe to drink. That is, water supplied for home use must meet some fundamental conditions (potable and wholesome) to ensure that the water ingested is free of public health hazards. (Bartram & Ballance, 1996). The goal of purifying domestic water or waste is not to make it physically or chemically pure, but to eliminate harmful bacteria, poisonous compounds, and excessive organic matter to levels that are safe for humans and crops when used in agriculture.

Water quality is difficult to define because it is dependent on the intended application. There are a variety of methods for determining water quality, each of which measures a different water parameter and varies in precision, speed, and cost (Dojlido & Zerbe, 1998) The cost and complexity of determining water quality in real time are prohibitive. Water purity is also an important component in the economy and agriculture (Blignaut & van Heerden, 2009). Poor water quality, for example, has an impact on crop quality (Ratajkiewicz, 2007; Woźnica & Waniorek, 2008). Water supply has been reported to be diminishing in recent years, making fresh water limited.

Water scarcity has become a global issue that is only getting worse with each passing day. Many parts of the world's water resources are insufficient to meet needs for food and fibre, as well as municipal, industrial, and environmental applications. Even countries with abundant water resources may be forced to deal with regional or temporary water shortages. The world's arid and semi-arid regions are suffering from the most severe water scarcity. It has been demonstrated elsewhere that science and technology development, particularly soft technologies, will be critical in helping countries and regions that are or will be water-short to manage more severe scarcity (Vaux & Jury, 2004).

2.4 The Water Quality Assessment Process

Water quality assessment refers to the total process of evaluating the physical, chemical, and biological characteristics of water, whereas water quality monitoring refers to the gathering of pertinent data. The practical guide by Bartram and Balance (1996) contains details on monitoring methods and approaches that can be used in the field

2.4.1. Monitoring, survey and surveillance

The necessity to verify whether the observed water quality is adequate for intended usage has traditionally been the main rationale for environmental water quality evaluation. Monitoring has also evolved to aid in determining trends in the quality of the aquatic environment, as well as how contaminants, other anthropogenic activities, and/or waste treatment operations affect that quality (impact monitoring). Monitoring to evaluate the background quality of the aquatic environment is now commonplace, as it allows for comparison with impact monitoring. It's also used to see if any unexpected changes are occurring in otherwise clean environments, such as through the long-range transfer of contaminants in the atmosphere (note, however, that natural water quality is very variable depending on local conditions). The table 2.1 shows the general definitions for several types of environmental observation programs that can be changed and interpreted for aquatic situations:

Table 2.1: General definitions of environmental observation programmes

Term	Definition
MONITORING	Long-term, standardized measurements and observations of the aquatic environment to determine status and trends
SURVEY	For a specified objective, a finite-duration, intensive program to assess and observe the quality of the aquatic environment.
SURVELLANCE	For the purposes of water quality management and operational efficiency, continuous, specific measurement and observation are required.

(Source: Helmer, 1994)

These several definitions are sometimes confused, and all three might be referred to as monitoring because they all entail the gathering of data at predetermined locations and times. They do, however, differ in terms of their primary application in the water quality evaluation procedure.

2.4.2 Water quality assessment needs.

No assessment program should begin without a thorough examination of the true need for water quality data (i.e., the "need to know" as opposed to "good to know"). Because water resources are often put to multiple competing beneficial purposes, the monitoring that is employed to gather data should match the data requirements of the various users involved (Helmer, 1994).

As a result, depending on how many evaluation objectives must be satisfied, there are two types of monitoring programs:

i. Single-objective monitoring, which can be set up to focus on a single issue. pH, alkalinity, and a few cations for acid rain; nutrients and chlorophyll pigments for eutrophication; various nitrogenous compounds for nitrate pollution; or sodium, calcium, chloride, and a few other elements for irrigation.

ii Multi-objective monitoring which may cover various water uses and provide data for more than one assessment Programme, such as drinking water supply, industrial manufacturing, fisheries or aquatic life, thereby involving a large set of variables.

The Commission of the European Communities has a list in excess of 100 micro-pollutants to be considered in drinking water alone.

2.5 Groundwater

Since the dawn of time, water from underneath the ground has been used for domestic purposes, cattle, and irrigation. Although the exact nature of its occurrence was not fully known at the time, successful techniques of getting the water to the surface were discovered, and groundwater utilization has steadily increased since then. However, the importance of groundwater in the freshwater component of the hydrological cycle is frequently neglected. Groundwater is by far the most important component, accounting for roughly two-thirds of the world's freshwater resources and virtually all usable freshwater if the polar icecaps and glaciers are excluded. Even if only the most active and accessible groundwater sources are considered, estimate by Lvovich, (1972) has it to be 4106 km^3, they still account for 95% of total freshwater. 3.5 percent is made up of lakes, marshes, reservoirs, and rivers, whereas just 1.5 percent is made up of soil moisture (Freeze & Cherry, 1979). Groundwater resources play a significant role in human existence and economic activity, and their use and conservation are consequently critical. It's easy to overlook the significance of groundwater in water sources. Table 2.2 shows the relative abundance of the constituents dissolved in groundwater, and Table 2.3 shows a review of the natural sources and concentration ranges of the primary constituents of groundwater.

Table 2.2: Relative abundance of dissolved constituents in groundwater

Major constituents (1.0 to1000 mgl^{-1})	Secondary constituents (0.01 to 10.0 mgl^{-1})	Minor constituents (0.0001 to 0,1 mgl^{-1})
Sodium	Iron	Arsenic
Calcium	Aluminium	Barium
Magnesium	Potassium	Bromide
Bicarbonate	Carbonate	Cadmium
Sulphate	Nitrate	Chromium
Chloride	Fluoride	Cobalt
Silica		Copper
		Iodide
		Lead
		Lithium
		Manganese
		Nickel
		Phosphate
		Strontium
		Uranium
		Zinc

(Source: Todd, 1980)

Table 2.3: Sources and concentrations of natural groundwater components

Components	Natural Sources	Concentration in Natural water
Dissolved solids	Mineral constituents dissolved in water	Usually < 5000 mgl^{-1}, but some brines contains as much as 300,000 mgl^{-1}
Nitrate	Atmosphere, legumes, plant debris, animal excrement	Usually < 10 mgl^{-1}
Sodium	Feldspars (albite), clay minerals, evaporates such as halite, Nacl, industrial wastes.	Generally < 200 mgl^{-1}, 10000 mgl^{-1} sea water , 25,000 mgl^{-1} in brines
Potassium	Feldspars (orthoclase, microcline), feldspathoids, some micas, clay minerals	Usually < 10 mgl^{-1}, but up to 100 mgl^{-1} in hot springs and 25,000mgl^{-1} in brines
Calcium	Amphiboles, feldspars, gypsum, pyroxenes, dolomite aragonite, calcite, day minerals	Usually < 100mgl^{-1}, but brines may contain up to 75,000 mgl^{-1}
Magnesium	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals	Usually < 50 mgl^{-1}, about 1000 mgl^{-1} in ocean water, brines may 57,000 mgl^{-1}
Carbonate	Limestone, dolomite	Usually < 10 mgl^{-1}, but can exceed 50 mgl^{-1} in water highly charged with sodium
Bicarbonate	Limestone, dolomite	Usually < 500 mgl^{-1}, but can exceed 1000 mgl^{-1} in water highly charged with CO_2
Chloride	Sedimentary rock (evaporates), a little from igneous rocks	Usually < 10 mgl^{-1} in humid areas: up to 1000 mgl^{-1} in more arid regions: approximately 19,300 mgl^{-1} I sea water and up to 200,000 mgl^{-1} in brines
Sulphate	Oxidation of sulphide ores, gypsum, anhydrite	Usually < 300 mgl^{-1}, except in wells influenced by acid mine drainage: up to 200,000 mgl^{-1} in some brines
Silica	Feldspars, ferromagnesian and clay minerals, amorphous silica, chert and opal	Ranges from 1-30 mgl^{-1} but as much as 100 mgl^{-1} can occur ad concentrations may reach 4,000 mgl^{-1} in brines
Fluoride	Amphiboles(hornblende), apatite, fluorite, mica	Usually < 10 mgl^{-1},but up to 1,600 mgl^{-1} in brines
Iron	Igneous rocks: amphiboles, ferromagnesian micas, FeS, Fes2 and magnetite, Fe2O3. Sandstone rocks: oxides, carbonates, sulphides or iron clay minerals	Usually < 0.5 mgl^{-1} in fully aerated water, groundwater withy pH <8can contain 10 mgl^{-1}; Infrequently, 50 mgl^{-1} may be present
Manganese	Arises from soils and sediments. Metamorphic and sedimentary rocks and mica biotite and amphibole hornblende minerals contain large quantities of Mn	Usually < 0.2 mgl^{-1} contains >10 mgl^{-1}

(Source: Todd, 1980)

2.5.1 Physical characteristics of groundwater

The temperature of ground water is recorded in degrees Celsius in physical analysis and must be determined immediately after collecting the sample. Groundwater colour can be caused by mineral or organic materials in the solution and is measured in milligrams per litre (mg/l) in contrast to reference solutions. Turbidity refers to the amount of suspended and colloidal stuff in water, including clay, silt, organic materials, and microscopic organisms. Measurements are frequently made based on the length of the light path through the water, which simply causes the image of a typical candle flame to vanish. Unconsolidated aquifers can create murky groundwater due to natural filtering. Bacteria, dissolved gases, mineral debris, and phenols are all possible sources of flavour and odour. These features are subjective experiences that can only be described in terms of a human's experience. The highest degree of dilution that can be differentiated from flavour and odour free water has been created as a basis for quantitative taste and odour determination. (Todd, 1980).

2.5.2 Chemical characteristics of groundwater

Because groundwater is frequently associated with geological materials containing soluble minerals, larger dissolved salt concentrations are typically expected in groundwater compared to surface water. The geological environment, as well as the source and transport of water, influence the kind and concentration of salts. The following paragraphs describe the primary ways in which groundwater's natural properties affect water quality for various purposes. Groundwater is classified as meteoric, connate, or juvenile using a basic hydro-chemical categorization. The most important type of groundwater is meteoric groundwater, which is produced by rainfall and infiltration within the regular hydrological cycle and subjected to hydro-chemical evolution. Groundwater's natural chemical quality is generally satisfactory, although high concentrations of a number of elements can pose difficulties with water consumption (Todd, 1980).

2.5.3 Biological characteristics of groundwater

Microbiological processes, which can change both inorganic and organic constituents of groundwater, can influence groundwater quality both directly and indirectly. Geochemical processes are generally accelerated by these biological reactions (Chapelle, 1993). Single and multicellular organisms have evolved to use dissolved and suspended materials in water, as well as solid stuff in the aquifer, in their metabolism, and subsequently release the metabolic products back into the water (Matthess, 1982). There is virtually no geological region on or near the earth's surface where the pH and Eh conditions do not sustain organic life in some way (Chilton & West, 1992). In addition to bacteria that tolerate pH and Eh extremes, there exist microorganisms that prefer low temperatures (psychrophiles), some that prefer high temperatures (thermophiles) (Ehrlich, 1990), and still others that prefer high pressure (Ehrlich, 1990). Warm, humid weather, on the other hand, are often the most physiologically favourable settings.

Microorganisms have no effect on the direction of reactions defined by the system's thermodynamic limitations, but they do have an impact on their rate. Sulphides, for example, can be oxidized without microbial assistance, but microbial processes can dramatically accelerate oxidation to the point where, given ideal moisture and temperature circumstances, sulphides can be oxidized in minutes. Most organisms require oxygen for respiration (aerobic respiration) and the decomposition of organic matter, however certain bacteria can utilise substitutes such as nitrate, sulphate, and carbon dioxide when oxygen levels are low (anaerobic respiration). Facultative anaerobes are organisms that can exist in the presence of oxygen (or without it). As a result, the presence or lack of oxygen is one of the most critical, but not the only, factors affecting microbial activity. Nutrients must be delivered in an optimal mix to allow an organism to grow and proliferate, meeting carbon, energy, nitrogen, and mineral requirements (Ehrlich, 1990).

2.6 Measuring Water Quality

Water can be tested for thousands of different elements or agents, but most drinking water regulations only cover roughly 100 of them. The US Environmental Protection Agency (USEPA) and the American Public Health Association (APHA) have classified the criteria for private wells into the following categories: microbiological, inorganic (IOCs), secondary contaminants, volatile organic chemicals (VOCs), and synthetic organic chemicals (SOCs), and radio-nuclides, i.e., radio-active substances. The Nigeria Standard for Drinking Water Quality (NSDWQ) and National Agency for Food and Drug Administration and Control (NAFDAC) have adopted the WHO water quality guidelines categorization. Microbiological (Total coliform, faecal coliform, and E coli) and physicochemical parameters may be included in drinking water (temperature, colour, and turbidity, and dissolved oxygen level, concentration of organic and inorganic compounds).

Table 2.4 shows the drinking water quality criteria established by the WHO in 2006 and the Nigeria Standards for Drinking Water Quality (NSDWQ) in 2010. These rules were put in place primarily to protect people's health. The rules, on the other hand, take into account the psychological influence and aesthetic aspect of drinking water, such as the objection of water due to colour or odour or turbidity.

Table 2.4: Drinking Water Quality Guidelines for the WHO, NAFDAC and NSDWQ

	WHO		NAFDAC	NSDWQ
	Highest Desirable	Maximum Permissible level		
Temperature(^{0}C)	-	40	-	Ambient
Colour (TCU)	6	15	15	15
Turbidity (NTU)	5	25		5
pH	7.0-8.5	6.5-9.2	6.5-8.5	6.5-8.5
Total dissolved solids(mg/L)	500	1500	500	500
Iron(mg/l)	-	0.3	-	0.3
Chloride(mg/L)	-	250	-	250
Fluoride(mg/L)	-	1.5	-	1.5
Total hardness (mg/L)	-	500	-	500
Sulphate(mg/L)	-	100	-	100
Nitrate(mg/L)	-	50	-	50
Faecal coliform (per 100ml)	-	0	0	0
E.coli (per 100ml)	-	0	0	0
Total coliform count (per 100ml)	-	0	10	10

WHO (2004) - World Health Organization

NAFDAC (2008) - National Agency for Food and Drug Administration and Control NSDWQ (2007) - Nigerian Standard for Drinking Water Quality

2.6.1 Microbiological parameters

Bacteria, protozoa, and viruses are examples of microbiological agents found in water. Because of unique health risks and the development of illness, microbiological pollutants are categorized as primary drinking water standards. Because testing for specific microbiological agents can be expensive, most drinking water guidelines rely on coliform bacteria as a contaminant indicator (Brian, 2012). Coliforms are rod-shaped, non-spore-forming, gram-negative bacteria that can proliferate in the presence of bile salts or other surface-active substances, according to the World Health Organization (2008). Continuing, coliforms are cytochrome-oxidase negative and capable of fermenting lactose at 35 or 37 °C with the generation of acid, gas, and aldehyde in 24 to 48 hours, according to the definition. The total coliform group is the most inclusive indicator classification, and pollution indicated by total coliforms is symptomatic of insufficient drinking water disinfection (Hach, 2000).

2.6.1.1 T*otal coliform*

These microorganisms may be easily analysed by certified laboratories and utilized as a microbiological indicator of your water's quality. If these bacteria are not present in your water, e.g., absent or less than one colony per 100 ml, this should be taken to suggest that the water does not contain a microbiological agent that could cause a health hazard. If the bacteria are present in your water, as indicated by a result of Present or 1 or more colonies per 100 ml, it is more likely that the water includes a microbiological agent that could cause a health risk, and that action is required (Brian, 2012).

2.6.1.2 F*aecal coliform*

This is a type of total coliform bacteria that is more commonly found in the excrement of warm-blooded animals, but can also be found in the faeces of non-mammals and insects. Faecal coliform bacteria should not be found in your drinking water, with a desirable result being absent or less than one colony per 100 ml.

2.6.1.3 E*scherichia coli (E. coli.)*

This is the most prevalent bacterial strain found in humans and animals. E. coli is the most reliable coliform indication of faecal contamination from human and animal waste. 90% to 100% of the coliform organisms isolated from human and animal faeces are E. coli. The number lowers to 59 percent in sewage and contaminated water samples. The presence of this group of bacteria would indicate that the source is human or mammalian waste, and an appropriate result would be Absent or less than one colony per 100 ml (American Public Health Association, 1992).

According to (Brian, 2012), if the results indicate the presence of total coliform bacteria, faecal coliform bacteria, and/or E. coli, it is more likely that a pathogen is present in your drinking water. A fourth, hydrogen sulphide production, has lately been advocated and used.

2.6.2 Physico-chemical parameter

2.6.2.1 C*olour*

The colour standard set by the United States Environmental Protection Agency (USEPA) is 15 colour units. Individuals tend to be able to discern a visual change in the appearance or tint of the water at this level on the colour scale. Increased amounts of dissolved organic material, such as tannins, corrosion by-products, and foaming agents, can be detected by colour (Brian, 2012).

Drinking water colour can have an aesthetic impact and be rejected by consumers. A spectrophotometer is used to determine it (Hach, 2000).

2.6.2.2 T*emperature*

Other factors like as conductivity and dissolved minerals may be affected by temperature, depending on whether it is high or low. It has an impact on the reaction rates and solubility of compounds in water. Temperature meter is used to determine it (Hach, 2000). Warm water is often less appealing than cool water.

2.6.2.3 C*onductivity*

The ability of water to conduct electric current is measured by its conductivity. It is proportional to the water's total dissolved salt concentration. Because salts dissolve into positive and negative ions and can conduct electric current proportional to their concentration, this is the case. A conductivity meter is used to measure it in micro Siemens per centimetre (S/cm) (Hach, 2000). Conductivity may be influenced by human activity. The presence of nitrate and phosphate in sewage and farm runoff can cause conductivity to rise. Salt and other elements that contribute ions to water can be carried by runoff from highways. For drinking water, the WHO (2006) recommends a conductivity threshold of 300 S/cm.

2.6.2.4 T*he* p*H*

The **pH** of water is a very important measurement concerning water quality. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). pH also determines whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. pH has an indirect effect on human health. Extreme exposure of pH has been associated with eye irritation and exacerbation of skin disorder (WHO, 1993; 2004).

It is a measurement of the water's acidity or alkalinity. The pH of most drinking water falls between 6.5 and 8.5. (WHO, 2004). It is one of the most significant operational water quality indicators, and it usually has little direct impact on consumers (WHO, 2006). The pH of a freshwater aquatic system is usually between 6 and 9. The presence of biological life in waters within this pH range is a sign of the presence of biological life, as most live organisms flourish in a very narrow and crucial pH range. Because aqueous chemical equilibriums invariably involve hydrogen ions, the pH of water is related to practically every other water quality measure in a variety of ways (WHO, 2006). The discharge of acidic water into these sources by agricultural and domestic activities is blamed for the low pH of the water sample. Ca_2^+ and HCO_3 predominate in 98 percent of all world groundwater, owing to limestone weathering in catchments and subterranean beds (Brian, 2012).

Despite the fact that pH has no direct impact on human health, all biological reactions are sensitive to changes in pH. The pH value of 7.0 is considered the best and optimal for most reactions and human beings. Metals can dissolve into ions depending on the pH and, in some cases, the temperature of the water. A pH meter is used to determine it.

2.6.2.5 T*otal dissolved solids (TDS)*

The entire amount of dissolved substances in a water sample is measured by total dissolved solids (TDS). It isn't a precise measurement of a particular element or pollutant. TDS levels beyond a certain threshold are linked to increased water hardness, chemical deposits, corrosion by-products, discoloration, and salty bitter tastes. If the TDS level in the water is high, the first step is to test it for other parameters including total hardness, iron, manganese, sodium, chloride, sulphate, alkalinity, and nitrate to ascertain the nature of the water quality issue. Salts are chemical compounds found in natural waters that are made up of anions such carbonates, chlorides, sulphates, and nitrates (mostly in ground water) and cations like potassium, magnesium, calcium, and sodium. It comes from a variety of places, including natural sources, sewage, urban run-off, and industrial waste water. Due to changes in mineral solubility, its concentration in water varies significantly between geological locations. Milligrams per litre (mg/l) is the unit of measurement (Hach, 2000; WHO, 2006).

The TDS test indicates whether or not there is a risk of water quality issues (Brain, 2012). According to (WHO, 2006), no adverse physiological effects have been reported in those who consume drinking water with TDS levels above 1000 mg/l. The WHO, on the other hand, advises a low level of the latter as a TDS guideline value. A critical TDS value of 2450 mg/l was found by Kempster *et al.* (1997), over which some long-term health concerns could be expected due to high dissolved particle concentrations in drinking water.

2.6.2.6 T*otal suspended solids*

Algal matter or non-algal matter, such as finely powdered calcium carbonate particles from limestone, can be found in total suspended solids (TSS). Depending on the source, these compounds can change the colour of the water in a variety of ways. A spectrophotometer is used to determine it (Hach, 2000).

2.6.2.7 C*hloride*

Chloride is found as a metallic salt in all drinking water supplies and sewage. Chloride has a USEPA Secondary Maximum Contaminant Level (SMCL) of 250 mg/l and a WHO recommended value of 250 mg/l. The criterion was established due to potential aesthetic issues related with the water's taste, as well as the fact that excessive levels can enable pipeline and fixture corrosion (Brian, 2012). Chlorides are found naturally in the environment, but they can also be present in septic system effluent, storm water runoff, brine water, cleaning solutions, and other industrial solutions at higher quantities. Precipitation titration is used to determine its concentration in water (Hach, 2000; WHO, 2006).

2.6.2.8 T*otal hardness*

Dissolved calcium and, to a lesser extent, magnesium salts cause total hardness in water. The equivalent concentration of calcium carbonate ($CaCO_3$) per litre of water is reported as the hardness of the water, while the actual test measures calcium, magnesium, manganese, iron, and other multivalent positively charged ions. Individuals often report aesthetic issues with the water when the overall hardness exceeds 160 mg $CaCO_3$/l, however corrosion issues could be linked to water with very low water hardness (Brain, 2012).

Hardness above 200 mg/l, depending on pH and alkalinity, can cause scale deposition, especially when heated. Titration with EDTA (Ethylene diamine tetra-acetic acid) is used to determine it (WHO, 2006). Water with less than 75 mg/l CaCO3 is considered soft, and water with more than 150 mg/l is considered hard. Appiah and Momende (2010) found that the total hardness of water from hand-dug wells ranged from 38.7 to 259 mg/l. Most of the hand-dug wells had less than half of the WHO maximum permissible value of 500 mg/l.

2.7 Heavy Metals

Arsenic (As) is a metalloid which its relative toxicity depends primarily on inorganic or organic form, valence state, solubility, physical state and purity, rates of absorption and elimination (ATSDR, 2007). Several previous studies have reported links between exposure to arsenic (As) and diseases conditions such as kidney disease, cardiovascular diseases, cancers, arterial hypertension, diabetes mellitus, cerebrovascular diseases, cognitive development, intelligence and memory lost (Juan & Emmanuel, 2018; Meliker *et al.*, 2007; Tolins *et al.,* 2014).

Cadmium (Cd) is referred as toxic heavy metal with implications associated to several health implications such as hypertension, arthritis, diabetes, cirrhosis, strokes, anaemia, arteriosclerosis, cancer, impaired bone healing, cardiovascular disease, reduced fertility, hyperlipidemia, headaches, kidney disease, hypoglycaemia, osteoporosis and schizophrenia when exposed to it for a long period of time (Bergeson, 2008).

Mercury (Hg) is a naturally occurring element that exists in either elemental (metallic) or inorganic or organic form. Exposure to any of these forms of mercury have toxic health effects which could results to abortion, genetic defects and others such as central nervous system, digestive and immune systems, lungs and kidneys, skin, eye and gastrointestinal tract (WHO, 2017).

Lead (Pb) is also a toxic metal with no known health benefit to human, exposure to it could result to bioaccumulation in human system which in turn leads to abdominal pain, adrenal insufficiency, anaemia, arthritis, arteriosclerosis, blindness, cancer, convulsions, deafness, depression, diabetes, dyslexia, epilepsy, fatigue, impaired glycogen storage, hallucinations, hyperactivity, impotency, inflammation, kidney dysfunction, learning disabilities, diminished libido, migraine headaches, multiple sclerosis, psychosis, thyroid imbalances, tooth decay and cardiovascular diseases (Bergeson, 2008).

Iron (Fe) is an essential element for human health with a vital role of facilitating oxidation of carbohydrate, protein, haemoglobin formation, enzyme activator, electron transport and oxygen transport in the body. The symptoms of its deficiency are nose bleeding, myocardial infection and gastrointestinal infection, while its overload due to excessive intake can result to disorder known as hemochromatosis, Alzheimer and Parkinson disease, heart disease, gastric upset, constipation, nausea, vomiting, abdominal pain and faintness (Durupt *et al.*, 2000; Taiwo & Awomeso, 2017).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area

Gashua is a town in Yobe State, Nigeria's North-eastern Region, located on the Yobe River after the confluence of the Hadeja and Jama'are rivers. It is the administrative centre of the Bade Local Government Area and one of Yobe State's largest and most developed towns. The average altitude is around 299 meters. In 2006, the population was estimated to be over 125, 000 people. March and April are the hottest months, with temperatures ranging from 38 to 40 degrees Celsius. Temperatures drop to 23-28 ^{O}C during the rainy season, which lasts from June to September, with 500-1000 mm of rainfall (Neiland & Ladu, 2010). Figure 3.1 and 3.2 shows the position of Yobe state and Gashua on the Map of Nigeria.

Gashua is located in a semi-arid environment with minimal surface water, necessitating a high reliance on groundwater. Access to portable water commodity for domestic and irrigation purposes are majorly through digging wells and sinking boreholes. Gashua town is located between latitude 12^{O} 52' 5" North and longitude 11° 2' 47" East.

Figure 3.1: Nigeria, with Yobe State map

(Source: https://commons.wikimedia.org/wiki/File:Nigeria_Yobe_State_map.png)

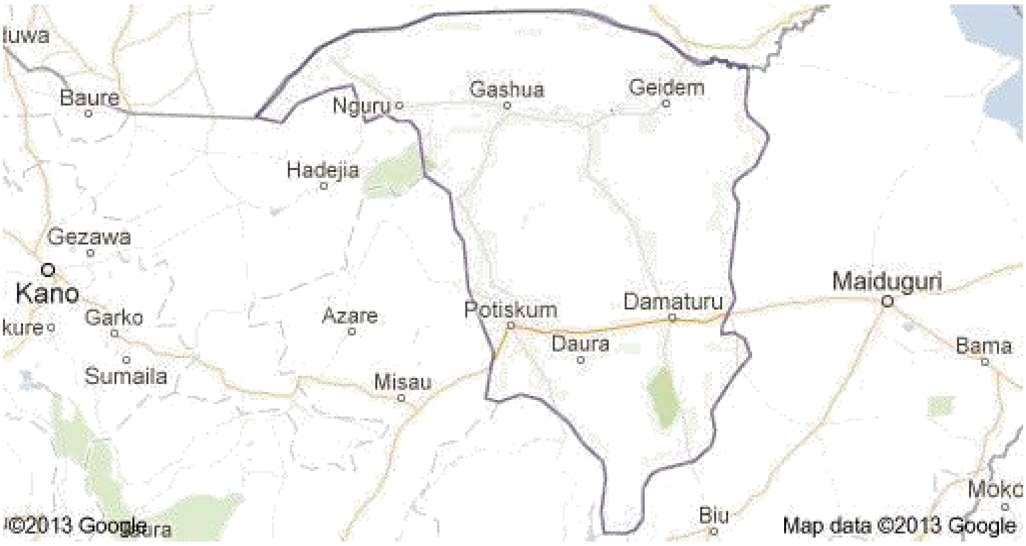

Figure 3.2: Gashua, Yobe State

(Source: https://www.naijahomebased.com/yobe-state-postal-code/)

3.2 Materials

The materials to be used for the study include:

i. Manual flow meters
ii. Calibrated bucket,
iii. Calibrated gallons,
iv. Stop clocks,
v. Hand held GPS,
vi. Tape measure,
vii. Generator set,
viii. Dip meter.
ix. Glass funnel, volumetric flask (50mL)
x. Atomic Emission Spectrophotometer (Model: Agilent, version)

xi. Denver and Mettler Toledo pH meters

xii. Plastic sample bottles (50mL)

xiii. Litmus Paper

xiv. Deionized water

xv. Digestion tubes (100mL)

xvi. Filter paper (Whatman; Size 110mm)

xvii. Micropipette (Model: perfect choice, sizes 200µl and 0-1000µl)

xviii. Conductivity meter

xix. Perkin-Elmer flame-photometer

3.3 Method of Data Collection

The method of investigation that was adopted for this work involved visit to the site of 20 selected boreholes to make in-situ assessment. Discussions where held with the various Managers/operators of different boreholes with each having its peculiar mode of operation and problems. Water sample and discharge of each borehole were obtained as well as the operational status such as productive or abandoned. The collected samples were stored in plastic bottles and transported to the Chemistry Department Laboratory Bayero University Kano. The data collected were used to determine the quality of water from each borehole and the discharge, finding out problems encountered and then analysing them.

3.4 Laboratory Analyses

The bacteriological parameter to be tested for is the total coliform count and the physiochemical parameters measured are: pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium hardness, magnesium hardness, free chlorine, sulphates, bicarbonate and carbonate and some heavy metals Arsenic (As), Cadmium (Cd), Iron (Fe), Mercury (Hg) and Lead (Pb) of the borehole water samples.

3.4.1 Measurement of total coliform count

One (1) millilitre of the well-mixed water sample was put into a sterile petri dish using a pipette and mixed with 100ml of sterile nutrient gelatine or agar. The gelatine was stored under sterile conditions in tubes, liquefied at 30°C before pouring into the petri dish. Tubes of nutrient agar water was liquefied in boiling water and cooled before pouring.

The petri dish was swung in a movement to achieve thorough mixing and left horizontally until it solidified. The culture plates where then inverted and incubated at 20°C and/or 37°C for 44h + 4h. The visible coliforms where then counted with the aid of a magnifying glass. The total coliform count is then scaled up for 100 ml of sample.

3.4.2 Measurement of physico-chemical parameters

The physico-chemical parameters were measured using standard procedure provided by the United States Environmental Protection Agency (US EPA, 1996) and standard procedures prescribed by American Public Health Association (APHA, 1998).

3.4.2.1 p*H*

The pH meter was electrically connected to a power source and switched-on followed by adjusting the general settings. The meter was calibrated with three selected standard buffers of pH such that the expected pH of the material under test falls within their range. The test sample was poured into a beaker and pH electrode sensor was immersed in the sample solution and stirred. The displayed pH result was recorded for each of the samples tested. The electrode was rinse with deionized water and blotted with tissue paper after each test before the next. The pH was also tested using the litmus paper to ascertain the results deduced from the pH meter.

3.4.2.2 E*lectrical conductivity*

A reference solution of standard potassium chloride, 0.01M was prepared by dissolving 745.6mg of anhydrous potassium chloride in freshly boiled CO_2 free double-distilled water and made-up to 1 litre. This standard reference solution has conductivity of 0.001413 Scm. The conductivity cell was rinsed with three of the tubes of the reference standard solution; and the resistance of the fourth solution was measured and the value recorded as $R_{(KCl)}$. The cell was rinsed with the one tube of the water sample and measured the resistance of the second tube of the sample; this process was continuing until all the water samples were measured (US EPA, 1996; Ademoroti, 1996). It is expressed in equation 3.1 to 3.2 as follows

Calculation:

First calculate the cell constant K (cm^{-1})

$$K = R_{(KCl)} \text{ x } Ct \ cm^{-1} \qquad (3.1)$$

Where, $R_{(KCl)}$ is the measured resistance of standard potassium chloride solution.

Ct = conductivity (µScm) of the standard potassium chloride solution at t°C (where t =25°C, Ct = 0.001413 Scm or 1413 µScm).

$$CS = \frac{K}{RS} = \frac{R_{(KCl)} \text{ x } Ct}{RS} \qquad (3.2)$$

Where, RS is the measured resistance of the water sample.

3.4.2.3 S*odium, Na*$^+$

A Perkin-Elmer flame-photometer was used to measure the sodium at the wavelength of 589nm. Various standard solution of Na was prepared and run on the flame photometer to generate a calibration curve, followed by a known volume of the samples. The displayed readings of both the standards solutions and the samples were recorded. The standard solution readings were used to plot calibration graph from which the concentration of the sodium (Na) was extrapolated.

3.4.2.4 C*alcium and magnesium*

A. Reagent solutions.

I. Ca and Mg solution: The calcium and magnesium solutions were prepared by weighing 0.5g of $CaCO3$ and 0.35g of $MgCO_3$ and dissolved completely in 2M HCl and diluted to 1 litre with 2M ammonium ethanoate (ammonium acetate).

AI. Eriochrome black t solution: Dissolve 0.1g of eriochrome black T indicator in 25ml analar grade methanol.

III.0.01M Zinc solution: Dissolve 0.6538g AR granulated zinc in 2 ml Conc. HCl, add few drops of bromine water and boil to remove the bromine.

IV. Ammonia-ammonium chloride buffer (pH10): Add 70g NH_4Cl to 570 ml $NH_4(OH)$ solution (0.880) and dilute to 1 litre with distilled water.

V. Standard EDTA solution: Pipette 25ml zinc solution into a conical flask and add ammonium chloride buffer solution and few drops of the indicator. Shake and titrate with EDTA until the colour changes from wine red to blue. The end point corresponds

B. **Procedure**

Distilled water (50ml) was measured and transferred into 250ml Erlenmeyer flask and added 25ml concentrated ammonia solution, 10 drops of Ca and Mg solution, and 3 drops of eriochrome black T. The mixture was shaken to obtain wine red colour and titrated against standard EDTA solution to obtained blue end point. This aspect of titration accounted for Ca and Mg that might have been present in 50ml distilled water taken and the distilled water for reagent preparations.

The water analyte sample (50ml) was added to the Erlenmeyer flask and shaken (initial wine colour is revived) and added 2.ml of 1.5M KCN to mask Zn, Cu, Co; 2ml of 2%

hydroxyl amine hydrochloride was added to mask Mn, and also 1ml of 30% triethanol amine was added to mask Fe, Al etc and finally titrated against standard EDTA with gentle shaken until blue end point was obtained and noted as the volume of the standard EDTA used. This volume (A) is for Ca and Mg.

Procedure for Ca alone

Distilled water (50ml) was measured and transferred into another Erlenmeyer flask and added 25ml of 20% KOH; 10 drops of Ca and Mg solution, and few grains of 1% calcein indicator and shaken to obtain light standard EDTA that gave fluorescent yellow end point. The water sample analyte (50ml) was added to the flask and shaken to revive the initial light colour followed by addition of 2ml of 1.5M KCN to mask Zn, Cu Co; 2ml of 2% hydroxyl amine hydrochloride to mask Mn, 1ml of 30% triethanol amine to mask Fe, Al etc. and titrated against standard EDTA, and shaken until the blue end point is obtained and noted as the volume of the standard EDTA used. This volume (B) is for Ca alone. Volume of Mg alone = A – B. It is expressed in equation 3.3 as follows

Calculations:

$$\text{Ca (mg/l)} = \frac{40080 \times M \times B}{\text{ml sample}} \quad (3.3)$$

where, A = volume (ml) of EDTA for Ca and Mg

titration B = volume (ml) of EDTA for Ca

titration

M = molarity of EDTA

3.4.2.5 C*hlorine*

The method use here is iodimetry titrimetric using standard thiosulphate (0.0125M) as titrant. The standard thiosulphate was prepared by dissolving 3.101g of $Na_2S_2O_3.5H_2O$ in boiled cooled distilled water and diluted to 1 litre and standardized with the mixture of KI, H_2SO_4 and KH (IO_3) solutions. One gram of KI was dissolved in 5ml of glacial ethanoic and the sample was added, mixed thoroughly and titrated with the standard 0.0125M thiosulphate solution. When the colour to pale straw, 2 ml of starch indicator solution was added and the titration was completed to the first disappearance of the blue colour. Blank titration was also carried out using a volume of distilled appropriate to the sample volume in the presence of all other reagents (US EPA, 1996; Ademoroti, 1996). It is expressed in equation 3.4 as follows:

$$\text{Mg/l, available chlorine} = \frac{(A-B) \times M \times 70{,}900}{\text{ml of sample}} \qquad (3.4)$$

Where, A = ml titration for sample
B = ml titration for blank
M = molarity of sodium thiosulphate

3.4.2.6 T*otal dissolved solids*

A clean dish of suitable size was dried at 103-105°C in an oven until constant weight was achieved. It was cooled at room temperature in a desiccator and weighed. 100-250 ml of the sample was accurately weighed into the dish and evaporated to dryness on a steamed water bath. The residue was dried in an oven for one hour at 103-105°C and the dish was cooled in a desiccator at room temperature and reweighed. The dish was returned to the oven and dried further for 10-20 minutes, cooled and reweighed. Further drying and reweighing was repeated until the weight of the dish plus is constant to within 0.05mg. The weight of the dish was subtracted to obtain the weight of the total solids (US EPA, 1996; Ademoroti, 1996). It is expressed in equation 3.5 as follows,

$$\text{Total solids (mg/l)} = \frac{\text{mg. Total solid} \times 1000}{\text{ml of sample}} \qquad (3.5)$$

3.4.2.7 M*agnesium hardness*

Reagents

- **a.** Methyl red indicator: Sodium salt **(**0.1g) of methyl red was weighed and dissolved in distilled water and diluted to 100ml.
- b. 30% diammonium hydrogen phosphate, $(NH_4)_2HPO_4$ solution

I. An aliquot of 100ml was made up to 150ml with distilled water, acidified with (1 +1) HCl and added 2-3 drops of methyl red to produce pink colour. A solution of NH_4HPO_4 was added and cooled in iced water bath. Concentrated NH_4OH was added drop-wise with constantly stirred until the indicator colour turns to yellow and further stirred for 5 minutes, added 5 ml of conc. NH_4OH and vigorously stirred for 10 minutes. The solution was covered and kept over-night in a cool place, filtered through ash less filter paper and washed with cold (1+19) NH_4OH. Discard the filter and washing.

AI. Measure 50 ml (1+9) of HCl, warm and washed the precipitate obtained from I above. Wash the filter paper thoroughly with hot (1 + 99) HCl. Take 125 ml filtrate and diluted to 150 ml and added 1-2ml $(NH_4)_2HPO$ solution and cooled in an iced water bath. Concentrated NH_4OH was added drop-wise to the solution and stirred until methyl red indicator turns yellow. Concentrated NH_4OH of 5 ml was added and stirred vigorously for 10 minutes, allowed to stand over-night in a cool place and filtered the precipitate through ash less filter paper. Washed 5-8 times with 3-5 ml portions of cold (1+19) NH_4OH until it was freed from chloride.

III. Dry a platinum crucible at $110^{o}C$ to constant weight cooled in a desiccator and placed the filter paper containing the precipitate in the crucible and ignited in a furnace at 1100 -$1200^{o}C$ to obtained constant weight.

Equation of Reaction: $2MgHPO_4 \rightarrow Mg_2P_2O_7 + H_2O$

Weight of the residues as $Mg_2P_2O_7$

Calculation:

$$\text{Mg (mg/l)} = \frac{Mg_2P_2O_7\ \text{(mg)} \times 218.5}{\text{Volume (ml) of sample}}$$

Magnesium hazard of water for irrigation is calculated by the formula in equation 3.6;

$$= \frac{{}^{2+}}{{}^{2+}{}_{+}{}^{2+}{}^{\times 100}} \qquad (3.6)$$

(Izah, 2015)

3.4.2.8 N*itrate-nitrogen by colorimetric method*

Stock standard solution of nitrate was prepared by weighing 0.7218g of anhydrous potassium nitrate, KNO_3^- and diluted to 1 litre with nitrate-free distilled water which gives 100mg/l N or 443mg/l). 20ml of the stock solution was diluted to 1 litre with nitrate-free distilled water (1ml of this solution = 2ngN or 8.86ng NO_3^-).

Procedure: Colour development: The sample residue was removed from oven, cool and added 2ml conc.H_2SO_4 and mixed quickly by swirling. The mixture was allowed to stand for 10-15 minutes with occasional swirling to ensure dissolution of all the solids. The mixture was allowed to cold and 15ml nitrate free-distilled water was pipette into the sample residue and swirled to mix. Titrate 15ml of sodium hydroxide against the mixture. The presence of nitrate indicated development of a yellow coloration, swirl again and allowed the solution to cold and stand at room temperature for one hour. The colour is stable for several hours. A blank sample (with addition of sodium salicylate addition) was prepared in the same manner without the analyte.

The absorbance of the sample analyte and the blank were read on spectrophotometer, making dilution where necessary. The nitrate was determined by extrapolating from generated calibration curve. The calibration standard solutions were prepared from standard solution (1ml = 2mg N) by pipetting 2, 4, 6, 8, 10, 12, 14 and 16 into 50ml beakers respectively and added 1ml of 1% sodium salicylate solution into each of the beakers and treated as the samples were treated following the same process viz: evaporation, drying and colour development. The reagent blank which contained all the reagents and 1ml of 1% sodium salicylate solution. The absorbances of the standard solutions against the blank on a spectrometer at 420 nm were read and the calibration curve of absorbance against NO_3^-N concentration was plotted (US EPA 1996; Ademoroti, 1996). It is expressed in equation 3.7

Calculation:

$$NO - N\ (mg/l) = \frac{\mu N \text{ read from curve x D}}{\text{ml of sample}} \qquad (3.7)$$

3.4.2.9 Sulphates

The water sample was measured (100ml), filtered and added 1:1 HCl in drops to litmus, 3 drops in excess was added and evaporated to 50ml. The solution was boiled and barium chloride solution was added until all the sulphates precipitated. The mixture was digested on water bath until the precipitate has settled. The precipitate was filtered with a vacuum pump through a sintered-glass crucible with a known constant weight. The residue was washed with hot water until the filtrate was chloride-free (tested with $AgNO_3$). The crucible precipitate was dried in an oven at 103-105°C to constant weight and the weight of the precipitate alone was obtained by the difference in weight as expressed in equation 3.8 (Ademoroti, 1996).

Calculation:

$$SO_4\ (mg/l) = \frac{\text{mg } BaSO_4 \text{ x } 411.5}{\text{ml of sample}} \qquad (3.8)$$

3. 5. Preparation of Stock Solutions (1000 mg/L) for Heavy Metals Analysis

Atomic Emission standards solution of 1000ppm (µg/mL) of the metals of interest were prepared by weighing out accurately 1.000g of the pure metal, dissolved in concentrated nitric acid or hydrochloric acid and made up to mark in 1 dm^3 volumetric flask with deionized water or weighed out the appropriate salt of the metal calculated in relation to the formula weight, dissolved in 1 dm^3 volumetric flask and made up to mark with deionized water (Dhanlal, 2000).

3.6 Analytical Procedure for Heavy Metals Analysis

The concentrations of heavy metals; Arsenic (As), Cadmium (Cd), Iron (Fe), Mercury (Hg) and Lead (Pb) in the borehole water samples were determined using Atomic Emission Spectrometer (AES). The equipment was switched-on and optimized based on the operating conditions presented in Table 3.1 and calibrated using the prepared reference standard solutions of the metals of interest followed by the analysis of the sample analyte. The data generated were processed using relationship in equation 3.9:

$$\text{Metal } (\mu g/ml) = \frac{C \times V_2 \times d.f}{V_1(ml) \text{ of sample used}} \tag{3.9}$$

Where; C is the concentration obtained from the AAS machine (mg/L); V_2 is the volume of the stock sample solutions in mL; V_1 is the sample's quantity in ml, d.f is dilution factor.

Table 3.1: Instrument Operating Condition for the Analysis

Element	Wavelength (nm)	Nebulizer Flow (L/min.)
As	193.695	0.75
Cd	326.106	0.50
Fe	371.993	0.65
Hg	253.652	0.75
Pb	405.781	0.75

3.7 Water Yield

In evaluating the yield performance of the boreholes and wells pumping tests will be carried out. The method used in conducting pumping tests on the selected boreholes, is the constant rate pumping test.

3.7.1 Constant rate pumping test

Constant rate pumping tests was conducted on the selected boreholes. The materials used for these tests include; 20-litre bucket as a standard measure, generating set to power the pump, stop watch to record time intervals and rubber hose to connect the pipe from the borehole to discharge the water into the buckets. In conducting this test, the initial or static level of the water in the boreholes was measured using a dip metre. The generating set was thereafter switched on to start the pumping. The pumping was allowed to run continuously for two hours before the rate of pumping was adjusted for the boreholes to maintain constant discharge. At this point, the water level was measured to know the drawdown and a calibrated 20 - litre bucket then filled from the constant discharge from the boreholes while a stopwatch was simultaneously set to record the time taken, in seconds, to fill the bucket. This process was repeated for four hours for each of the selected boreholes. With the constant discharge from the boreholes, a state of equilibrium was maintained between the rate of discharge and the rate of recharge from the aquifer. In this condition of equilibrium, the rate of pumping or discharge was taken directly proportional to the yield of the borehole or well at the constant drawdown. In other words, the discharge per unit time in litres per second gives the yield of each of the selected boreholes at the constant drawdown.

The efficiency of the boreholes will be evaluated using the equation 3.10:

$$, \eta = \frac{\quad}{\quad} \times 100 \tag{3.10}$$

(Sanyaolu, 1991)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 pH

The results of the pH of the borehole water sample shown in Table 4.1 revealed that 20% of the water samples from the boreholes have pH ranging from 6.50 to 6.82 which is within the WHO maximum permissible limit, while 80% of the water samples have pH range from 5.84 to 6.42 which were more acidic and below NSDWQ permissible limit. Results of similar study from South-western Nigeria reported borehole water pH range of 7.04 to 9.12 (Akinola *et al*, 2018); while from other parts of the world pH range of 7.41 to 8.17 was reported, with a mean of 7.6 which indicated slight alkaline condition (Pallavi *et al.*, 2016). Acidic groundwater was usually generated from ASS (Acid sulphate soil-mainly pyrite) which is a major environmental and socioeconomic problem that occurs due to disturbances in the land and hydrological systems such as deep flood mitigation drains and due to rainy and drought seasons. This requires remediation technology for acidic groundwater which is known as permeable reactive barrier (PRB). PRB is a process where a reactive material-filled trench installed in the subsurface to pass a contaminant plume through reactive media during which reactions take place between contaminated groundwater and the reactive material. The reaction process can be via chemical precipitation, dissolution, sorption, and oxidation/reduction (Rumer & Ryan, 1995). PRBs have been identified as promising remediation technology, which can run for several years or decades (Gavaskar *et al.*, 1998).

Table 4.1: Physico-chemical and bacteriological properties of sampled

GB	*Location*	*CFU/100ml*		*EC, μs/cm*	TDS	TH	Ca	Mg	Cl^-	SO_4^-	NO_3^-	pH
		Total Coliform	E. Coli									
1	State Lowcost	1.00	2.00	0.06	0.04	0.88	0.65	0.13	8.92	23.15	5.80	6.21
2	Biltimari	2.00	2.00	0.23	0.12	1.01	0.93	0.16	10.64	15.16	22.67	6.14
3	Biltimari	3.00	1.00	0.18	0.07	0.98	2.01	1.01	10.62	20.32	4.50	6.13
4	Yusufari Road	1.00	0.00	0.07	0.06	0.93	1.23	0.55	2.13	36.11	13.21	6.25
5	Esari	4.00	1.00	0.06	0.13	1.02	0.87	0.62	19.1	28.13	23.87	6.25
6	Biltimari	0.00	0.01	0.15	0.04	0.76	2.59	1.03	4.65	16.60	12.54	6.54
7	Custom	3.00	2.00	0.25	0.04	0.95	2.06	0.94		13.98	5.76	6.26
8	Kabalankara	1.00	1.00	0.14	0.11	0.83	1.12	0.57	12.19	37.61	2.28	6.29
9	Karamin Tanda	0.10	0.00	0.22	0.04	0.99	0.89	0.87	24.07	19.79	33.21	6.82
10	Karamin Tanda	2.01	1.00	0.08	0.05	0.95	0.92	0.96	3.05	32.76	4.54	6.34
11	Kabala	4.00	1.00	0.09	009	0.80	1.05	0.31	2.07	29.10	3.01	6.36
12	Damdin PDP	1.00	0.10	0.21	0.12	0.99	1.94	0.18	14.43	17.22	1.99	6.38
13	Zangwan	2.00	1.00	0.18	0.11	0.91	2.07	0.69	17.04	25.01	21.54	6.34
14	Pompom Kutare	3.00	1.01	0.15	0.04	0.72	0.73	0.15	23.65	33.19	5.76	6.35
15	Kangalapaya	2.00	1.00	0.23	0.05	0.94	2.21	1.06	4.56	20.11	31.55	6.42
16	Abasha	4.00	2.00	0.07	0.05	0.96	0.76	0.13	19.13	19.28	3.12	6.50
17	Fada	0.00	0.00	0.09	0.10	0.93	2.13	1.00	2.90	27.66	3.98	6.72
18	Fire Service	4.00	2.00	0.06	0.04	0.87	2.22	1.01	3.45	14.23	2.40	5.84
19	Takari	1.00	0.00	0.20	0.08	0.95	1.79	0.17	8.70	30.05	7.91	6.42
20	Dawari	1.00	3.00	0.16	0.06	0.92	1.90	0.61	5.56	26.59	2,87	6.41
NSDWQ	Maximum Permissible limit	10.00	0.00	1.00	500	100	-	20	250	100	50	6.5-8.5

4.2 Bacteriological and Physico-chemical Impurities in the Test Samples

The results obtained from bacteriological and physicochemical parameters analysis are reported in Table 4.1 and compared with standards established maximum permissible limits by Nigerian Standard for Drinking Water Quality (NSDWQ). The result of total coliform tests ranges from 0.00 to 4.0 CFU/100ml, which indicated 100% the samples passed NSDWQ maximum permissible limit, while E. coli test result range from 0.00 to 3.0 CFU/100ml from which only 20% of the samples (Takari, Fada, Karamintanda and Yusufari Road) passed NSDWQ. The samples that failed E. coli test are not fit for human consumption because they may lead to cases of diarrhoea, cholera, fever, and stomach pain in the area. This finding agreed with EL-Ishaq *et al,* (2013), which reported the bacteriological analysis from the same state but different locations Izah and Ineyougha (2015) review of the microbial quality of potable water in Nigeria, their study found out that the microbial load often exceeds the NSQWD maximum permissible level of 10 cfu/ml for total coliform.

The results of other physicochemical parameters (Table 4.1); Electrical conductivity (EC), Total dissolve solids (TDS), Total hardness (TH), nitrate ($NO3^-$), sulphates ($SO4^-$), chloride (Cl^-), Magnesium (Mg) and calcium (Ca) ranges as 0.06 – 0.25 µs/cm; 0.04-0.13 mg/L; 0.72-1.01 mg/L; 1.99-31.55 mg/L; 13.98-37.61 mg/L; 2.07-24.07 mg/L; 0.13-1.06 mg/L and 0.65-2.59 mg/L respectively all passed both NSDWQ maximum permissible limit.

4.3 Heavy metals

Arsenic (As): The results of arsenic concentration in the borehole water samples analysed ranges 0.18 - 0.88 mg/l which indicated 100 % of the borehole water samples contained arsenic above NSDWQ permissible limits established (NSDWQ, 2007) as shown in Figure 4.1.

Cadmium (Cd): In this study, the concentrations of Cd in the samples analysed ranges from 0.05 to 0.13 mg/L which 100 % of the borehole water samples contained cadmium (Cd) above the NSDWQ permissible limits (NSDWQ, 2007), as shown in Figure 4.2.

Mercury (Hg): The results obtained from this study mercury concentration within the range of 0.01- 0.50 mg/L from which 100 % of the borehole water samples analysed were contaminated with mercury above NSDWQ permissible limits, as shown in Figure 4.3.

Iron (Fe): High level of Fe may affect the acceptability of drinking water in terms of odour, taste and corrosion (WHO, 2017). The level of iron in the analysed borehole water samples ranged from 0.09 to 0.30 mg/L which are all (100%) within the NSDWQ permissible limit, as shown in Figure 4.4.

Lead (Pb): The level of Pb in all the borehole water samples were below the detection limit of the equipment used, therefore in terms of contamination by lead, the samples have passed NSDWQ permissible limit, as shown in Figure 4.5.

Table 4.2 Heavy metals observed compared with NSDWQ standard

Samples	Heavy Metals				
	As	Cd	Fe	Hg	Pb
GB 1	0.18	0.05	0.16	0.2	0
GB 2	0.24	0.05	0.11	0.05	0
GB 3	0.22	0.09	0.26	0.03	0
GB 4	0.28	0.06	0.16	0.03	0
GB 5	0.22	0.07	0.12	0.02	0
GB 6	0.24	0.08	0.14	0.02	0
GB 7	0.34	0.07	0.09	0.02	0
GB 8	0.29	0.09	0.2	0.02	0
GB 9	0.25	0.11	0.19	0.02	0
GB 10	0.46	0.08	0.13	0.02	0
GB 11	0.41	0.08	0.17	0.02	0
GB 12	0.45	0.09	0.19	0.01	0
GB 13	0.64	0.08	0.17	0.02	0
GB 14	0.55	0.13	0.13	0.02	0
GB 15	0.71	0.07	0.16	0.02	0
GB 16	0.6	0.08	0.13	0.03	0
GB 17	0.69	0.11	0.13	0.03	0
GB 18	0.7	0.06	0.3	0.02	0
GB 19	0.74	0.06	0.18	0.03	0
GB 20	0.88	0.11	0.11	0.03	0
NSDWQ	0.01	0.003	0.3	0.001	0.01

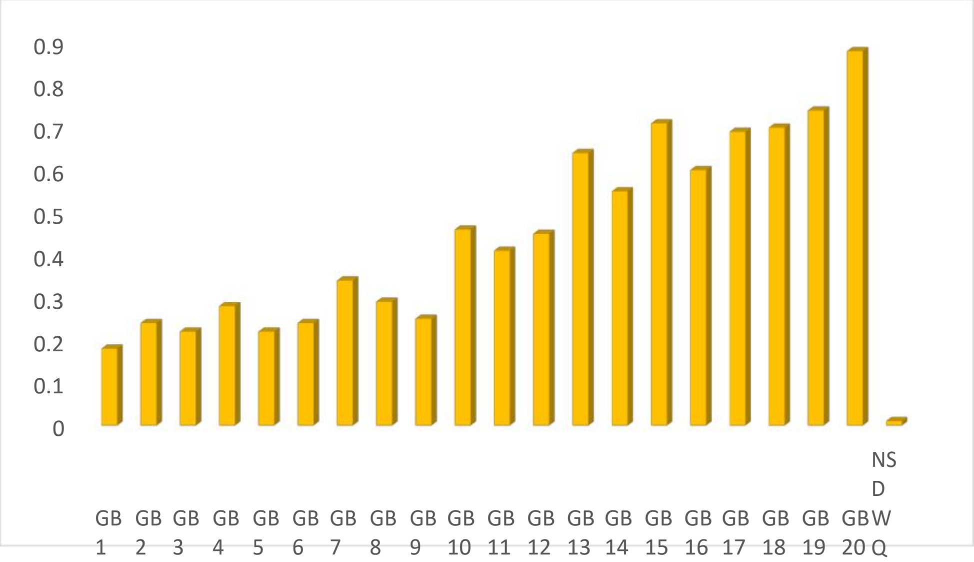

Figure 4.1: Arsenic content compared with NSDWQ

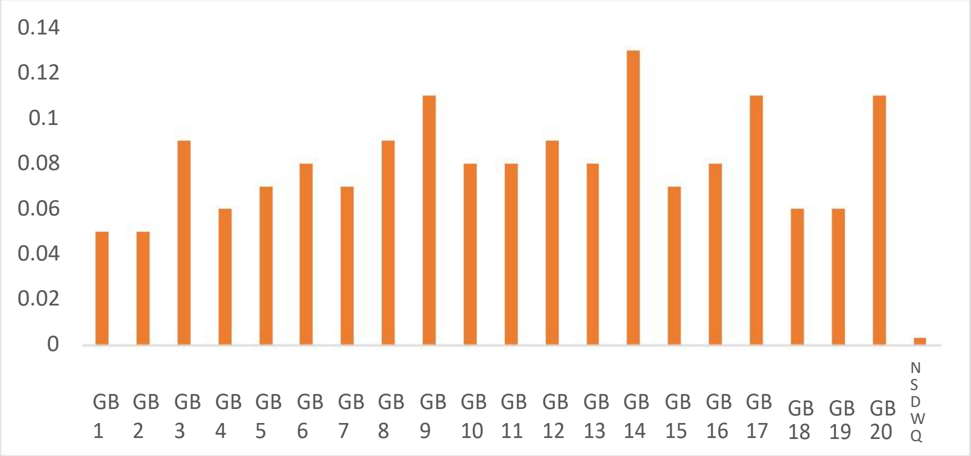

Figure 4.2: Cadmium content compared with NSDWQ

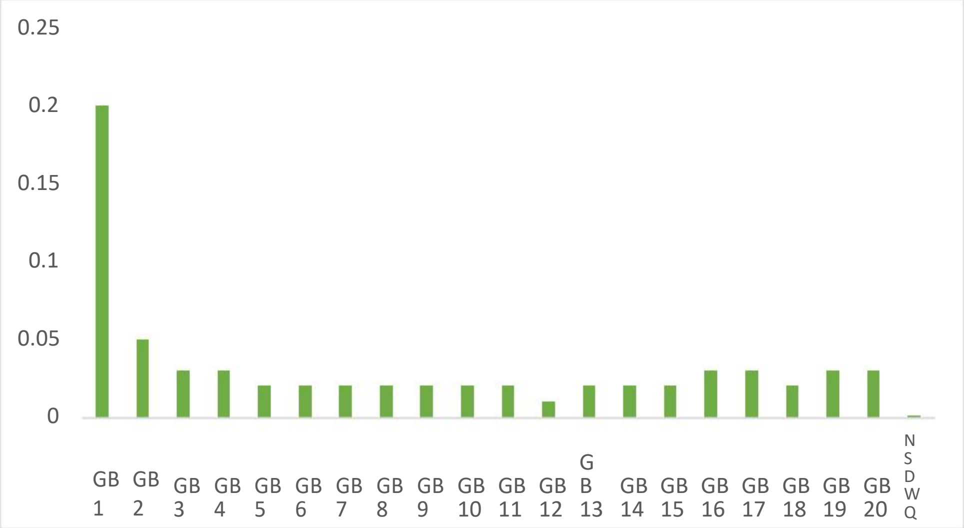

Figure 4.3: Mercury content compared with NSDWQ

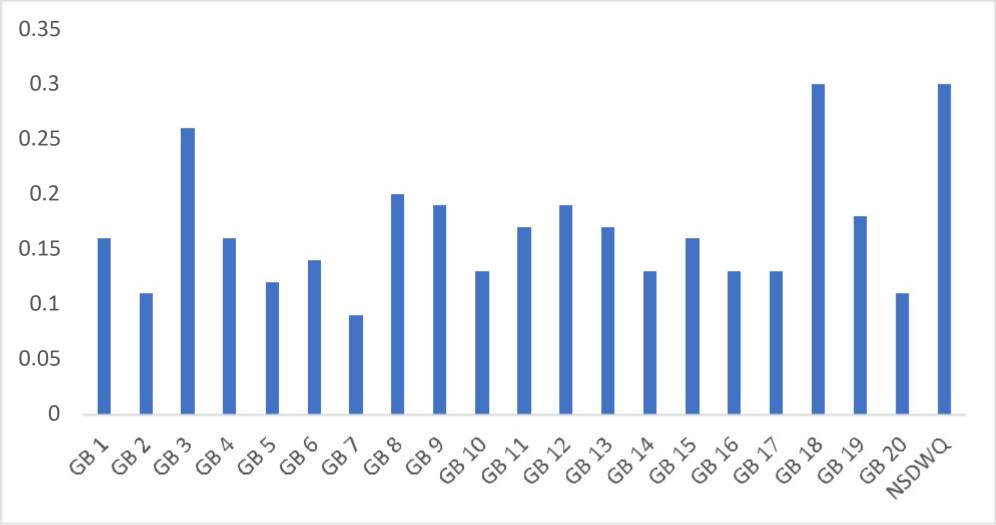

Figure 4.4: Iron content compared with NSDWQ

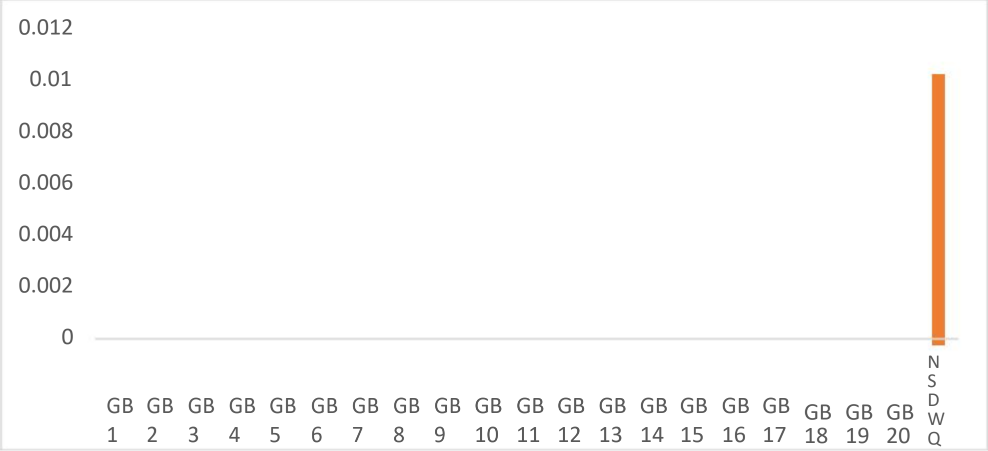

Figure 4.5: Lead content compared with NSDWQ

4.4 Borehole Yield

Table 4.3 presented the constant rate pumping test data of all the boreholes studied, while Figure 4.6 shows the percentage yield observed from the pumping tests in comparison with the design yields of the boreholes and the efficiency of the boreholes is represented in Figure 4.7. The percentage (%) efficiency of the twenty (20) boreholes analysed ranges from 16.1% to 99.5% the least being observed at Takari location (GB19), while the highest at Kabalankara location (GB8); within this range, 85% of the boreholes were producing below 50% efficiency, only 15% produce above as shown in Table 4.24. The observed inefficiency of production of could be linked to operation/maintenance and hydro-geological failures of the state/local government water board official who are supposed to be mandated with the responsibility.

Table 4.3: Constant Rate Pumping Test Data

Borehole Ref.code	Location	Borehole depth (m)	Average P.test	Average Discharge(L/S)	Capacity of submersible pump (Hp)	Draw down	Duration of use Months	Operational status
GB1	State low-cost	66	12.800	1.563	1.5	57	144	Productive
GB2	Biltimari	60	21.540	0.929	1	57	96	Productive
GB3	Biltimari	30	46.580	0.429	0.5	18	3	Productive
GB4	Yusufari road	60	16.520	1.211	1.5	21	84	Productive
GB5	Esari	66	14.672	1.363	1	50	96	Productive
GB6	Biltimari	66	14.180	1.41	1.5	25	72	Productive
GB7	Custom	60	20.224	0.989	2	30	240	Productive
GB8	Kabalankara	60	13.764	1.453	1.5	37	84	Productive
GB9	Karamin Tanda	66	13.642	1.466	1.5	27	24	Productive
GB10	Karamin Tanda	66	13.640	1.466	1.5	25	96	Productive
GB11	Kabala	66	13.680	1.462	1.5	29	60	Productive
GB12	Damdin PDP	60	23.550	0.849	1.5	26	72	Productive
GB13	Zangwan	60	19.426	1.03	1	21	96	Productive
GB14	Pompom kutare	60	16.690	1.198	1	17	120	Productive
GB15	Kangalapaya	60	20.220	0.989	1.5	18	72	Productive
GB16	Abasha	66	15.016	1.332	1	33	96	Productive
GB17	Fada	60	27.780	0.72	1	29	72	Productive
GB18	Fire service	60	18.376	1.088	1.5	18	108	Productive
GB19	Takari	60	13.768	1.453	1	24	156	Productive
GB20	Dawari	63	18.016	1.11	1	30	84	Productive

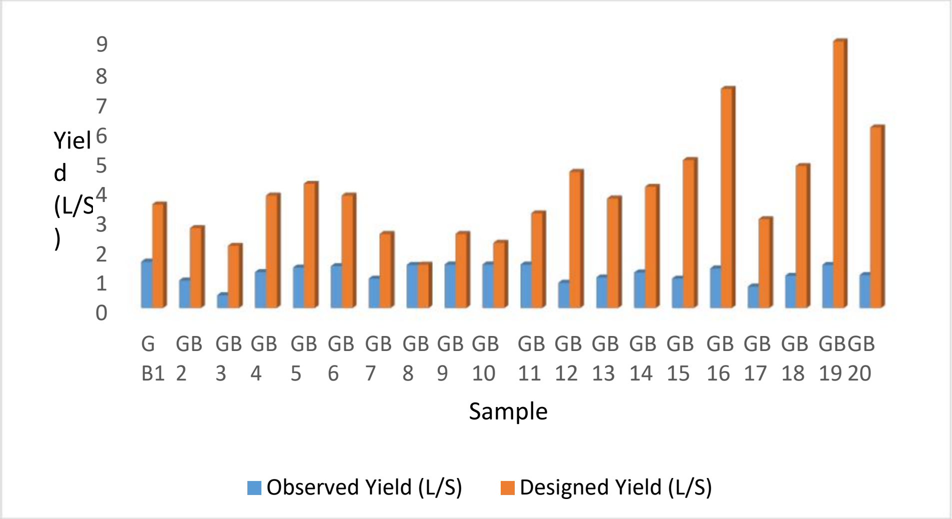

Figure 4.6: Comparison of designed and observed yields from the selected 20 boreholes studied

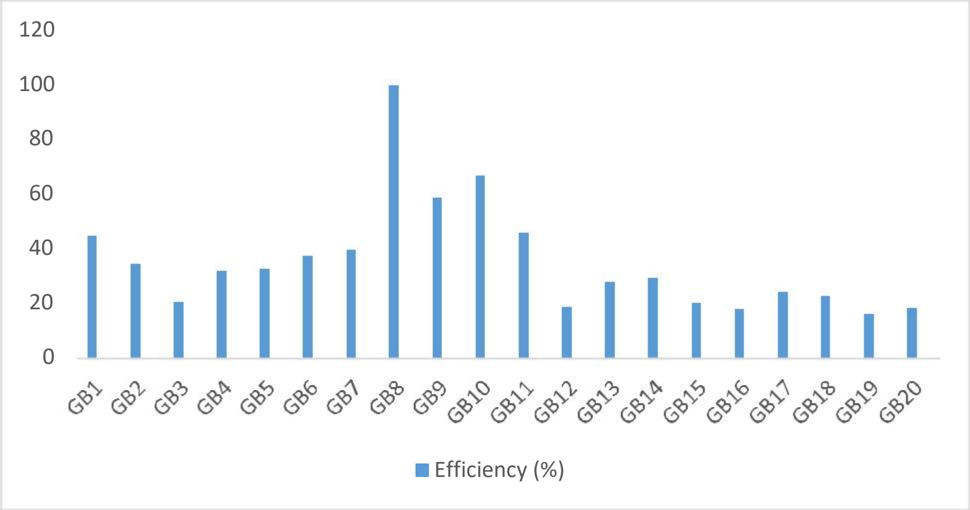

Figure 4.7: Efficiency of selected boreholes

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study revealed that, 85% of the 20 boreholes from Gashua, Yobe State of Nigeria were producing below 50% efficiency with the average performance of 35.3%. It was also discovered 100% of the water samples from the studied boreholes contained toxic heavy metals (As, Cd, Hg) above NSDWQ maximum permissible limit and 80% were acidic and below NSDWQ permissible limit, the bacteriological parameters of most of the samples were however not within the established acceptable limits; while other physicochemical parameters were mostly within acceptable limits. The high level of contamination with heavy metals and bacteriological organism could result to tendency of potential health risk to the consumers.

The factors attributing to the low yield/performance of these boreholes could be due to hydrogeological (groundwater level fluctuation, borehole tapping aquiclude, inadequate recharge), technical/constructional (poor borehole construction and completion, improper pump selection and casing) problems and operations/maintenance (pump failure, power failure and blockage due to siltation); while, toxic heavy metals and bacteriological contamination could be due to agricultural activities such as irrigation farming which involve use of waste water, chemical fertilizer and other agrochemicals; traditional potash mining activities which warranted for littered faecal deposits in the area by the miners and the irrigation farmers.

The need to deploy expertise by State and Local Government Council in each of the affected aspect will alleviate the situation and adequately supply portable water that can meet the demand of the increasing population and agricultural activities of the area.

5.2 Recommendations

I. There is need for water engineers to revisit all the boreholes in the study area for professional advice and correctional measures that can improve efficiency for optimal performance/productivities. Also, necessary geotechnical survey and test should be carried out before approval to drill borehole in the area.

AI. Treatment measures that can neutralize the acidity of the borehole water to acceptable pH range by relevant professional are required.

BI. Routine maintenance schedules need to be put in place and thoroughly followed by Yobe State Water Board in order to correct any deficiencies and avert total breaking down of the boreholes.

IV. The need to embrace significance of safety, hygienic-chain measures of environmental laws with regard to waste disposals, agrochemicals and enforced implementation of regulations through monitoring and evaluation surveillance on the quality of water in the study area is urgently required.

V. The present status of the boreholes in the study area requires urgent attention in order to remediate it from total collapse and also mitigate the chemical contamination of the water samples from those boreholes.

5.3 Contribution to Knowledge

Borehole water quality from 20 locations were analysed and the results shows that 100% of samples contained As, Cd, Hg and Fe while for the bacteriological analysis only 20% meet the NSDWQ limit of 0 cfu/100mil.

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APPENDICES

Appendix A: Result of Heavy metal content in samples

Calibration Parameters for As, Cd, Fe, Hg and Pb

Label (Wavelength nm)	Minimum Concentration	Maximum Concentration	Correlation coefficient
As	0 mg/L	0.55 mg/L	1.00000
Cd	0 mg/L	0.55 mg/L	0.99928
Fe	0 mg/L	11 mg/L	0.99827
Hg	0 mg/L	11 mg/L	0.99950
Pb	0 mg/L	0.55 mg/L	0.99919

GB 1 (State Low-cost): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.18	0.02	240.03	0.18	0.01
Cd	0.05	0.01	621.68	0.05	0.003
Fe	0.16	0.01	1311.77	0.16	0.3
Hg	0.20	0.03	593.48	0.20	0.001
Pb	0.00	0.00	-9.80	0.00	0.01

GB 2 (Biltimari): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.24	0.02	274.24	0.24	0.01
Cd	0.05	0.01	660.84	0.05	0.003
Fe	0.11	0.00	936.22	0.11	0.3
Hg	0.05	0.01	156.59	0.05	0.001
Pb	0.00	0.00	-10.44	0.00	0.01

GB 3 (Biltimari): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.22	0.05	259.05	0.22	0.01
Cd	0.09	0.02	1242.42	0.09	0.003
Fe	0.26	0.02	2196.95	0.26	0.3
Hg	0.03	0.01	83.03	0.03	0.001
Pb	0.00	0.00	-12.41	0.00	0.01

GB 4 (Yusufari road): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits
As	0.28	0.12	287.35	0.28	0.01
Cd	0.06	0.01	805.98	0.06	0.003
Fe	0.16	0.01	1299.41	0.16	0.3
Hg	0.03	0.00	90.45	0.03	0.001
Pb	0.00	0.00	-11.61	0.00	0.01

GB 5 (Esari): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.22	0.02	263.90	0.22	0.01
Cd	0.07	0.01	905.42	0.07	0.003
Fe	0.12	0.00	965.69	0.12	0.3
Hg	0.02	0.00	74.86	0.02	0.001
Pb	0.00	0.00	-13.54	0.00	0.01

GB 6 (Biltimari): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.24	0.05	271.00	0.24	0.01
Cd	0.08	0.02	1023.20	0.08	0.003
Fe	0.14	0.01	1129.96	0.14	0.3
Hg	0.02	0.01	70.70	0.02	0.001
Pb	0.00	0.00	-8.47	0.00	0.01

GB 7 (Custom): Mineral Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.34	0.07	317.48	0.34	0.01
Cd	0.07	0.01	985.79	0.07	0.003
Fe	0.09	0.01	711.29	0.09	0.3
Hg	0.02	0.01	53.37	0.02	0.001
Pb	0.00	0.00	-11.70	0.00	0.01

GB 8 (Kabalankara): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.29	0.08	295.00	0.29	0.01
Cd	0.09	0.01	1209.03	0.09	0.003
Fe	0.20	0.00	1700.03	0.20	0.3
Hg	0.02	0.01	65.31	0.02	0.001
Pb	0.00	0.00	-7.70	0.00	0.01

GB 9 (Karamin Tanda): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.25	0.05	278.64	0.25	0.01
Cd	0.11	0.01	1431.77	0.11	0.003
Fe	0.19	0.01	1563.85	0.19	0.3
Hg	0.02	0.01	64.97	0.02	0.001
Pb	0.00	0.00	-8.19	0.00	0.01

GB 10 (Karamin Tanda): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.46	0.08	359.55	0.46	0.01
Cd	0.08	0.02	1088.60	0.08	0.003
Fe	0.13	0.02	1043.70	0.13	0.3
Hg	0.02	0.00	1043.70	0.02	0.001
Pb	0.00	0.00	-16.35	0.00	0.01

GB 11 (Kabala): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.41	0.03	344.26	0.41	0.01
Cd	0.08	0.01	1056.96	0.08	0.003
Fe	0.17	0.00	1452.66	0.17	0.3
Hg	0.02	0.01	65.12	0.02	0.001
Pb	0.00	0.08	-7.27	0.00	0.01

GB 12 (Damdin PDP): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.45	0.07	356.44	0.45	0.01
Cd	0.09	0.02	1171.76	0.09	0.003
Fe	0.19	0.01	1624.55	0.19	0.3
Hg	0.01	0.01	43.26	0.01	0.001
Pb	0.00	0.00	-11.22	0.00	0.01

GB 13 (Zangwan): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.64	0.05	413.48	0.64	0.01
Cd	0.08	0.02	1076.27	0.08	0.003
Fe	0.17	0.01	1383.70	0.17	0.3
Hg	0.02	0.00	65.36	0.02	0.001
Pb	0.00	0.00	-17.99	0.00	0.01

GB 14 (Pompom Kutare): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.55	0.09	386.63	0.55	0.01
Cd	0.13	0.02	1810.64	0.13	0.003
Fe	0.13	0.00	1097.17	0.13	0.3
Hg	0.02	0.03	57.07	0.02	0.001
Pb	0.00	0.00	-11.07	0.00	0.01

GB 15 (Kangalapaya): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.71	0.13	434.63	0.71	0.01
Cd	0.07	0.01	924.71	0.07	0.003
Fe	0.16	0.03	1369.11	0.16	0.3
Hg	0.02	0.00	50.14	0.02	0.001
Pb	0.00	0.00	-5.16	0.00	0.01

GB 16 (Abasha): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.60	0.18	402.97	0.60	0.01
Cd	0.08	0.01	1053.67	0.08	0.003
Fe	0.13	0.01	1051.90	0.13	0.3
Hg	0.03	0.00	91.73	0.03	0.001
Pb	0.00	0.00	-7.68	0.00	0.01

GB 17 (Fada): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.69	0.07	430.21	0.69	0.01
Cd	0.11	0.02	1496.11	0.11	0.003
Fe	0.13	0.02	1069.76	0.13	0.3
Hg	0.03	0.00	78.90	0.03	0.001
Pb	0.00	0.00	-9.44	0.00	0.01

GB 18 (Fire Service): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.70	0.08	433.28	0.70	0.01
Cd	0.06	0.01	817.33	0.06	0.003
Fe	0.30	0.02	2529.69	0.30	0.3
Hg	0.02	0.00	55.35	0.02	0.001
Pb	0.00	0.00	-1.72	0.00	0.01

GB 19 (Takari) : Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.74	0.06	444.15	0.74	0.01
Cd	0.06	0.01	868.61	0.06	0.003
Fe	0.18	0.01	1471.72	0.18	0.3
Hg	0.03	0.01	95.10	0.03	0.001
Pb	0.00	0.00	0.89	0.00	0.01

GB 20 (Dawari): Element Content

Label	Solution concentration	SD	Intensity	Calculated Mean Concentration (mg/L)	NSDWQ Limits (mg/L)
As	0.88	0.21	488.18	0.88	0.01
Cd	0.11	0.01	1450.91	0.11	0.003
Fe	0.11	0.01	912.72	0.11	0.3
Hg	0.03	0.00	93.38	0.03	0.001
Pb	0.00	0.00	-3.84	0.00	0.01

Appendix B; Result of Borehole Yield

Comparison between Observed and Designed Yields from the selected 20 boreholes

Borehole Ref	Location	Borehole depth(m)	Observed Yield (L/S)	Designed Yield (L/S)	Efficiency (%)
GB1	State low-cost	66	1.563	3.5	44.7
GB2	Biltimari	60	0.929	2.7	34.4
GB3	Biltimari	30	0.429	2.1	20.4
GB4	Yusufari road	60	1.211	3.8	31.9
GB5	Esari	66	1.363	4.2	32.5
GB6	Biltimari	66	1.41	3.8	37.1
GB7	Custom	60	0.989	2.5	39.6
GB8	Kabalankara	60	1.453	1.46	99.5
GB9	Karamin Tanda	66	1.466	2.5	58.6
GB10	Karamin Tanda	66	1.466	2.2	66.6
GB11	Kabala	66	1.462	3.2	45.7
GB12	Damdin PDP	60	0.849	4.6	18.5
GB13	Zangwan	60	1.03	3.7	27.8
GB14	Pompom kutare	60	1.198	4.1	29.2
GB15	Kangalapaya	60	0.989	5	19.8
GB16	Abasha	66	1.332	7.4	18.0
GB17	Fada	60	0.72	3	24.0
GB18	Fire service	60	1.088	4.8	22.7
GB19	Takari	60	1.453	9	16.1
GB20	Dawari	63	1.11	6.1	18.2