HEAVY METAL CONTAMINATION IN DRINKING WATER SOURCES OF SMALL SCALE GOLD MINING COMMUNITIES: THE CASE OF TALENSI-NABDAM DISTRICT IN THE UPPER EAST REGION OF GHANA

By:

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DECLARATION

It is hereby declared that this thesis is the outcome of research work undertaken by the author, any assistance obtained has been duly acknowledged. It is neither in part nor whole been presented for another degree elsewhere.

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DEDICATION

This research is dedicated to God Almighty, my wife Patricia Tindan and my Children Lelia

Aurora Yinsonya Zoogah and Sachu Jr. Yinmo-ya Zoogah

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ABSTRACT

Small scale gold mining in Talensi-Nabdam District and its environs is a potential source of heavy metal contamination in the environment. Heavy metals may accumulate to toxic level which can cause a potential risk to human health. This study was designed to assess water quality in Boreholes, Kulubiliga River and Pit water of heavy metal concentration in the Talensi-Nabdam District. Water samples were collected, from the following communities; Nangodi, Pelugu, Duusi, Gbane, Datoko and Bingo. Samples from each community were analyzed separately for the following chemicals; Pb, Cr, Cd, Cu, Zn, Fe, Mn, As and Hg. Physico – chemical parameters such as pH, conductivity, colour, turbidity and total dissolved solids, total suspended solids etc were measured using standard methods. Results recorded for physico-chemical parameters and heavy metals analyzed from the boreholes values were below the WHO guidelines. Therefore, water from boreholes has no health implications to humans. Turbidity however, recorded high values in the pits and river water. While the true colour from the river was lost due to the suspended matter. All the heavy metals analyzed from the boreholes samples recorded values that were below the WHO guidelines and therefore pose no health risk to humans. However, water samples analyzed from the (pits) and river in the mining area were contaminated with lead, cadmium, mercury and arsenic with their mean values higher than WHO guideline values. The study has therefore revealed that water from the river and mine pits was unsafe for drinking and other domestic purposes in the area.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

KNUST

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Gold mining activities in the Talensi-Nabdam District of the Upper East Region date back to the early 1930s, when the first exploratory activities were conducted by a German mining venture in the village of Nangodi (Anon, 2000). Since the economic mainstay of the communities had long been subsistence farming, gold mining, at the time, did not seem to be a worthwhile venture worth pursuing, but the debilitating drought of 1994/95, coupled with its socio-economic setbacks, changed everything. The return of retrenched gold miners from the southern towns of Obuasi and Tarkwa led to the re-commencement of small-scale gold mining and culminated in the gold rush which occurred in Nangodi and many adjacent localities, including Pelungu, Duusi, Kongo, Gbane and Datoko (Anon.2000).

In a move to manage the illegal gold mining situation within the wider Talensi-Nabdam District, an area of 72 km^2 was earmarked and gazetted to regularize small scale mining. The restricted area, which is near the district capital Tongo, has become a major area for illegal miners. The activities of these miners are being regulated by authorities. However, this liberalization has attracted several small scale operators, whose activities have had a significant impact on the environment (Mireku Gyimah and Suglo 1993). A critical assessment of their operations highlighting activities which are potential health hazards and environmentally unacceptable is therefore necessary, with the view to identifying ways to address these impacts. Different types of waste water effluents may be produced as a result of mining (Priester and Hentscal 1992). They arise as a result of the extraction or preparation of

1

the mineral deposits or from the disposal of associated waste rock. Generally the major environmental issues in the sector are contamination from suspended solids, dissolved metals and acidity in the Kulubiliga River and Pits water miners used for mining activities in the area.

1.2 STATEMENT OF THE PROBLEM

Small scale mining in the Talensi/Nabdam District is vital to the livelihoods of the people. This makes addressing its environmental impacts imperative (Anon.2000). In view of this the study was designed to answer the question" What is the level of contamination of heavy metals in the water bodies by Artisanal Mining in the Talensi-Nabdam District?

Artisanal Mining affects the quality of fresh water through water contamination from discharged mine effluent and seepage from tailings and waste rock impoundments (Kuma, 2004). Increasingly, activities of Artisanal Mining threaten the water bodies on which most of the communities depend. According to Kuma, 2004, water has been called "mining's most common casualty". Mining by its nature consumes, diverts and can seriously pollute water resources.

Water pollution from mine waste rock and tailings from the study area may have to be managed for decades, if not centuries, after closure. These impacts among others depend on a variety of factors, such as the composition of minerals being mined in the area, the type of technology employed, the skill, knowledge and environmental commitment of the mining groups, and finally, the ability to monitor and enforce compliance with environmental regulations by relevant Institutions/Agencies.

2

1.3 OBJECTIVES

The main objective of the study was to assess the quality of water in the Talensi-Nabdam District mining areas.

The specific objectives of the study were to:

➢ measure the Physico-Chemical parameters of the water bodies (Kulubiliga River, Pits and Boreholes).

➢ determine the levels of Nitrate, Phosphate, etc in the water bodies.

➢ determine the levels of heavy metals (Pb, Cr, Cd, Cu, Zn, Fe, Mn, As and Hg) in the Kulubiliga River (KR) and Mine Pits .

➢ assess the water quality in the Boreholes within the mining areas by using standard methods.

1.4 SCOPE AND DELIMITATIONS OF THE STUDY

The study was based on Artisanal or small scale mining activities in the Talensi/Nabdam District. The study examined the mode of operations of Artisanal or Small Scale gold mining in the Talensi-Nabdam District. The study assessed water samples taken from the Kulubiliga River (surface water), Mine Pits and Boreholes.

1.5 JUSTIFICATION OF THE STUDY

Water is wealth and water is health. In totality, water is life. The Inhabitants depend on the Kulubiliga River for drinking water and for processing of the mined ore. Using water for drinking and mining at the same, could pose huge health hazard to the community and

3

animals. It is therefore important to assess the environmental impacts the mining has brought

to bear on the water bodies in the community. In view of the above, the study was designed to

assess the level of contamination in the water bodies by Artisanal Mining in the

Talensi/Nabdam District.

4

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

Artisanal small scale mining was first recognized as a district activity when the United Nation published data on small scale mining activities in developing countries. With time, Small Scale Mining increase in production has provided minerals such as stone, coal, gold and diamonds, (Shielding,1972). (Warhurst and Thomas 1998) lending support to the assertion also emphasized that small scale mining is an economic activity associated with both poverty and remote regions where there are few income earning opportunities. A review of literature has shown that small scale mining does not have a universally accepted definition. According to (Amegbey et al., 1994), the definition varies from country to country and from region to region based on various underlying factors. Therefore, any individual definition is not likely to be appropriate for general use. However, several criteria for direct comparison of Small Scale Mining activities have been proposed including output, size of concession, quantity of reserves, production capacity, gross annual income, degree of mechanization, intensity (volume) of capital employed, production volume, number of people per production unit, labour productivity, sales volume, operational continuity and reliability, and duration of mining cycle (Mireku Gyimah and Suglo 1993).

In the less developed countries (LDCs), small scale mining operations are typically low technology, operated by unskilled labour with high unemployment per unit output, moderate infrastructure and minimum start up time and investment (Priester and Hentscal 1992)

5

149). This prevented the indigenous people winning gold by any means prevailing these times from employing various Small Scale Mining (SSM) methods, including gold nuggets eroded by rain water, retorted gold, gold ore, gold amalgam, slag, concentrates, etc. These and other restrictive laws effectively banned Artisanal mining activities in areas under colonial control. Artisanal mining activities declined for many decades but some operators mostly from the West Africa Sub-region continued operating illegally and sold their produce on the black market out of the country. However, the potential for the development of small scale mining sector was explicitly recognized when the Ghana Government launched the programme for Mining Sector Resuscitation under the Economic Recovery Programme (ERP) in 1983 (Mireku Gyimah, 1993)

2.4 CHARACTERISTICS OF SMALL SCALE MINING IN GHANA

Small scale mining is artisanal and characterized by the phenomena where lack of or limited use of mechanization and a lot of physical work at the initial stage are practiced. Low level of occupational safety and health care and poor qualification of personnel at all levels of operation characterized activities of small scale mining. The level of inefficiency in exploitation and processing of mineral production as well as exploitation of marginal and/or very small deposits which are not economically exploitable by mechanized mining are related to small scale mining operations in Ghana. Other distinctive values of the industry are low level of productivity, periodic operation by local peasants or according to the market price development, lack of social security, insufficient consideration of environmental issues and low levels of working investment capital.

These are normally the bottlenecks encountered by small scale miners, which need to be addressed in order to make the sector attractive to investors (Mireku-Gyimah, 1993).

2.5 THE ROLE SMALL SCALE MINING PLAYS IN THE ECONOMY OF GHANA

It is estimated that over one (1) million people are involved directly in Artisanal Mining (ASM) and more than a million people benefit directly or indirectly from this activity in Ghana today (Minerals Commission,2010). Small scale mining contributes significantly to the economy of Ghana. In 2010, for instance total gold produced by small scale miners was 767,196 ounces (approximately 800,000 ounces) representing 23% of total gold produced in Ghana amounting to 1.35 billion United State Dollars (Minerals Commission, 2010). All the diamonds produced was by small scale miners. Small scale miners also generate substantial employment for the youth both directly and indirectly and their activities also create economic linkages with other sectors of the national economy. Small scale mining activities therefore play an important role in the economy both at the local and national levels.

These positive impacts are quite often negated by certain negative tendencies bordering on socio-economic and environmental issues. In recent times, activities of small scale miners have been linked with significant environmental degradation, thus giving rise to a number of complaints from stakeholders. There are good practices of mineral extraction with minimal harm to the environment and small scale miners must observe these practices (Al-Hassan *et al.*, 1997).

2.6 THE ROLE OF GOVERNMENT IN SMALL SCALE MINING ACTIVITIES

Following the initial implementation of the (ERP) in 1983, the small scale gold mining sector was formalized and regularized through the enactment of the Small Scale Mining Law (PNDC Law 218). With regards to the minerals industry, the government's main tasks in the sector were to:

- promulgate new mining legislation
- license mining titles
- manage the exploitation of national mineral resources in a socially and environmentally sound and sustainable manner
- incorporate generous investment incentives for potential investors
- strengthen the supervision and the regularization institutions responsible for the development of the minerals sector

Under the small scale Gold Mining Law (PNDC Law 218), the Small Scale Mining Project was established as a department under the Minerals Commission with nine district offices located at Tarkwa, Akim Oda, Assin Foso, Bibiani, Bolgatanga, Dunkwa-on-Offin, Asakrangwa, Wa and Konongo (Minerals Commission, 2012)

The government initiated these measures to exert control over the activities of the unregulated 'galamsey' operators and provide an open market for Small Scale Miners.

Presently, the small scale mining sector gets support from the government in several ways including the following.

a) **Taxes:** (From the Small Scale Gold Mining Law (SSGML), the Small Scale Gold Mining Law (218) of 1989 had to exempt small scale mining operators from payment

9

of taxes and royalties for three years as an incentive to entice more people to engage in the legal activities of mining gold on small scale level.

b) **Technical Assistance:** The technical staff of the small scale mining offices usually delivers extension service to the small scale gold mining operators by monitoring the element of SSGM operation; educate and ensuring healthy, and good environmental practices in mining areas; providing technical advice on mining operations; and ensuring proper processing of ore.

c) **Market**: the Precious Minerals Marketing Company (PMMC) was established to buy gold from small scale miners either directly or through the Licensed Buying Agents. The Licensed Buying Agents (LBA) must be Ghanaians who can go to the country side and do the purchasing.

d) **Incentives**

The government through the Minerals Commission loaned some equipment to the miners to assist them in their works. The items include: Generators, Compressors, Jack hammers, drilling bits, pumps etc. Government has also ear-marked some areas to be explored for gold throughout the country for easy access by prospective small scale miners.

Government, with support from Development Partners, is implementing the Natural Resources and Environmental Governance (NREG) Programme with one major objective of reducing if not eliminate completely the negative impacts of small scale mining in Ghana. Under the programme, several areas are being geologically explored to find suitable grounds for small scale miners. The National Security has also intervened and set up a National Security Sub-Committee on Lands and Natural Resources, of which the Minerals Commission

is a major player. This Sub-Committee, amongst others, strategizes on how to deal with illegal mining. Government has therefore intensified education on this and expects support from all stakeholders to develop a framework to help address the menace of illegal mining in the country.

2.7 IMPACT OF SMALL SCALE MINING AND ENVIRONMENTAL DEGRADATION

Illegal miners believe to account for the most significant part of the environmental damage of the small-scale mining industry. Amalgamation is the technique mostly used (Ntibery *et al.*, 2003). The main environmental problems associated with the small scale mining industry are land degradation, pollution of rivers and streams by mercury; atmospheric impacts from mercury fumes during gold recovery and dust, mercury in groundwater from accidental spillage during gold processing (Akosa *et al.*, 2002) and Acid Mine Drainage (AMD) from solid waste from sulphidic ore leaching heavy metal and acidity into water and soil (Akosa *et al.*, 2002). Siltation of surface waters (Akosa *et al.*, 2002) and Deforestation due to wood used for stabilizing mining shafts (Ntibery *et al.*, 2003) as well as damage to infrastructure due to undermining of roads and houses are challenges the industry is bedeviled with.

Small-scale mines particularly illegal ones do not have a waste management plan but simply leave the waste. It is estimated that 5 tonnes mercury is released from small-scale mining operations in Ghana each year (Hilson, 2002). High concentrations of mercury have been found in sediments and fish in the vicinity of small-scale mining activities using amalgamation as their main technique (Ntibery *et al.*, 2003). The concentration in most fish

11

fillets in these areas exceeds the recommendations of the United States Food and Drug Agency (Babut *et al.*, 2003).

2.7.1 Contamination of Kulubiliga River in the Talensi-Nabdam area

The Kulubiliga River (KR) runs through majority of communities in the Talensi-Nabdam District where some of the inhabitants use it as a source of drinking water. People have good reasons to live along rivers/streams especially in a developing economy such as Ghana, where provision of potable water is an illusion even for many urban communities not to talk about the mining communities, which are rural and remote. The river dries up in the dry season as a result of the huge pressure exerted on it. Human activities in the river are quiet extensive which cause harmful effects to the water. This occurs because of the introduction of toxic chemicals from the effluents of mining operations. Mining is an activity classified as most polluting as well as draining the dwindling Kulubiliga water resources. In the District, the effects of the activities of mining companies on the water body through dewatering, ground water pollution, the virtually free use of water for mining operations, and other waste spillages, are affecting the health status of residents of the mining communities.
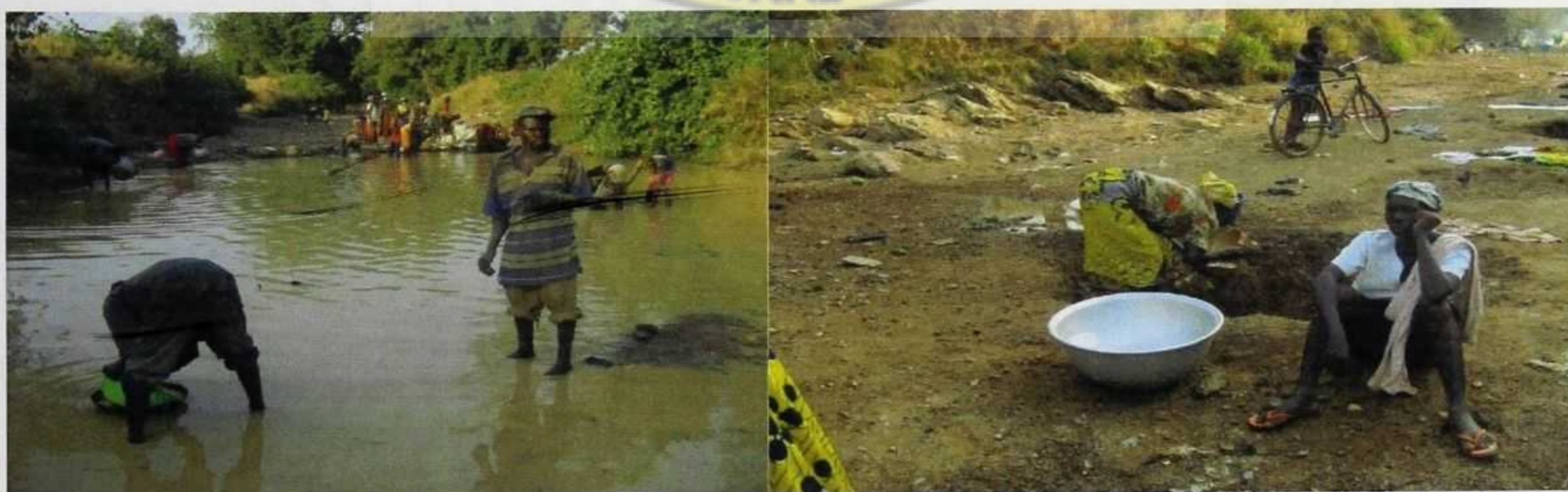
Plate 1: Mining upstream and fetching of drinking water downstream in Kulubiliga River

2.7.2 Mining Methods

In Ghana there are both small-scale mining and large-scale mining. The general processing techniques are handpicking, amalgamation, cyanidation, flotation, electrowinning and roasting of ore (Akosa *et al.,* 2002). The technique differs between large-scale and small-scale mining and also varies depending on the type of deposit and its location (Ntibery *et al.*, 2003). The three different types of mining methods namely: Underground, Surface and Alluvial methods are practiced in the study area.

2.7.3 Underground Mining

Miners enter the pit-bottom for every day's work by means of ropes supported by foot-holes in vertical pits. Hazards associated with current small scale mining industries in Ghana, is the frequent pit failure (collapse) due to disturbance of stone concentration owing to closeness of pits. Pitting is done right on shear and fault areas. Miners access the pit-bottom through vertical or incline shafts. In small scale underground mining, ventilation is provided by two openings to the underground workings for natural flow of air stream underground (Priester and Hentscal 1992). Water management practices from pits are a challenge to small scale miners due to their inability to handle the volumes of water underground. Timbering underground is characterized by indiscriminate felling of trees for the support system. Blasting activities underground is confined and the fumes are most of the time trapped within the fractures and cracks of rocks. One of the commonest underground mining methods adopted by small scale miners is Cut and Fill or Backfill methods in a way to handle waste-rock generated from blasting (Priester and Hentscal 1992).

13

Plate 2: Shaft being accessed by a miner

2.7.4 Surface Mining

All mining operations or activities are open to the atmosphere. The method is applicable to surface and near surface deposits that cannot be mined economically by other mining methods.

The main features of Surface Mining are creation of holes opened to the surface, removal of overburden to expose the ore body, requirement of large areas of operation, requirement for machinery some times and production of large tons of materials (Kesse, 1985).

However, a unique feature of the surface mining method, termed as 'dig and wash' or pitting to about five metres is mostly adopted by small scale miners to extract the oxidised ore and sometimes the transitional ore. The method requires that miners primarily trace narrow reefs of gold bearing ore which are easily accessible and minable by using some degree of mechanization for high production. The overburden is removed or stripped from the surface to expose the reef of interest and deposited to stockpile. After the extraction of the gold, the

overburden is then returned to the pit that is created to fill the hole left behind. The process is then repeated in subsequent reefs (Amankwah and Suglo 2003).

Plate 3: Surface mining operations underway

2.7.5 Alluvial Mining

Shallow alluvial mining techniques, which are popularly called dig and wash area used to mine shallow alluvial deposits usually found in valleys or low lying areas. Such deposits have depths not exceeding three meters. Vegetation is initially cleared and soil excavation until a gold-rich layer is reached. The mineralised material deposits and treating such ores, is removed and transported to nearby streams for sluicing to recover the gold. It should be noted that in view of the relative ease of reaching these deposits and treating such ores, a significant promotion of the industry operations are of this type. For Similar reasons, illegal workings are predominantly of this type (Asante *et al.,* 2007).

Plate 4: Alluvial materials being worked by illegal miners mostly women

2.7.6 Processing Method

This involves mineral (gold) extraction from mined-out ore. Processing stages include ore crushing / milling, chemical treatment to amalgamation with mercury and smelting and effluent containment. The milled ore is then sluiced on a board to produce the gold concentrate. The concentrated ore is then amalgamated with mercury. The amalgamated ore is subsequently separated by placing the amalgam in the retort glass or the open and heating to such a temperature that the gold would be separated from the mercury which is either collected ready for re-use or escapes into the environment. The gold is further smelted and refined to about 98% with Nitric acid and with other chemicals including borax and silica (Asante *et al.*, 2007).

Plate 5: Crushing and sieving of the ore for sluicing

Plate 6: Washing of the pulp into slurry on sluice-box

Plate 7: Mercury added to concentrate for Amalgamation

Plate 8: Amalgam being burnt to free the gold from Mercury

2.7.7 Hazards of processing methods

In small scale mining or artisanal mining, the following hazards are associated with the various processing methods for the extraction of the gold.

> Exposure to excessive airborne dust, during communition (crushing and milling) and winnowing activities, with attendant health complications

> High noise levels associated with crushing and grinding

> Prolonged association with wet conditions during sluicing

> Monotonous body positioning in sluicing operations

> Mercury fumes inhalation from burning of amalgam, and direct bodily contact with mercury during amalgamation

> Introduction of mercury into the immediate environment from open-cycle amalgamation methods (Al-Hassan *et al.*, (1997).

2.8 PHYSICO-CHEMICAL PARAMETERS

2.8.1 Turbidity

This is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU). The extinction depth (for lakes), measured with a Secchi disc, is an alternative means of expressing turbidity. High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces

light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant (WHO, 2011).

2.8.2 Colour

This is a measure of the dissolved colouring compounds in water. The colour of water is attributed to the presence of organic and inorganic materials; different materials absorb different light frequencies. Colour is expressed as Pt-Co units according to the platinum-cobalt scale. Water colour can naturally range from 0-300 Pt-Co. Higher values are associated with swamps and bogs. Colour is regarded as a pollution problem in terms aesthetics, but is not generally considered a detriment to aquatic life. Increased colour may interfere with the passage of light, thereby impeding photosynthesis (WHO, 2007).

2.8.3 Conductivity

This is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Ions are dissolved metals and other dissolved materials. Conductivity is reported in terms of microsiemens per centimeter (µS/cm). Natural waters are found to vary between 50 and 1500 µS/cm. Conductivity may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water [dissolved solids = conductivity x 0.55 to 0.9 (the most often used is 0.7)] (WHO, 2011).

2.8.4 Total Suspended Solids (TSS)

TSS is the measure of the suspended particles in the water column. High levels of turbidity can come from many sources, such as urban runoff, soil erosion, wastewater discharges, agriculture, and removal of riparian zones. Increased levels of turbidity may cause water to darken, which in turn leaves less light for aquatic plants to perform photosynthesis. This in turn decreases the amount of dissolved oxygen being added to the water, which can affect aquatic organisms that are higher on the food chain. Extreme levels of TSS can also clog fish gills. The suspended particles also help the attachment of heavy metals and many other toxic organic compounds and pesticides (IPCS, 2004).

2.8.5 Total Dissolved Solids (TDS)

This is a measure of the amount of dissolved material in the water column. It is reported in mg/L with values in fresh water naturally ranging from 0-1000 mg/L. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated filterable residue values. TDS is a general indicator of overall water quality. High levels of TDS in surface water may be due to several factors, including: sedimentation, mining, or storm water runoff (Gyau-Boakye and Dapaah-Siakwan, 1999). Increased TDS may impart a bad odor or taste to drinking water, as well as cause scaling of pipes and corrosion. High concentrations of TDS limit the suitability of water as a drinking source and irrigation supply. High TDS waters may interfere with the clarity, colour and taste of manufactured products WHO (2003).

2.8.6 Calcium

Calcium is an element that is found naturally in water due to its abundance in the Earth's crust. Large bodies of surface water, such as rivers, typically contain 1-2 mg/L of calcium. High levels of calcium in surface water mean that the water is hard, which helps aquatic life by buffering the pH of the water and protecting those organisms with gills from direct metal uptake. However, if calcium and hardness are too high, hardening of pipes and staining may occur (WHO, 2005).

2.8.7 Magnesium

Magnesium is found in large concentrations in both the Earth's crust and the human body. It is highly soluble in water, and is the third most abundant element in sea water. Concentrations of magnesium in freshwater vary according to surrounding geology. Along with calcium, magnesium concentrations are used to determine water hardness. High concentrations of magnesium cause similar problems to high concentrations of calcium, including staining and hardening of pipes and fixtures (Kuma, 2004).

2.8.8 pH

Values of pH in surface water outside acceptable ranges can indicate human impacts such as agricultural runoff, mining, or infiltration of untreated wastewater. Low pH is acidic and can cause corrosion of pipes, as well as increased dissolved metals concentrations in surface water. High pH is alkaline and can cause scale buildup in fixtures, bad taste, and reduce the

effectiveness of chlorine disinfection, as well as increased metal concentrations in stream sediments. No health-based guideline value is proposed for pH. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters WHO (2007).

2.8.9 Alkalinity

This is the measurement of the water's ability to neutralize acids. It usually indicates the presence of carbonate, bicarbonates, or hydroxides. Alkalinity results are expressed in terms of an equivalent amount of calcium carbonate. Note that this does not mean that calcium carbonate was found in the sample. Natural waters rarely have levels that exceed 500 mg/L. Alkalinity values in coastal areas of BC typically range from 0 to 10 mg/L, while interior regions of the province can have alkalinity values that exceed 100 mg/L. Waters that have high alkalinity values are considered undesirable because of excessive hardness and high concentrations of sodium salts. Water with low alkalinity has little capacity to buffer acidic inputs and is susceptible to acidification (low pH) (WHO, 2003).

2.8.10 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 WHO (2003). Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. No health-based guideline value is proposed for chloride in drinking-water. However,

chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water WHO (2003).

2.8.11 Potassium

Potassium is an essential element in humans and is seldom, if ever, found in drinking water at levels that could be a concern for healthy humans. The recommended daily requirement is greater than 3000 mg. Potassium occurs widely in the environment, including all natural waters. It can also occur in drinking-water as a consequence of the use of potassium permanganate as an oxidant in water treatment. In some countries, potassium chloride is being used in ion exchange for household water softening in place of, or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions. Possible replacement or partial replacement of sodium salts with potassium salts for conditioning desalinated water has been suggested. The latter seems to be an unlikely development at this stage, in view of the cost difference WHO (2007).

Currently, there is no evidence that potassium levels in municipally treated drinking- water, even water treated with potassium permanganate, are likely to pose any risk to the health of consumers. It is not considered necessary to establish a health-based guideline value for potassium in drinking-water.

Although potassium may cause some health effects in susceptible individuals, potassium intake from drinking-water is well below the level at which adverse health effects may occur. Health concerns would be related to the consumption of drinking- water treated by potassium-based water treatment (principally potassium chloride for regeneration of ion exchange water softeners), affecting only individuals in high-risk groups (i.e. individuals with kidney

dysfunction or other diseases, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants). It is recommended that susceptible individuals seek medical advice to determine whether they should avoid the consumption of water (for drinking or cooking) treated by water softeners using potassium chloride. When high-risk individuals have been advised by a physician to avoid elevated potassium intake from water, the recommended strategy is to limit the addition of potassium to water that will be ingested or to avoid ingesting such water. This can be done by having a proportion of the water bypass the softener altogether; this approach is recommended by several countries. Although technologies are available to remove potassium, they are generally more expensive and redundant when combined with the softening treatment WHO (2009).

2.8.12 Sodium

Sodium salts (e.g. sodium chloride) are found in virtually all food (the main source of daily exposure) and drinking-water. Although concentrations of sodium in potable water are typically less than 20 mg/l, they can greatly exceed this in some countries. The levels of sodium salts in air are normally low in relation to those in food or water. It should be noted that some water softeners can add significantly to the sodium content of drinking-water. No firm conclusions can be drawn concerning the possible association between sodium in drinking-water and the occurrence of hypertension. Therefore, no health-based guideline value is proposed. However, concentrations in excess of 200 mg/l may give rise to unacceptable taste WHO (2003).

2.8.13 Sulphate

Sulphates occur naturally in numerous minerals and are used commercially, principally in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however, the highest levels usually occur in groundwater and are from natural sources. In general, the average daily intake of sulphate from drinking-water, air and food is approximately 500 mg, food being the major source. However, in areas with drinking-water supplies containing high levels of sulphate, drinking-water may constitute the principal source of intake. The existing data do not identify a level of sulfate in drinking-water that is likely to cause adverse human health effects. Data from a liquid diet study with piglets and from tap water studies with human volunteers indicate a laxative effect at concentrations of 1000–1200 mg/l, but no increase in diarrhoea, dehydration or weight loss. No health-based guideline is proposed for sulphate. However, because of the gastrointestinal effects resulting from ingestion of drinking-water containing high sulfate levels, it is recommended that health authorities be notified of sources of drinking water that contain sulfate concentrations in excess of 500 mg/l. The presence of sulfate in drinking-water may also cause noticeable taste and may contribute to the corrosion of distribution systems WHO (2003).

2.9 SOURCES OF HEAVY METALS IN WATER BODIES AND THEIR PRESENCE IN THE ENVIRONMENT

2.9.1 Lead

Lead is used principally in the production of lead-acid batteries, solder and alloys. The organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these purposes in many

26

countries has largely been phased out. Owing to the decreasing use of lead- containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining; in most countries, lead levels in blood are also declining unless there are specific sources, such as dust from leaded paint or household recycling of lead-containing materials. The presence of lead in the study, area may be due to weathering and leaching of the metal from waste rocks dumps (AGC, 2001). Other sources of lead are the weathering of the Birimain and Granitiods rocks, which contain high levels of lead.

Lead is a neurotoxin metal. It affects the central nervous system. Children exposed to high levels of lead contaminated water have low IQs. Other symptoms associated with exposure to lead are behavioural disorders and tremors (Asklund and Eldvall, 2005). The guideline value is provisional on the basis of treatment performance and analytical achievability. Occurrence of lead in drinking-water is generally below 5µg/l, although much higher concentrations (above 100 µg/l) have been measured where lead fittings are present. The primary source of lead is service connections and plumbing in buildings; therefore, lead should be measured at the tap. Lead concentrations can also vary according to the period in which the water has been in contact with the lead-containing materials.

2.9.2 Chromium

Chromium is widely distributed in Earth's crust. It can exist in valences of +2 to +6. In general, food appears to be the major source of intake. Chromium (III) is an essential nutrient. In water, chromium (III) is a positive ion that forms hydroxides and complexes, and is adsorbed at relatively high pH values. The ratio of chromium (III) to chromium (VI) varies

widely in surface water. In general, Chromium (VI) salts are more soluble than those of chromium (III), making chromium (VI) relatively mobile. The daily chromium requirement for adults is estimated to be 0.5-2 µg of absorbable chromium (III) WHO (2011). That equals to approximately 2-8 µg of chromium (III) per day since only about 25% can be absorbed. The average concentration of chromium in rainwater is approximately 0.2-1µg/l WHO (2004). Natural chromium concentrations in seawater have been measured to 0.04-0.7 µg/l. The chromium concentration in groundwater is generally low (<1 µg/l). The natural total chromium content of surface water is approximately 0.5-2 µg/l and the dissolved chromium content 0.02-0.3 µg/l. Most surface water contain between 1 and 10 µg of chromium per litre (Armah *et al.,* 2010). In general, the chromium content of surface water reflects the extent of industrial activity. The health effects are mostly determined by the oxidation state. Therefore two different guidelines for chromium (III) and chromium (VI) should be derived. However, current analytical methods and the variable speciation of chromium in water favour a guideline value for total chromium. However, there is evidence that the dose–response relationship at low doses is non-linear, because chromium (VI) is reduced to chromium (III) in the stomach and gastrointestinal tract. In epidemiological studies, an association has been found between exposure to chromium (VI) by the inhalation route and lung cancer. As a practical measure, the guideline is set to 0.05 mg/l, which is considered being unlikely to give rise to significant risks to health (WHO 1996). Previous studies show maximum levels in groundwater to be 0.066 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.49 mg/l (Kuma and Younger 2004).

2.9.3 Cadmium

Cadmium is a soft, ductile metal which is obtained as a by – product from the smelting of lead and zinc ores. It is also found in chalophile as a mineral called greenockite, CdS. Volcanic eruption is another source of cadmium in the environment (Foulkes, 1986). Naturally, cadmium levels in the atmosphere are thought to be about $2ng/m^3$, though high values are found near zinc smelters. Cadmium in the study area may come from the mining and processing of zinc and other chalophilic metals. The anthropogenic sources of cadmium in the environment poses serious threat because of its surface input to soil system making the metal more accessible for plant and animal uptake. Cadmium is obtained mainly as a by-product during the processing of zinc-bearing ores and from the refining of lead and copper from sulphide ores. Cadmium is used primarily for the production of nickel-cadmium batteries, in metal plating, and for the production of pigments, plastics, synthetics and metallic alloys. Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer WHO (2011). Other symptoms include; irritation of upper respiratory tract, metallic taste in the mouth, cough and chest pains (Foulkes, 1986). Absorption of cadmium compounds is dependent on the solubility of the compounds. Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10–35 years. There is evidence that cadmium is carcinogenic by the inhalation route, and International Agency for Research on Cancer (IARC) has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans). However, there is no evidence of carcinogenicity by the oral route and no clear evidence for the genotoxicity of cadmium. The kidney is the main target organ

29

for cadmium toxicity. In its recent evaluation of cadmium, Joint Expert Committee on Food Additives (JECFA) found that data relating to excretion of the biomarker β2-microglobulin in urine to cadmium excretion in urine for individuals who are 50 years of age and older provided the most reliable basis on which to determine a critical concentration of cadmium in the urine.

2.9.4 Copper

Copper is both an essential nutrient and a drinking-water contaminant. It is used to make pipes, valves and fittings and is present in alloys and coatings. Data on gastrointestinal effects of copper must be used with caution, as the effects observed are influenced by the concentration of ingested copper to a greater extent than the total mass or dose ingested in a 24-hour period. Recent studies have delineated the threshold for the effects of copper in drinking-water on the gastrointestinal tract, but there is still some uncertainty regarding the long-term effects of copper on sensitive populations, such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis WHO (2011). Other sources of copper are the weathering of the Birimain and Granitiods rocks, which contains high levels of copper (Obiri, 2005). Copper can be released into the environment by both natural sources and human activities. Mining, metal production, wood production and phosphate fertilizer production can release copper into the environment. Copper is released both naturally and through human activity; it is very widespread in the environment. Copper is often found near mines, industrial settings, landfills and waste disposal sites (Coakley, 1996). Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Copper can be found in many kinds of

food, in drinking water and in air. Thus absorb some quantities of copper each day by eating, drinking and breathing. The absorption of copper is necessary, because copper is a trace element that is essential for human health. Although humans can handle proportionally large concentrations of copper, too much copper can still cause health problems. Copper concentrations in air are usually quite low, so that exposure to copper through breathing is negligible. However, people that live near smelters that process copper ore into the metal do experience this kind of exposure. Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea (Essumang *et al.*, 2007). Intentionally high uptakes of copper may cause liver and kidney damage and even death. Industrial exposure to copper fumes, dusts or mists may result in metal fume fever with atrophic changes in nasal mucous membranes (Donkor *et al.*, 2006).

2.9.5 Zinc

Zinc is an element of moderate abundance in the earth crust. It occurs in rocks as chalcophile and sphalarite, ZnS (referred to as zinc in Europe). Zinc is an essential trace element found in virtually all foods and potable water in the form of salts or organic complexes. The diet is normally the principal source of zinc. Although levels of zinc in surface water and groundwater normally do not exceed 0.01 and 0.05 mg/l, respectively, concentrations in tap water can be much higher as a result of dissolution of zinc from pipes. It was considered that, taking into account recent studies on humans, the derivation of a formal guideline value is not required at this time. The presence of zinc in the environment is associated with mining and smelting which pollutes the air, water and soil with fine particles, which ultimately undergo oxidation to release Zn^{2+}. Zinc is used in a wide variety of industrial, agricultural, and

31

consumer products. It is found in all human tissues and all body fluids and is essential for growth, development and reproduction. Zinc is usually present in tap water at concentrations less than 0.2 mg/L, although drinking water in galvanized pipes can contain up to 2 to 5 mg/L. Typically, concentrations are much less than 5 mg/L, which is based on the threshold for metallic taste in water. Zinc is an essential trace element for all bacteria, plants and animals including human beings. It has many biochemical functions (catalytic, regulatory and structural). The catalytic role of zinc is understood in terms of the fact that it forms part of the specialized enzymes and proteins. Although zinc is an essential element to plants, animals and man, very high concentrations of zinc is very toxic, hence harmful to the body. The toxicity of zinc is due to having cadmium as an impurity. It causes phytotoxicity. Zinc therefore affects many functions of the body such as reproduction, skin health, sense of smell and taste, brain functions and growth. However, low blood levels of zinc are also associated with hypogeusia, in which there is loss of sense of taste. Gastrointestinal distress is a common symptom following acute oral exposure to zinc compounds. The United State Environmental Protection Agency (USEPA) has given zinc a carcinogenicity weight-of-evidence classification of D (not classifiable as to human carcinogenicity), based on inadequate evidence in humans and laboratory animals WHO (2003).

2.9.6 Iron

Iron is an essential element in human nutrition, particularly in the iron (II) oxidation state. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/ day. An allocation of 10% of this Provisional Maximum Tolerable Daily Intake (PMTDI) to drinking-water gives a value of

about 2 mg/l, which does not present a hazard to human health. The taste and appearance of drinking-water will usually be affected below this level WHO (2003). Iron is one of the most abundant metals in Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/l. 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 in the study area is associated with the Birimian and intrusive rock system. The Birimian and the intrusive rock systems contains high amount of iron. The concentration of iron in the study area may come from the weathering of the Birimian and the intrusive rock system.

2.9.7 Manganese

Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron. It is used principally in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient in various products. Manganese is an essential element for humans and animals. Although there have been epidemiological studies that report adverse neurological effects following extended exposure to very high levels in drinking-water, there are a number of significant potential confounding factors in these studies, and a number of other studies have failed to observe adverse effects following exposure through drinking water WHO (2011). Manganese is naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking-water. Manganese occurs naturally in many food sources, and the greatest exposure to manganese is usually from food. Manganese at 0.02 mg/l, will form coatings on piping that may later tear off as a black precipitate. Manganese concentrations above 0.1 mg/l impart an undesirable

taste to drinking water. When manganese (II) compounds in solution undergo oxidation, manganese is precipitated. Humans can consume as much as 20 mg/day without apparent ill effects. Manganese is believed to have a neurotoxic effect; a provisional health-based guideline value of 0.5 mg/l is proposed to protect public health (WHO 1996). Previous studies show maximum levels in groundwater to be 1.3 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 2.43 mg/l (Kuma and Younger 2004).

2.9.8 Arsenic

Arsenic is found widely in the Earth's crust in oxidation states of -3, 0, $+3$ and $+5$, often as sulfides or metal arsenides or arsenates. In water, it is mostly present as arsenate ($+5$), but in anaerobic conditions, it is likely to be present as arsenite ($+3$). It is usually present in natural waters at concentrations of less than $1–2$ $\mu g/l$. However, in waters, particularly groundwaters, where there are sulphide mineral deposits and sedimentary deposits deriving from volcanic rocks, the concentrations can be significantly elevated. Arsenic is found in the diet, particularly in fish and shellfish, in which it is found mainly in the less toxic organic form. There are only limited data on the proportion of inorganic arsenic in food, but these indicate that approximately 25% is present in the inorganic form, depending on the type of food. Apart from occupational exposure, the most important routes of exposure are through food and drinking-water, including beverages that are made from drinking-water. Where the concentration of arsenic in drinking-water is 10 $\mu g/l$ or greater, this will be the dominant source of intake. In circumstances where soups or similar dishes are a staple, part of the diet, the drinking water contribution through preparation of food will be even greater. Arsenic is found in the deep bedrock materials as well as the shallow glacial materials in the study areas.

They are also found alongside the gold ores such arsenopyrites (FeAsS) (Coakley, 1996). Arsenic is usually present in the environment in inorganic form. The inorganic arsenic easily dissolves and enters underground and surface waters. The presence of arsenic in the environment may be attributed to one of the following sources: residual arsenic from pesticidal use, smelter emission from ores of gold such as arsenopyrites. According to (Tseng et al., 1968), chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high. Tseng et al., (1968), noted that, hyperpigmentation, keratosis and possible vascular complications were seen at Lowest-Observed-Adverse-Effect-Level (LOAEL) = 0.17mg/L (0.014mg/kg/day). The No Observed Adverse Effect Level (NOAEL) = 0.009mg/L of water (0.0008mg/kg/day). According to (IARC, 1980), inorganic form of arsenic is classified as a class A Carcinogen (Human Carcinogen). This classification is based on sufficient evidence from human data i.e., increased lung cancer mortality was observed in multiple populations exposed to arsenic primarily through drinking of arsenic contaminated water. Again, an increased mortality from multiple internal cancers (liver, kidney, lung and bladder) and an increased incidence of skin cancer had been observed in populations consuming drinking water with high inorganic arsenic concentration. Guideline value 0.01 mg/l (10 µg/l is designated as provisional on the basis of treatment performance and analytical achievability. Occurrence levels in natural waters generally range between 1 and 2 µg/l, although concentrations may be elevated (up to 12 mg/l) in areas containing natural sources. There remains considerable uncertainty over the actual risks at low concentrations, and available data on mode of action do not provide a biological basis for using either linear or non-linear extrapolation. In view of the practical difficulties in removing arsenic from drinking-water, as well as the practical quantification

35

limit in the region of 1–10 µg/l, the guideline value of 10 µg/l is retained and designated as provisional. It is technically feasible to achieve arsenic concentrations of 5 µg/l or lower using any of several possible treatment methods. However, this requires a careful process optimization and control, and a more reasonable expectation is that 10 µg/l should be achievable by conventional treatment (e.g. coagulation). As arsenic is one of the chemicals of greatest health concern in some natural waters, its chemical fact sheet has been expanded.

2.9.9 Mercury

Elemental mercury is a silvery metallic liquid that is volatile at room temperature. Mercury is found in soil and rocks typically as an ore known as cinnabar, consisting of insoluble mercuric sulphide. Methylation of inorganic mercury has been shown to occur in fresh water and in seawater, although almost all mercury in uncontaminated drinking-water is thought to be in the form of Hg^{2+}. Thus, it is unlikely that there is any direct risk of the intake of organic mercury compounds, especially of alkylmercurials, as a result of the ingestion in drinking-water. In Ghana, the presence of mercury in the environment may be attributed to the use of mercury in gold recovery processes where the inorganic form of the metal either is washed into rivers or is vaporized readily into the atmosphere (Obiri, 2005; Essumang et al., 2007). Mercury compounds are also used as germicides and fungicides, and as industrial catalyst in the manufacture of plastics, pulp paper, paints, cosmetics, batteries, etc. Mercury is a non essential element, a neurontoxin and has tertogenic effects. It also affects the renal system, nervous system, gastrointestinal tract and the respiratory system. According to International Programme on Chemical Safety (IPCS), 2004, it was responsible for the death of 52 people in Minamata, Japan in 1952 through eating of contaminated fish (Lee, 1994). Mercury has been

shown to be toxic to human populations because of occupational exposure and accidental ingestion of mercury-contaminated food. The nature of mercury toxicity depends on its chemical form. For example, methylmercury (MeHg) is very toxic as compared to inorganic mercury. The methylmercury is of special concern because of its enhanced lipohilicity, bioaccumulation and volatility as compared with the inorganic mercury. For this reason, it is able to cross biological membranes more easily and enters the brain, spinal cord, the peripheral nerves and the placenta. The foetus in the uterus may show symptoms of cerebral palsy through mercury intoxication, even though the mother may not show symptoms of mercury poisoning (Kpekata, 1974; W.H.O., 1990). Accidental exposure to high levels of organic mercury compounds has produced developmental toxicity in humans. Aryl mercury compounds are even more dangerous and cause brain damage giving numbness, loss of vision, deafness, madness and death WHO (1990). The USEPA has classified both mercuric chloride and methylmercury as possible human carcinogens (Group C), based on the absence of data in humans and limited evidence of carcinogenicity in animals, whereas elemental mercury is in Group D, i.e., not classifiable due to inadequate data (Barregard, *et al.,* 1990). The toxic effects of inorganic mercury compounds are seen mainly in the kidney in both humans and laboratory animals following short-term and long-term exposure. In rats, effects include tubular necrosis, proteinuria and hypoalbuminaemia. In humans, acute oral poisoning results primarily in haemorrhagic gastritis and colitis; the ultimate damage is to the kidney. The overall weight of evidence is that mercury(II) chloride has the potential to increase the incidence of some benign tumours at sites where tissue damage is apparent and that it possesses weak genotoxic activity but does not cause point mutations WHO (2005).

CHAPTER THREE

MATERIALS AND METHODS

3.0 STUDY AREA

3.1 Location and Size

Talensi-Nabdam, was carved out of the Bolgatanga District in August 2004. Tongo is its district's capital. It has a population of about 94,650 (Talensi/Nabdam, 2011) and located in the Upper East Region in Fig.1. The District is bordered to the North by the Bolgatanga District, South by the West and East Mamprusi Districts, Kassena-Nanakana District to the West and the Bawku West District to the East. The district lies between latitude 10.15° and 10.60° north of the equator and longitude 0.31° and 10.5. The district is made up of eleven towns and has agriculture as the main source of employment. Others activities undertaken by the people are fuel wood gathering, food processing and mining. The area lies within the Nangodi gold belt of Ghana (Kesse, 1985).

Figure 1: Location of Talensi-Nabdam District

3.2 Topography and Drainage

The topography of the district is dominated by relatively undulating lowlands gentle slopes ranging from 1% to 5% gradient with some isolated rock out crops and some uplands slopes at the Tongo and Nangodi areas (Talensi/Nabdam, 2011). It falls within the Birimanian, Tarkwanian and Voltarian rocks of Ghana. There is evidence of the presence of minerals especially gold in the district. Figure 2 below shows a 72sq km mining area used for the study. The district is drained mainly by the Red and White Volta and their tributaries (Talensi/Nabdam, 2011).
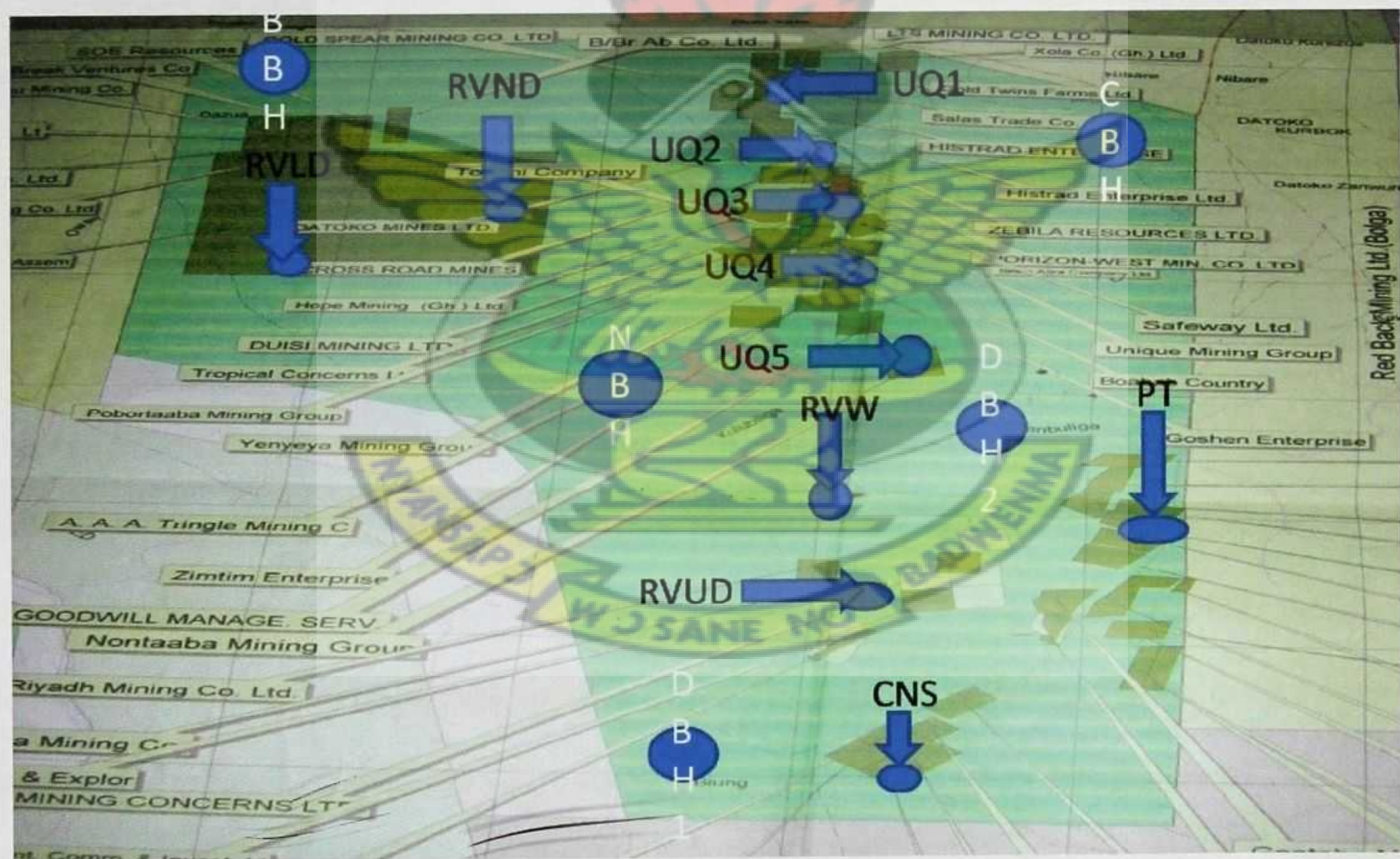
Figure 2: Location of the study area

3.3 Climate and Vegetation

Talensi-Nabdam district is situated on the border of two climatic regions. The southern part belongs to the savanna zone and the northern part has Sahel zone. Generally the rainfall pattern follows the northward advance and the southward retreat of the inter-tropical convergence zone that separates dry air from Sahara and the moisture-monsoon air from the Atlantic Ocean. The north air mass, locally called the Harmattan, brings in hot and dry weather from December to February (Dickson and Benneh, 1980). The area is characterized by one rainy season from May to October. Rainfall peak occurs in August-September. The mean annual rainfall is approximately 75 mm and the area is very humid and warm with temperatures between 35-40 °C (Meteorological Services Department-Bolga, 2011).

3.4 Geology

3.4.1 The Birimian

The District is located within the Birimian system with basement by at least 6 discreet volcanic belts with intervening sedimentary basins of very similar Early Proterozoic age (about 2200-213 Ma). Within the Volcanic belts there are many largely coeval, intermediate to mafic plutons. All Birimian-age units have been metamorphosed during the major Eburnean tectonic cycle (about 2135-2100 Ma). The upper part of the system is dominantly of volcanic and pyroclastic origin. The rocks consist of bedded groups of green lava (Kortatsi, 2004). Lava and tuff dominate this part (Gyau-Boakye and Dapaah-Siakwan 2000). Several bands of phyllite occur in this zone and are manganiferous in places. In the Birimian system, gold occurs in five parallel, more than 300km long, northeast trending volcanic belts. They are

separated by basins containing pyroclastic and metasedimentary units. The gold occurrence is 2 to 30 ppm in quartz veins of laterally extensive major ore bodies. They deeply penetrate fissures and shear zones in contact between meta-sedimentary and meta-volcanic rocks. The veins consist of quartz with carbonate minerals, green sericite, carbonaceous partings and metallic sulphides and arsenides of Fe, As, Zn, Au, Cu, Sb and Pb (Dzigbodi-Adjimah, 1993). The Birimian system has a higher content of heavy metals (Kortatsi, 2004).

3.4.2 Granitoids

Large masses of granitoids of the Bongo Granitoids have intruded the Birimian system. It is well foliated and the potash rich rocks consist of muscovite and biotite granite and granodiorite ore porphyrblastic biotitic gneiss, applite and pegmatite. They are characterized by the presence of many enclaves of schists and gneisses. It consists of hornblende granite or granodiorite grading locally into quartz diorite and hornblende diorite. The complex forms non-foliated discordant or semidiscordant bodies in the enclosing country rock, generally Upper Birimian meta-volcanics (Kesse, 1985)

3.4.3 Hydrogeology

Groundwater is the main source of water supply in the study area. In the Talensi-Nabdam area groundwater occurrence is associated with the development of secondary porosity through fissuring and weathering (Hydrological Dpt Bolga, 2010). The weathering depth is greatest in the Birimian system where depths between 90 m and 120 m have been reached. Also in granites, porhyrites, felsites and other intrusive rock the weathering depth is great. The

weathered aquifer occurs mainly above transition zone between fresh and weathered rock. Due to the soils content of clay and silt, these aquifers have high porosity and storage but low permeability (Hydrological Dpt Bolga, 2010).

Groundwater circulation in the Talensi-Nabdam area is mainly localized due to the numerous low hills that act as groundwater divides. Groundwater circulation is mainly restricted to quartz veins and fissures-faults-brecciated zones in the area (Hydrological Dpt Bolga, 2010).

3. 5 SAMPLING

The water samples were collected at upstream and downstream of the Kulubiliga River which runs through some of the communities as well as water from the boreholes within the communities in the study areas. Water samples were also collected, from mine shafts from the following communities; Nangodi, Pelugu, Duusi, Gbane, Datoko and Bingo. A total of one hundred and forty-four (144) samples were collected from sixteen sampling points from February 2012 to April 2012, in every month. Samples from each sampling point were analyzed separately for the following chemicals; Pb, Cr, Cd, Cu, Zn, Fe, Mn, As and Hg. Physico – chemical parameters such as pH, conductivity, colour, turbidity, total suspended solids and total dissolved solids were measured using standard methods. Water samples were collected using a hand held GPS in order to locate the coordinates of the sampled area as shown in Fig.2.

3.5.1pH MEASUREMENT

An electrode was connected to the pH meter and the system was calibrated using pH 4 and 7 buffers. pH was read at in-situ from the sampling points before water samples were collected

into the pre treated plastic bottles to analyze for both physico-chemical parameter and heavy metals.

3.6 SAMPLE COLLECTION, PREPARATION AND STORAGE:

The water samples were collected from the sampling points into plastic bottles that have been pre – washed with detergent and tap water, and later rinsed with 1:1 conc. nitric acid and distilled water.

The sampling bottles were rinsed three times with the water samples from the sampling points after which 1.5 L of the water samples were acidified with nitric acid at collection point for heavy metals analysis. The samples that were collected for physico-chemical parameters analysis were not acidified. Labels were fixed on each sample for easy identification. Samples were stored in an ice – chest at 4 °C and transported to the laboratory for analysis. In the laboratory, the acidified samples were filtered using Whatman's no. 0.45 μm filter paper. The filtered samples used for heavy metals and the unfiltered samples which were used for pysico-chemical parameters were all stored in the refrigerator.

3.7 LABORATORY ANALYSIS

Laboratory analyses were carried out in the laboratories at Water Research Institute of Centre for Scientific and Industrial Research (CSIR), and the Environmental Chemistry laboratory of (CSIR), in Accra. The physico- chemical parameters determined included turbidity, colour, conductivity, total dissolved solids, total suspended solids (TSS), sodium, potassium, calcium,

magnesium, total iron, ammonium, chloride, sulphate, phosphate, nitrate, nitrite, total hardness, fluoride, bicarbonate and carbonate.

3.7.1 Digestion of samples for the analysis of heavy metals

Water samples of 100 ml from the Kulubiliga River, Pits and Boreholes water sample were mixed with 5 ml conc. HNO_3. The mixture was then heated until the volume was reduced to about 20 ml. The digested sample was allowed to cool to room temperature. The final volume was adjusted to 100 ml with distilled water and stored for analysis.

3.7.2 Measurement of heavy metals

Equipment Unilam 969 AAS equipped with cold vapour accessory was used to measure the heavy metals. Arsenic and Mercury were measured using the cold vapour cell of the AAS unit. The reduction of the Hg was done with 1.1% $SnCl_2$ in 3% HCl.

Table 1: Fuel gas, Oxidant gas, Wavelength, Slit width and Lamp current of the HCL

Element	Fuel Gas	Oxidant Gas	Wavelength nm	Slit Width nm	Lamp Current mA
Cu	Acetylene	Air	324.8	0.5	4
Cr	Acetylene	Air	357.9	0.2	7
Zn	Acetylene	Air	213.9	1.0	5
Mn	Acetylene	Air	279.5	0.2	5
Fe	Acetylene	Air	248.3	0.2	5
Pb	Acetylene	Air	217.0	1.0	10
Cd	Acetylene	Air	228.8	0.5	4
As	Argon	Air	193.7	0.5	10
Hg	Argon	Air	253.7	0.5	4

3.7.3 Recovery and Reproducibility

In order to determine for the sensitivity and efficiency of the method used in the chemical analysis, recovery and reproducibility studies were conducted.

In the reproducibility studies, distilled water containing 1.0 mg/l of Lead Chromium, Cadmium, Iron, Copper, Zinc, Manganese, Arsenic and solutions were determined using Unilam 969 AAS with 50mm burner and cold vapour for mercury. From Table3.2 the percentage of the metals recovered varies from 97.5% for lead with a standard error of 0.006 to 99.6% for Arsenic also with a standard error of 0.005. The standard error is less than 1 which suggests that the method employed for the chemical determination of Lead Chromium, Cadmium, Iron, Copper, Zinc, Manganese, Arsenic and Mercury was reproducible

3.8 PHYSICO-CHEMICAL METHODS USED FOR WATER ANALYSES

The physico-chemical parameters were determined according to procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Turbidity was measured with a HACH 2100 P Turbidimeter, and colour by visual comparison method comparator, and pH by pH Meter. Conductivity was measured with Cybersan PC 510 conductivity meter, total dissolved solids and suspended solids were measured gravimetrically after drying in an oven to a constant weight at 105^0C. Sodium and potassium were measured by flame emission photometry, calcium and magnesium by the EDTA titration, sulphate by the turbidimetric method, and chloride by Argentometric titration. Other analyses included alkalinity was measured by acid titration. Nutrients (nitrates-nitrites and phosphate-) were determined using hydrazine reduction method and stannous chloride method respectively and

ammonium by direct nesslerisation and spectrophotometric determination at 410 nm. Fluoride by SPADNS method, total iron and manganese by Atomic Absorption spectrophotometry (AAS).

3.8.1 Turbidity (Nephelometric method)

Turbidity was measured in NTU: Nephelometric Turbidity Units. The method measured the amount of light that was scattered and absorbed by particles in the sample. It was a measurement that required the use of nephelometer to compare a reference solution to the sample. Turbidity measurement did not require any sample preparation, other than shaking the sample bottle well before analysis. The sample was poured into a glass tube, placed inside the instrument with a reference solution and the result was read directly from the instrument

3.8.2 Colour by Visual Comparison Method

The Nessler tube was filled to the 50 ml mark with the water sample. The sample was placed on the compartment of the Nesslerizer lighted cabinet. Distilled water was placed on the compartment for reference. The colour disk was placed in the disk compartment and the light of the Nesslerizer was switched on. The disk was rotated until a colour match was obtained. The colour in the Hazen from the disk was read. If the colour exceeded 70 units, it was diluted.

Colour was calculated using the following equation:

$$\text{Colour units (Hz)} = \frac{A \times 50}{B}$$

Where A = estimated colour of diluted sample

B = Volume ml of sample

3.8.3 Conductivity

The conductivity cell and the beaker to be used were rinsed with the portion of the sample to be examined. The beaker was filled completely. The cell of the conductivity meter was inserted into the beaker. When the water sample and the equipment reached the same temperature, the value indicated on the conductivity on the meter was recorded.

Conductivity was calculated using the following formula:

$$k = \frac{(K_m) \times C}{1 + 0.0191\ (t - 25)}$$

Where:

K_m = measured conductivity, µS/cm at 25°C

C = Cell constant, cm^{-1}

t = Temperature of sample.

3.8.5 Suspended solids (Gravimetric method)

Filtration apparatus was assembled. The filter was wet with 10 ml of deionised water to seat it. The sample bottle was vigorously shaken and 100 ml of the samples was transferred to the funnel and filtered. The filter was washed with three successive 10 ml volume of distilled water allowing drainage between washings and suction continued for about three minutes after filtration was complete. The filter was carefully removed from the holder and transferred into a weighing dish. It was dried for an hour at 105 ^{0}C in an oven. It was cooled in a dessicator and weighed. The drying cycle was repeated until weight loss less than 0.5mg was obtained. Total suspended solids were calculated as follows:

$$TSS \ (mg/l) = \left(\frac{A-B}{C} \times 10^6 \right)$$

Where A = weight of filter + dish + residue

B = Weight of filter + dish,

C = Volume ml of sample filtered

3.8.6 Total Dissolved Solids (TDS) (Gravimetric method)

A clean evaporation dish was heated to 180 ^{0}C for one hour in the oven. It was cooled in a desicator and stored. It was weighed immediately before use. The sample bottle was vigorously shaken and 100 ml volume was transferred to the funnel by means of a 100 ml graduated cylinder. The sample was filtered through the glass fibre and continued vacuum was applied for about three minutes after filtration. It was washed with three 10 ml volume of deionised water and suction continued for three minutes. The total filtrate with the washings

48

was transferred to a weighing evaporating dish and evaporated to dryness on a water bath. The sample was dried for at least one hour. It was cooled in a desicator weighed to a constant weight. The drying cycle was repeated until weight loss less than 0.5mg was obtained.

$$TDS \ (mg/l) = \left(\frac{A-B}{C} \times 10^6 \right)$$

Where A = mass of residue + dish,

B = mass of dish,

C = Volume of sample,

3.8.7 Sodium Determination (flame Photometric Method)

A digital Flame Analyser (Gallenkamp, FGA-350-1) was used. It was calibrated with five (5) freshly prepared sodium (Na) standards in the range of 1-10 mg/l.

Power from the mains to the flame photometer and the compressor was switched on. The filter selector on the flame photometer was pushed to Na. The coarse sensitivity knob was adjusted to the third position for Na i.e.589 nm. The liquefied petroleum gas attached to the machine was turned on. The gas knob on the photometer element was turned full time anticlockwise to allow the gas to flow into the machine. Sodium concentration was determined.

This method read intensify and the actual concentration in mg/l was read from the calibration curve, where Na concentration was high, it was diluted.

The results were calculated as:

mg/l Na = (mg/l Na in aliquots) x D

Where D = dilution ratio   i.e.

$$D = \frac{\text{ml sample} + \text{ml distilled water}}{\text{ml sample}}$$

3.8.8 Potassium Determination (flame Photometric Method)

A digital Flame Analyser (Gallenkamp, FGA-350-1) was used. It was calibrated with five (5) freshly prepared potassium (K) standards in the range of 1-10 mg/l to produce a straight line curve. It operated on the wavelength of 768 nm.

Power from the mains to the flame photometer and the compressor was switched on. The filter selector on the flame photometer was pushed to potassium. The coarse sensitivity knob was adjusted to the third position for K i.e.768 nm. The liquefied petroleum gas attached to the machine was opened. The gas knob on the photometer element was turned full time anticlockwise to allow the gas to flow into the machine. Potassium concentration was determined.

This method read the optical density, and the actual concentration in mg/l was read from the calibration curve, where K concentration was high, it was diluted.

The results were calculated as:

Mg/l K = (mg/l K in aliquots) x D

Where D = dilution ratio i.e. $D = \dfrac{\text{ml sample} + \text{ml distilled water}}{\text{ml sample}}$

3.8.9 Calcium by EDTA Titrimetric Method

50 ml of the sample was taken and 2 drops of 1M NaOH solution was added. It was stirred and 0.1-0.2 g of murexide indicator added and titrated immediately.

Ethylenediaminetetraacetic acid disodium salt (EDTA) titrant was added slowly with continous stirring until the colour changed from salmon to orchid purple. The end-point was checked by adding 1 or 2 drops of the titrant in excess to ensure no colour change took place. Calcium content was calculated from the following formula:

$$Ca \left(^{mg}/_{l}\right) = \frac{A \times B \times 400.8}{ml \; sample}$$

Where A= ml of EDTA titrant used

$$B = \frac{ml \; of \; standard \; calcium \; solution}{ml \; of \; EDTA \; titrant}$$

3.8.10 Total hardness by EDTA Titrimetric Method

Fifty (50) ml of the sample was pipetted into a conical flask 1ml of the buffer solution was added to produce a pH of 10 ± 0.1. A few crystals (0.1 - 0.2 g) of Eriochrome Black T indicator were added. It was mixed constantly and titrated with standard 0.01M EDTA (Ethylenediaminetetraacetic acid disodium salt) until the last traces of purple disappeared.

$$Total \; Hardness = \frac{ml \; EDTA \times B \times 1000}{ml \; sample}$$

Where B = mg of $CaCO_3$ equivalent to 1.00ml EDTA titrant.

$$i.e \quad \frac{\text{ml } CaCO_3}{\text{ml EDTA}}$$

3.8.11 Magnesium (Calculation Method)

Magnesium hardness was calculated from the difference between the total hardness and the calcium hardness. Magnesium content was obtained by multiplying the magnesium hardness by 0.243.

Total hardness and Calcium were calculated as follows:

(i) From the Calcium titration, calcium hardness was calculated;

(a) Calcium hardness $\left(\frac{CaCO_3}{mg}\right) = \frac{A \times B \times 1000}{ml\ sample}$

where

A= ml titrant for sample

B= mg $CaCO_3$ equivalent to 1.00ml EDTA titrant at the calcium endpoint

(ii) Magnesium hardness was calculated as

Mg/l $CaCO_3$ = Total hardness – Calcium hardness

(iv) mg/l Mg = (Total hardness - Calcium hardness) X 0.243

Where 0.243 = atomic weight of Mg/ molecular weight of $CaCO_3$.

3.8.12 Chloride Determination (Moli's Method)

50 ml of clear sample was measured in a beaker and diluted to 100 ml and directly titrated in the pH range of 7 to10. The pH of the sample was adjusted from 7 to 10 with H_2SO_4 with the pH meter, 1 ml of K_2CrO_4 indicator solution was added and titrated with standard $AgNO_3$

titrant to an endpoint colour pinkish yellow. A reagent blank value was established using the same titration method.

The Chloride content was determined by:

$$Cl^-(mg/ l) = (A- B) \times M \times 35,450$$

Where

    A = ml titration for sample

    B = ml titration for blank

    M = Molarity of $AgNO_3$

3.8.13 Sulphate by Turbidimetric Method

One hundred (100) ml of the sample was measured into a 250ml Erlenmeyer flask. Five (5) ml of conditioning reagent (prepared from 50 ml glycerol mixed with a solution containing 30 ml concentrated HCl, 300 ml distilled water, 100 ml 95% ethyl or isopropyl alcohol and 75g sodium chloride) was added and mixed by stirring. A spoonful of barium chloride crystals was added while still stirring and was timed immediately for 60 seconds at a constant speed. After stirring, the absorbance was measured on the Spectrophotometer within 5 minutes.

3.8.14 Phosphate (PO_4-P) by (Molybdenum Blue Method)

One hundred (100) ml of sample free from colour and turbidity was taken and 0.05 ml (1 drop) phenolphthalein indicator was added. Strong sulphric acid was added to decolourise the sample if it taken and diluted to 100 ml with distilled water and phenolphthalein indicator was added and discharged. Four (4.0) ml of Molybdate Reagent I and 0.5 ml (10 drops) Stannous

53

Chloride reagent I (prepared from dissolving 2.5 g of fresh $SnCl_2.H_2O$ in 100 ml glycerol) was added with thorough mixing after each addition. The absorbance was measured at a wavelength of 690 nm on the Spectrophotometer- UV/VIS Ultraspec model II after 10 minutes. The spectrophotometer was zeroed with a blank solution (prepared with 100 ml of distilled water).

3.8.15 Nitrate – Nitrogen by hydrazine Reduction method

Ten (10) ml of water sample was pipetted into a test tube. 1.0 ml of 0.3M NaOH was added and mixed gently. 1.0 ml of reducing mixture which was prepared by adding 20 ml copper sulphate ($CuSO_4$) solution and 16 ml hydrazine sulphate to 20 ml of 0.3M NaOH, was added and mixed gently. It was heated at 60 ^{0}C for 10 minutes in a water bath. It was cooled to room temperature and 1.0 ml of colour developing reagents added. It was shaken to mix and the absorbance was measured at 520 nm with the Spectrophotometer- UV/VIS Ultraspec model II.

3.8.16 Alkalinity by Acid Titration Method

Alkalinity was determined by Titration using strong acid.

One hundred (100) ml of the sample was mixed with two drops of phenolphthalein indicator in a conical flask. If no colour change was produced, the alkalinity to phenolphthalein was zero. If the sample turned pink, the alkalinity to phenolphthalein was determined by titration with standard acid until the pink colour just disappears. In both cases, the determination was continued using the sample to which phenolphthalein has been added. A few drops of methyl

orange indicator were added. If the sample turned yellow, it was titrated with a standard acid until the first perceptible colour change towards orange took place.

$$\text{Phenolphthalein alkalinity (P) as } CaCO_3 = \frac{50,000 \times A \times N}{V} \text{ mg/l}$$

$$\text{Total alkalinity (T) as } CaCO_3 = \frac{50,000 \times B \times N}{V} \text{ mg/l}$$

Where A = Volume (ml) of standard acid solution added to obtain the phenolphthalein endpoint of 8.3 pH.

B = Volume (ml) of standard acid solution added to obtain the methyl orange endpoint of 4.5 pH

N = Normality of the mineral acid

V = Volume of the sample used

3.9 DATA ANALYSIS

Statistical Package for Social Sciences (SPSS) and Micro soft Excel were used to analyze the data. The results of the analysis were presented in tables and figures.

CHAPTER FOUR

RESULTS

4.1 PHYSICO-CHEMICAL PARAMETERS

Appendix 8, Appendix 9 and Appendix 10 contained mean values of physico-chemical parameters from the different sources of the water samples.

4.1.1 Mean levels of Turbidity in water from the sampling points

Water samples from boreholes recorded a value of 4.6 NTU lower than WHO guideline of (5NTU). However, the water samples from the pits water and river water recorded values of 20.3 NTU and 122.6 NTU respectively in Fig.3 shown below.
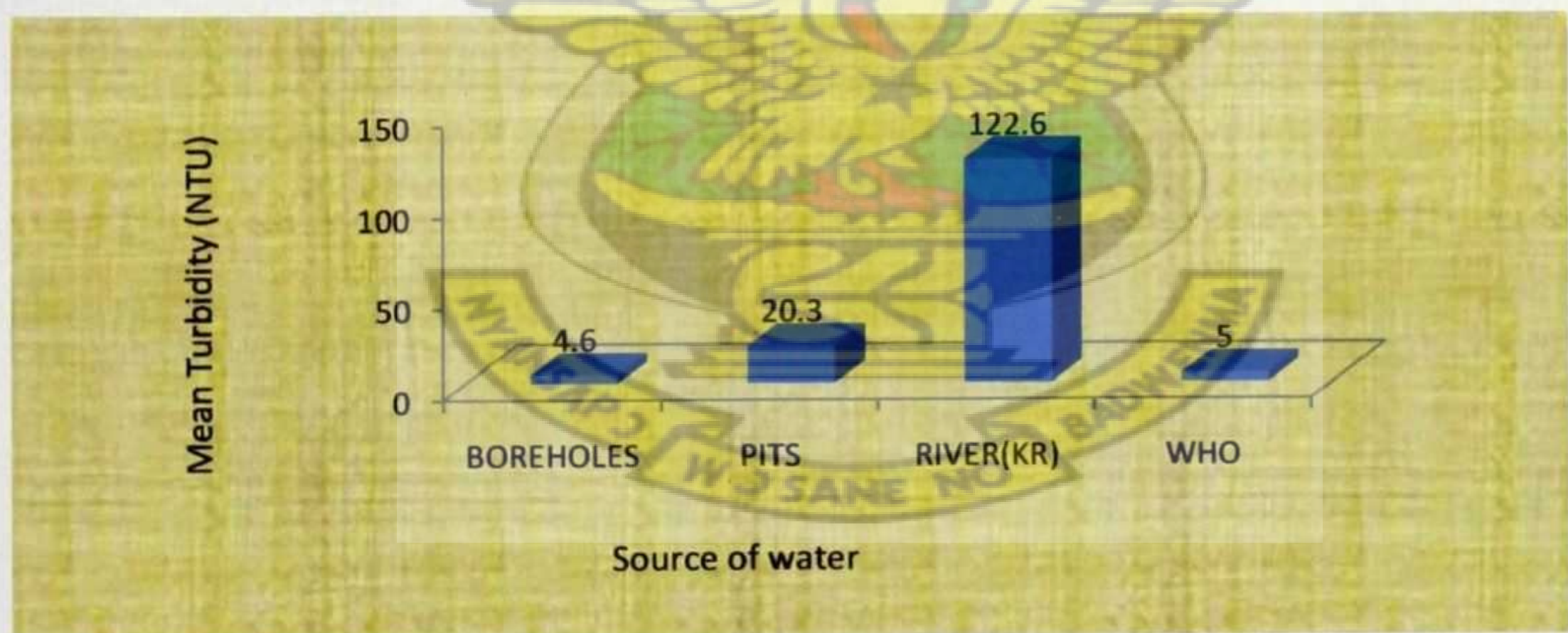
Figure 3: Mean level of turbidity of water samples

4.1.2 Mean levels of Colour in water from the sampling points

Mean levels of water samples recorded in Fig.4 showed below indicates that the river water samples analysed for colour were high in the river compared to WHO guideline of 15 Hz .
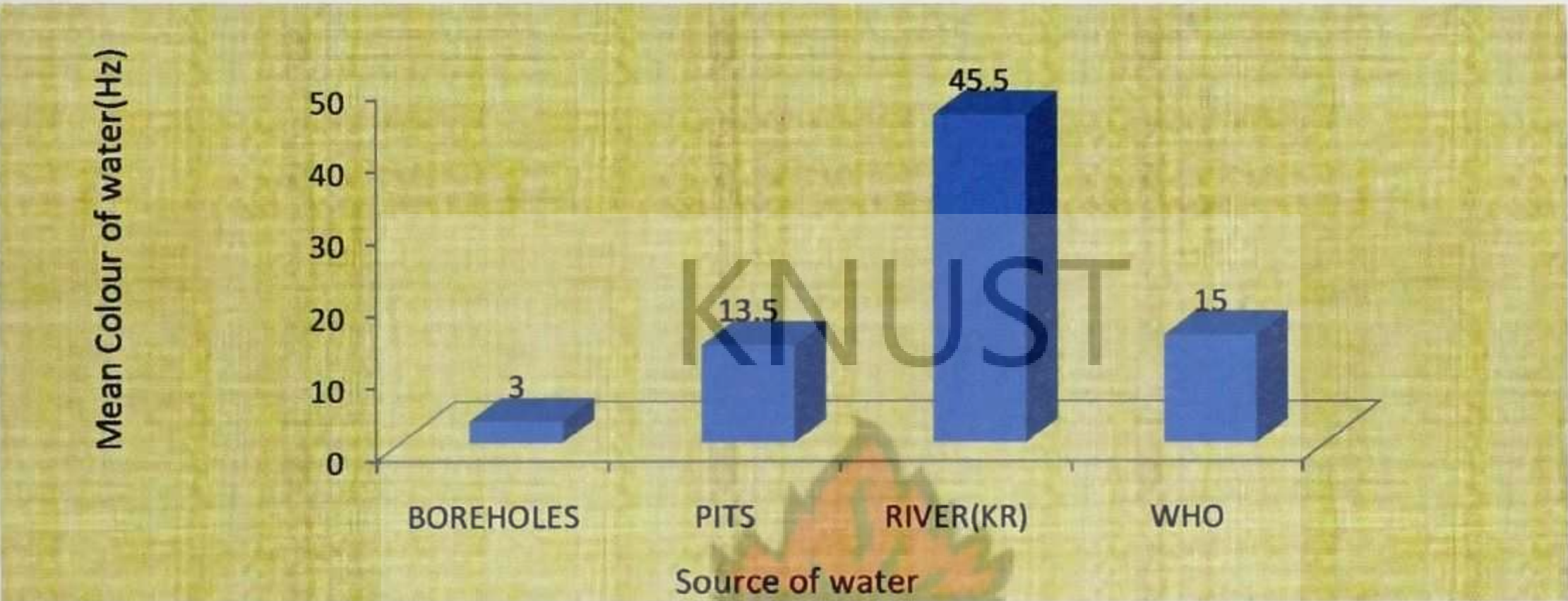
Figure 4: Colour of water samples

4.1.3 Mean levels of pH in water from the sampling points

Mean values of pH level of water from boreholes, pits and river were 7.1, 7.2 and 7.4 respectively indicating values within WHO range values of 6.5-8.5 in (Fig. 5)
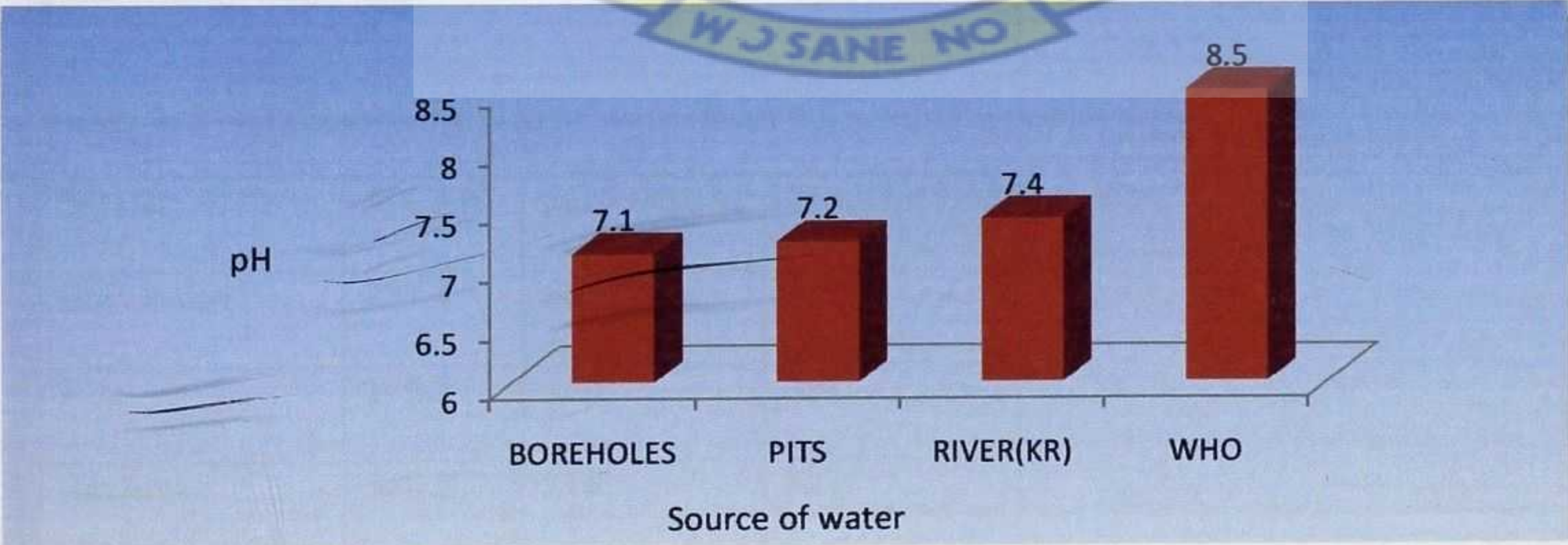
Figure 5: pH of water samples

4.1.4 Mean levels of Total Suspended Solids in water from the sampling points

Total suspended solids in water samples recorded 8.8 mg/l in the river. Meanwhile, the water from pits recorded a mean value of 5.6 mg/l. The borehole however recorded a mean value of 1 mg/l.
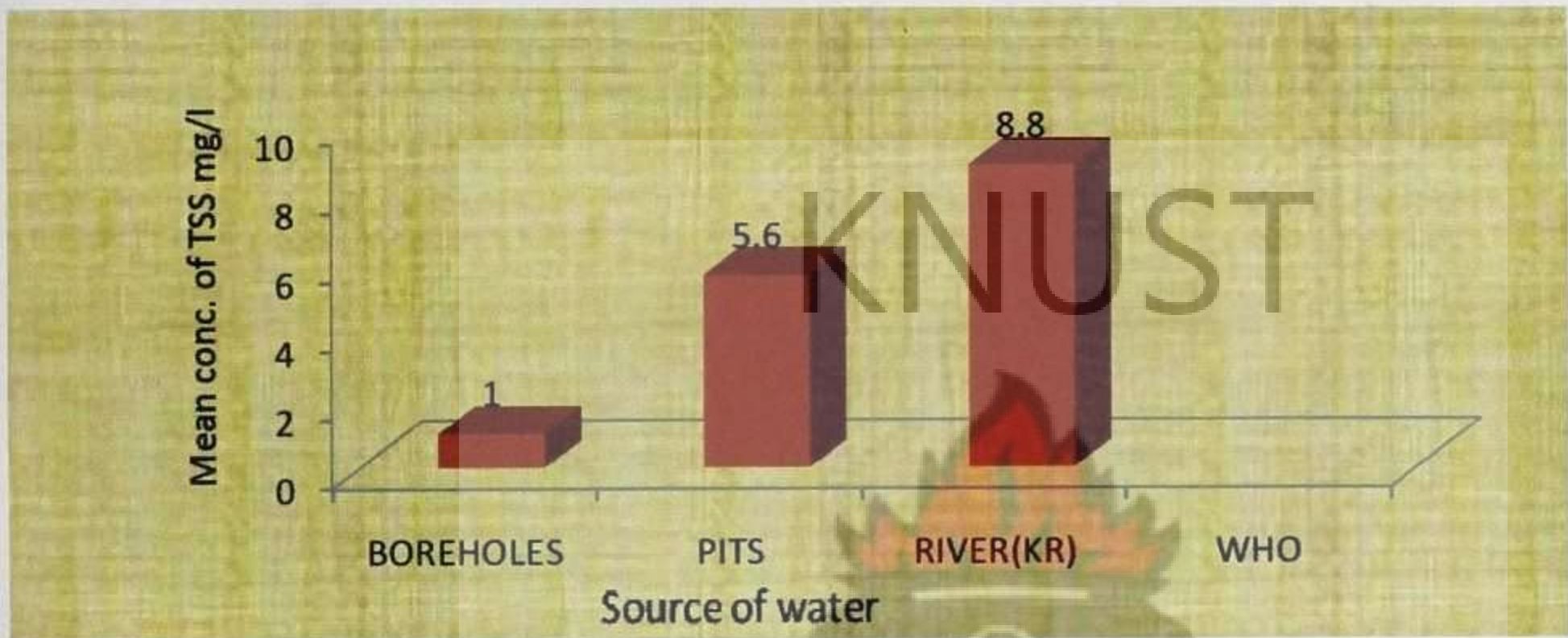
Figure 6: Total Suspended Solids in water samples

4.1.4 Mean levels of Total Dissolved Solids in water from the sampling points

Total dissolved solids in water samples from boreholes; pits and river were 227.4 mg/l, 295.2 mg/l and 548.2 mg/l respectively. In (Table 2), the recorded values fell below the WHO guidelines of 1000 mg/l.

Table 2: Total dissolved solids of water from the sampling points

SOURCE	MEAN	MINIMUM	MAXIMUM
Boreholes	227.4	66	417
Pits	295.2	270	338
Surface	548.2	218	891
WHO	1000	1000	1000

4.1.5 Mean levels of Sodium ion concentration in water from the sampling points

Mean levels of sodium ions concentration in water samples from the boreholes was 4.1 mg/l, while that of the pits and river were 19.9 mg/l and 175 mg/l respectively. However, the high value of WHO guideline of 200 mg/l was above the recorded values in (Fig.7).
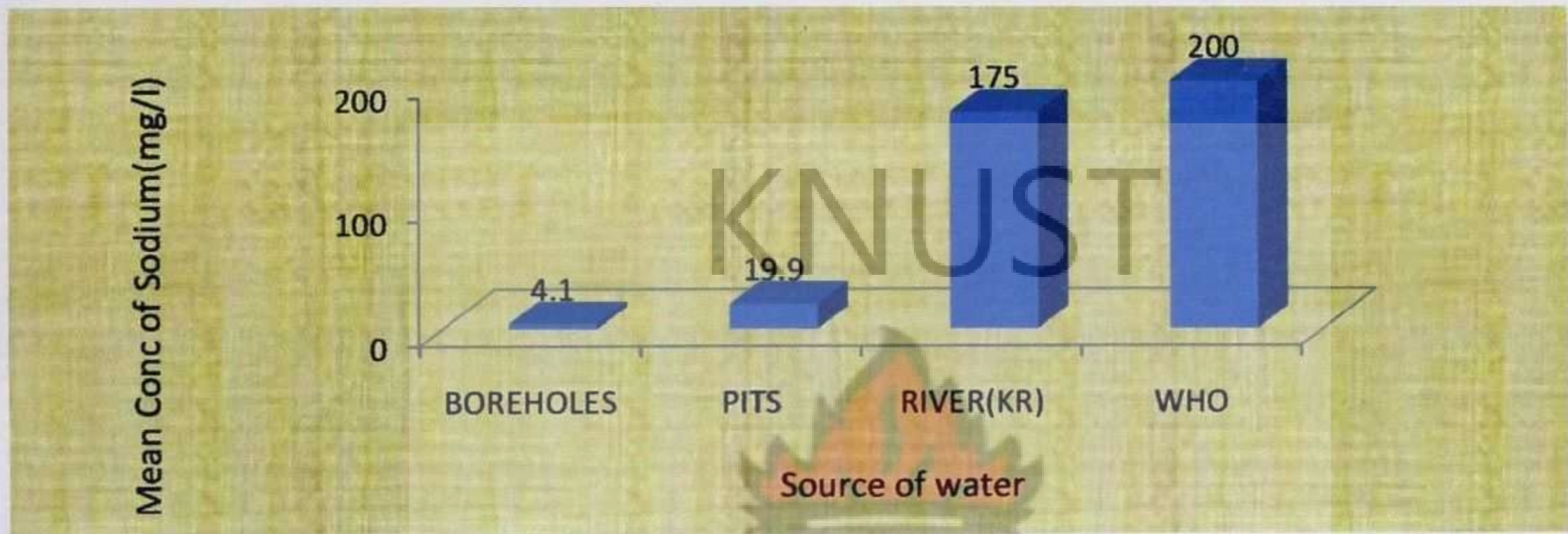
Figure 7: Sodium concentration in water samples

4.1.6 Mean levels of Potassium concentration in water from the sampling points

The water sampled from boreholes, mine pits and the river recorded low mean levels of potassium as presented in (Fig.8). The sampled values fell far below WHO guideline of 30 mg/l.
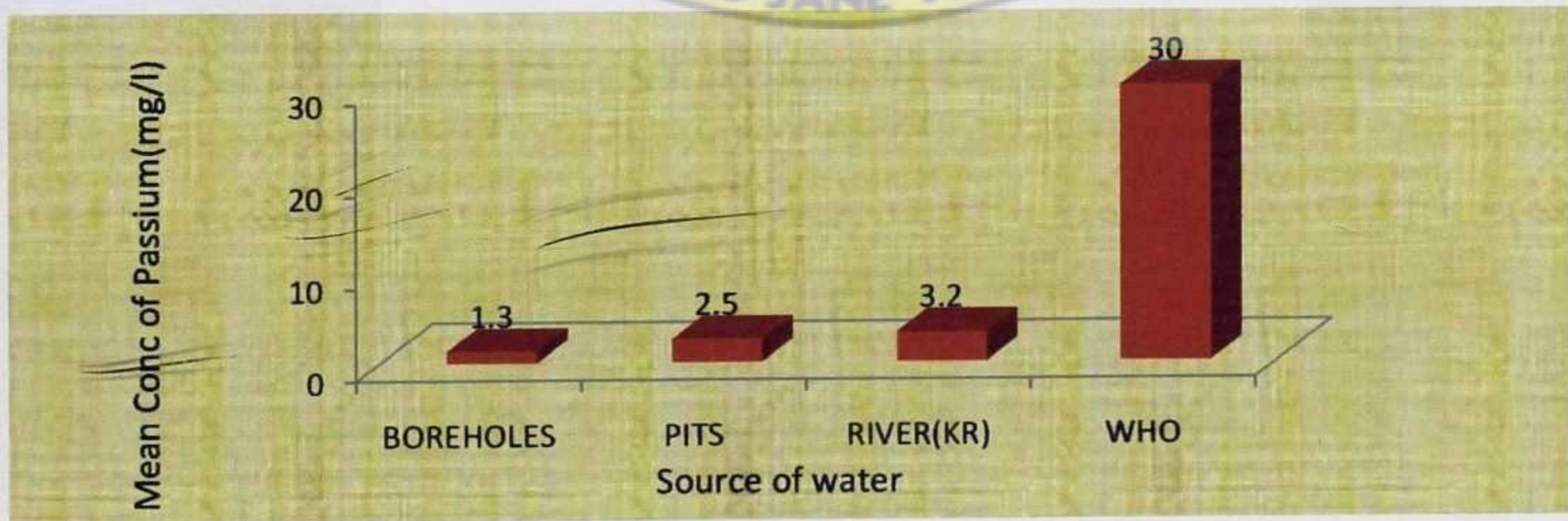
Figure 8: Potassium concentration in water samples

4.1.7 Mean levels of Calcium concentration in water from the sampling points

Calcium levels from all the different sampling points were far below the WHO guideline of 200 mg/l. Water from boreholes recorded mean Ca levels of 24.3 mg/l while 42.9 mg/l was recorded the same for water from both pits and river in (Fig.9).
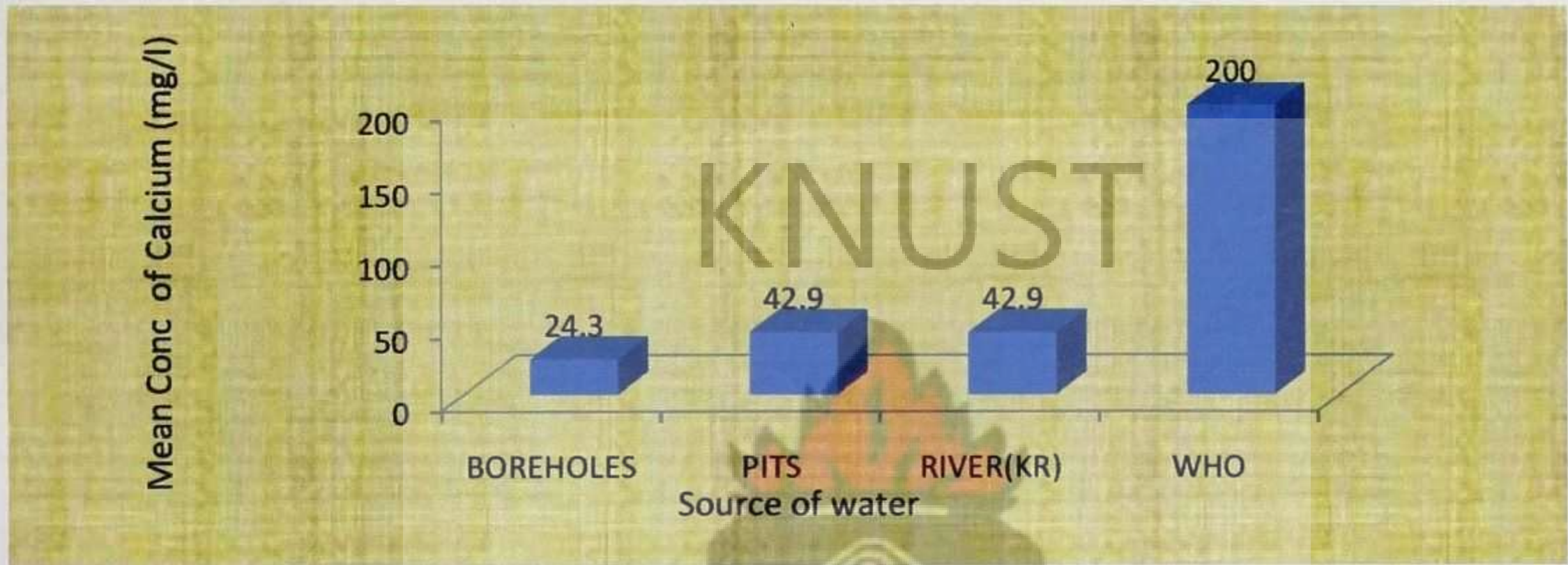
Figure 9: Calcium concentration in water samples

4.1.8 Mean levels of Magnesium concentration in water from the sampling points

Mean levels of magnesium of 18.2 mg/l in boreholes, 24.8 mg/l in pits and 19.7 mg/l in river recorded below the WHO guideline of 150 mg/l as showed in (Fig.10).
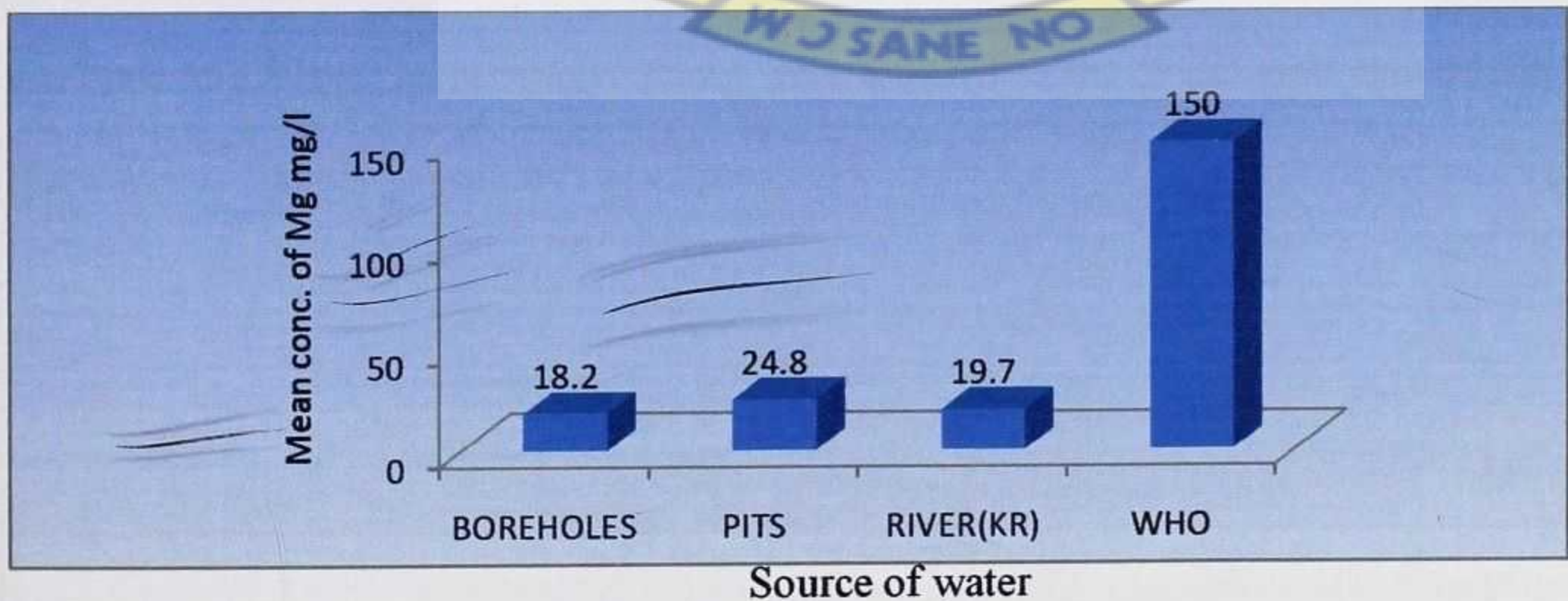
Figure 10: Magnesium concentration in water samples

4.1.9 Mean levels of Chloride concentration in water from the sampling points

Mean levels of chloride in water from boreholes, pits and river were 4.6 mg/l, 21.8 mg/l and 162.1 mg/l respectively in (Fig.11). All these were lower than the WHO guideline of 250 mg/l.
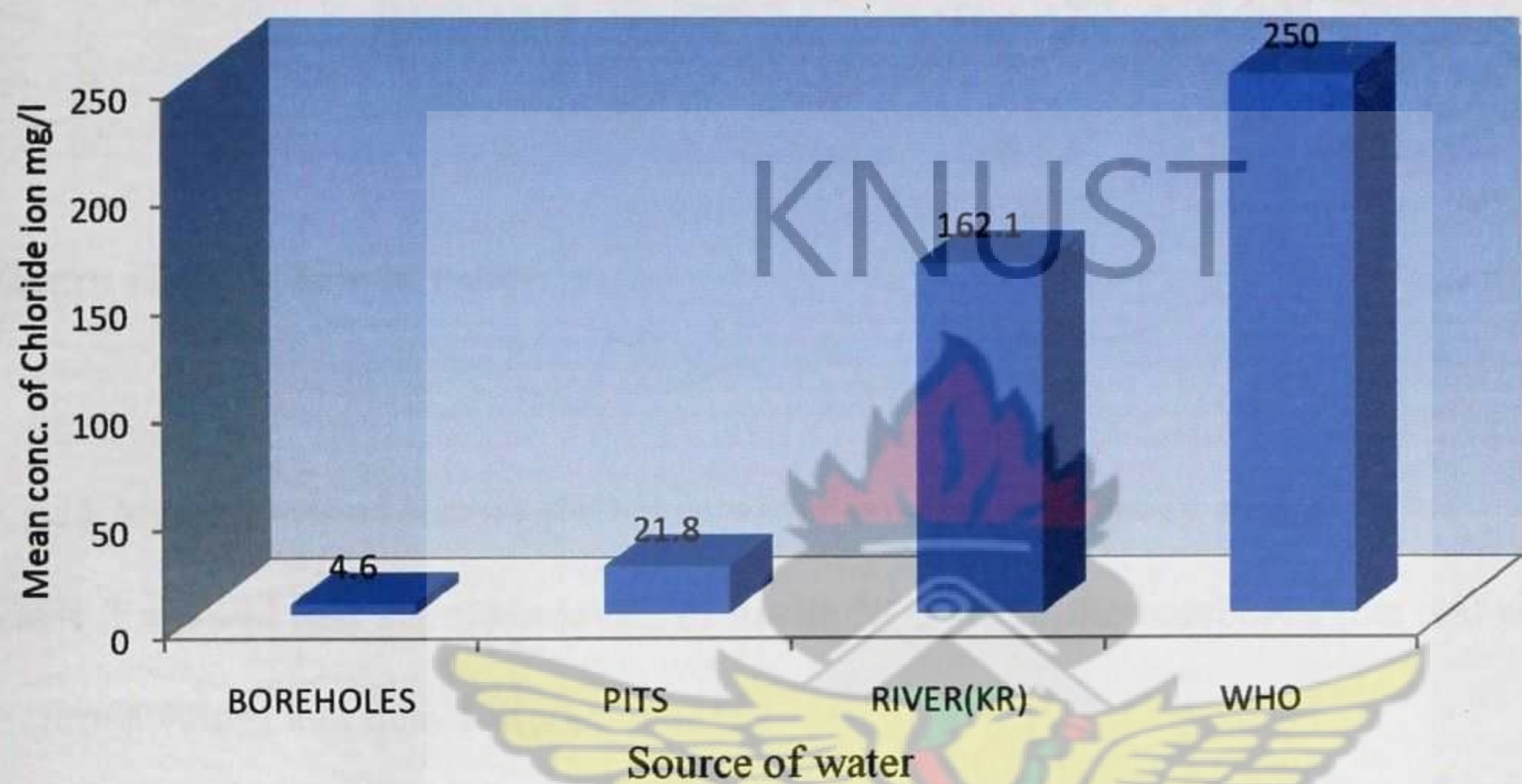
Figure 11: Chloride ion concentration in water samples

4.1.10 Mean levels of Sulphate in water from the sampling points

Sulphate mean levels in water samples from boreholes, pits and river recorded 18.6 mg/l, 34.7 mg/l and 167.8 mg/l respectively. These were lower than the WHO guideline of 250 mg/l in (Fig.12).
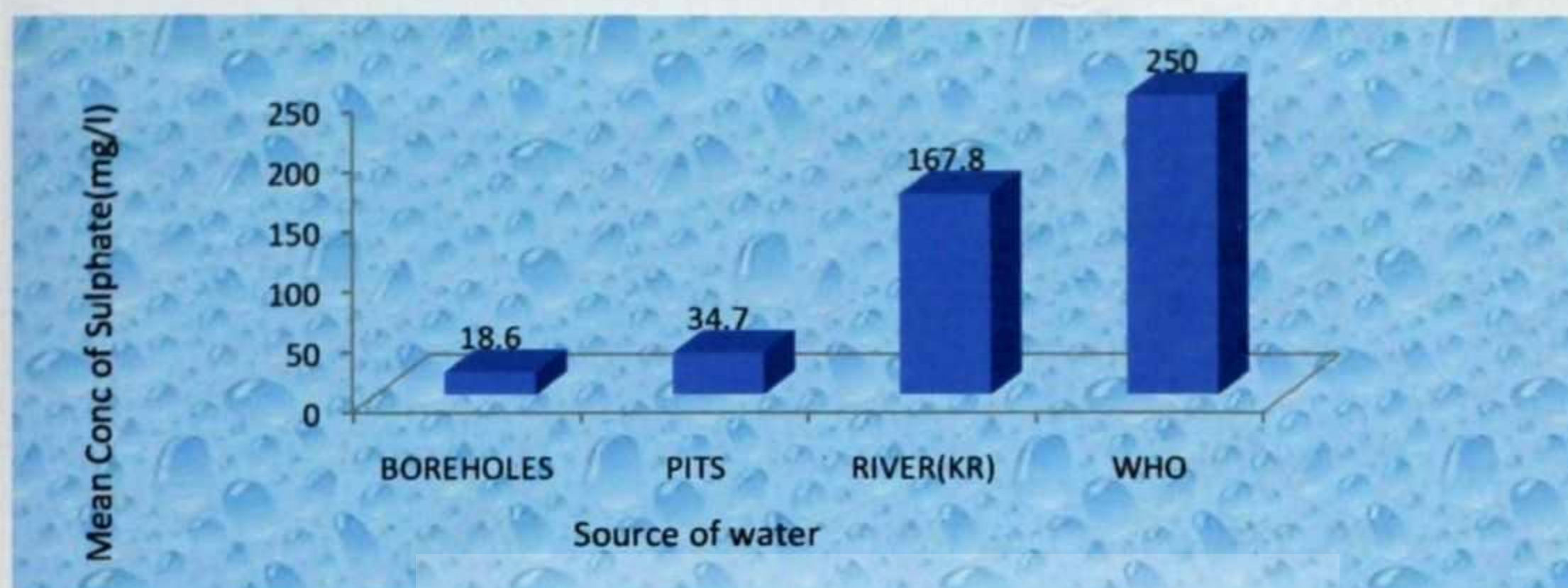
Figure 12: Sulphate in water

4.1.11 Mean levels of Nitrite (NO_2^-) in water from the sampling points

Table 3 showed that the mean levels of nitrite NO_2^- from the boreholes, pits and river water recorded values less than 1 mg/l.

Table 3: Mean level of nitrite NO_2^- in water samples

SOURCE	MEAN	MINIMUM	MAXIMUM
Boreholes	0.001	0.001	0.002
Pits	0.2	0.022	0.842
Surface	0.042	0.013	0.065
WHO	1	1	1

4.1.12 Mean levels of Nitrate NO_3^- in water from the sampling points

In Fig.13, mean levels of nitrite NO_3^- in water samples from boreholes, pits and river were 1.47 mg/l, 0.85 mg/l and 0.1 mg/l respectively. WHO guideline of 10.0 mg/l was however

above the mean values recorded from the experiment.
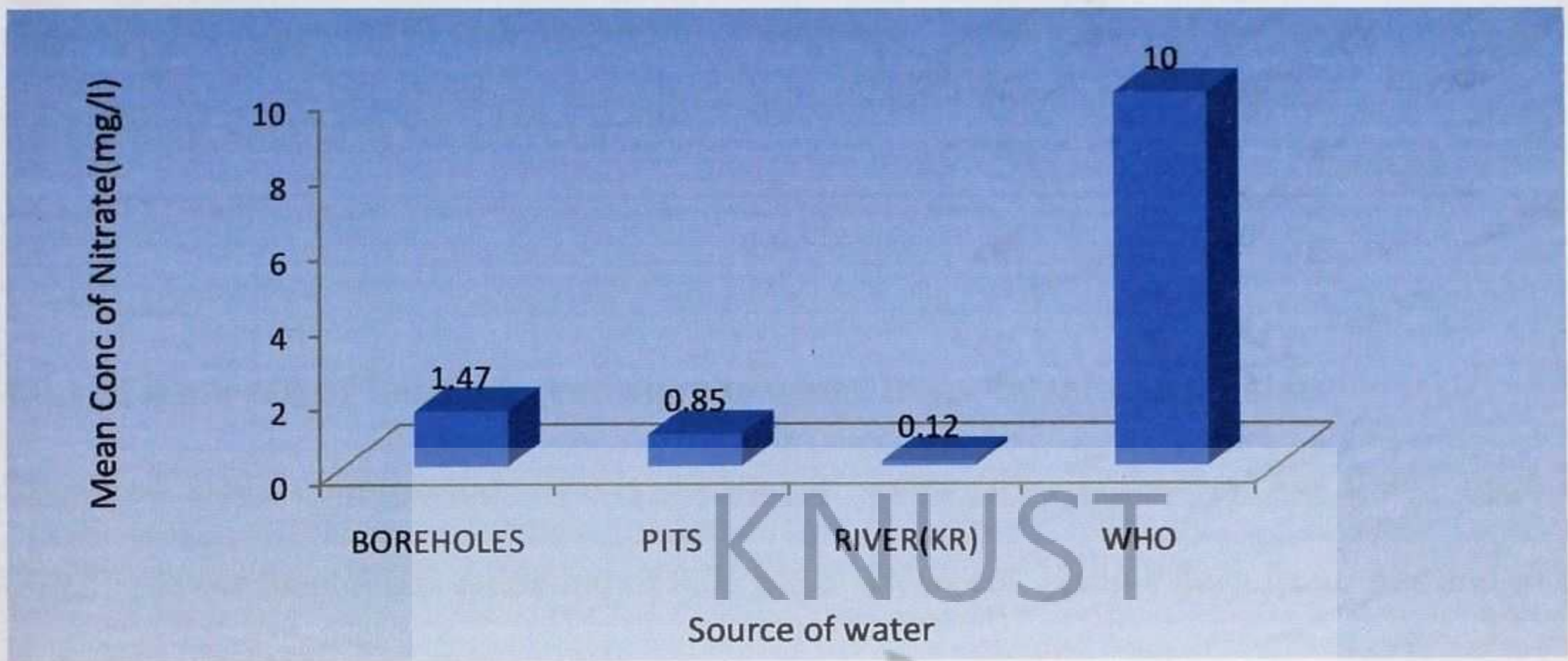
Figure 13: Nitrate NO_3 in water samples

4.1.13 Mean levels of Total hardness $CaCO_3$ in water from the sampling points

The mean levels of total hardness $CaCO_3$ in water samples from boreholes, pits and river were 201.7 mg/l, 214.4 mg/l and 192.3 mg/l respectively.These values recorded lower than WHO value of 500 mg/l.
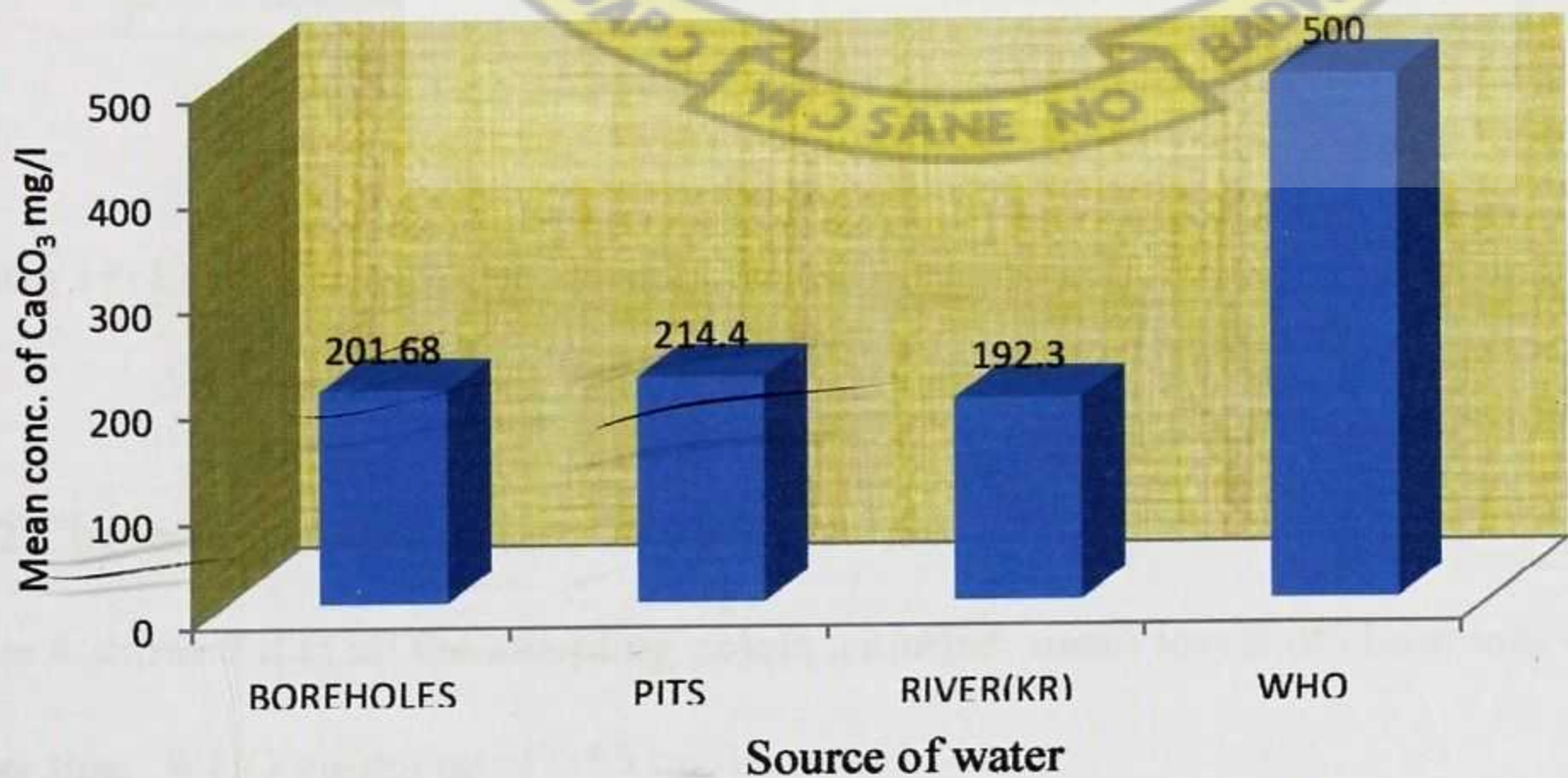
Figure 14: Total hardness $CaCO_3$ in water

4.2 HEAVY METALS COMTAMINATION LEVELS

Appendix11, Appendix12 and Appendix13 contained mean values of the heavy metals from the different sources of the water samples.

4.2.1 Mean levels of Lead concentration in water from the sampling points

Recorded mean concentration levels of lead in water from boreholes was 0.005 mg/l in (Fig.15) lower than WHO guideline of 0.01 mg/l. However, mean values from pits and river water were 0.18 mgl and 0.69 mg/l respectively.
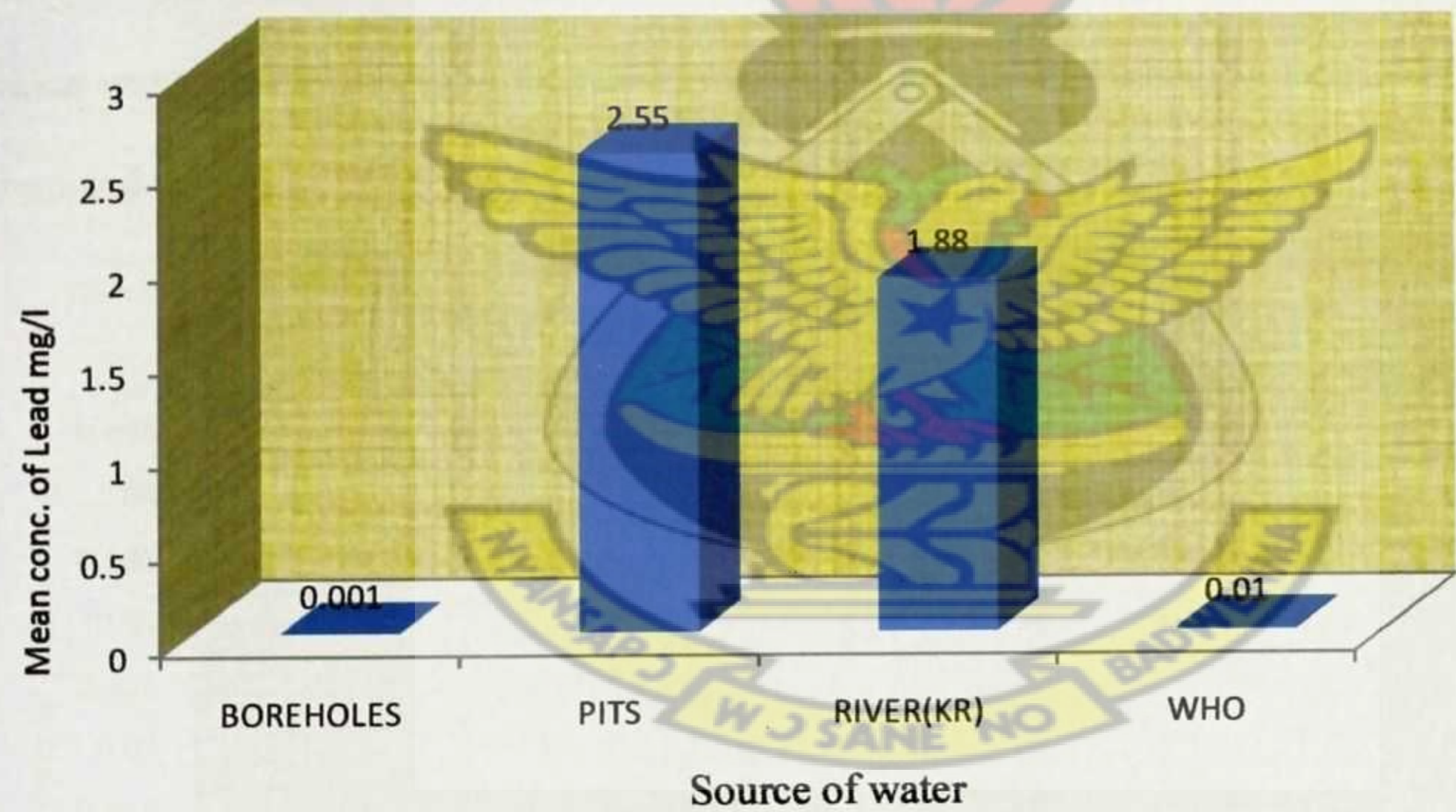
Figure 15: Lead concentration in water samples

4.2.2 Chromium concentration in water sample

Table 4 showed that all the sampling points recorded mean levels of chromium of 0.01 mg/l lower than WHO guideline of 0.05 mg/l.

Table 4: Mean level of chromium in water from the sampling points

SOURCE	MEAN	MINIMUM	MAXIMUM
Boreholes	0.01	0.01	0.01
Pits	0.01	0.01	0.01
Surface	0.01	0.01	0.01
WHO	0.05	0.05	0.05

4.2.3 Cadmium concentration in water samples

Samples water analysed for cadmium in boreholes was 0.002 mg/l and that of WHO guideline value was 0.003 mg/l. However, water samples from the pits and river water recorded 0.02 mg/l and 0.044 mg/l respectively in Fig.16
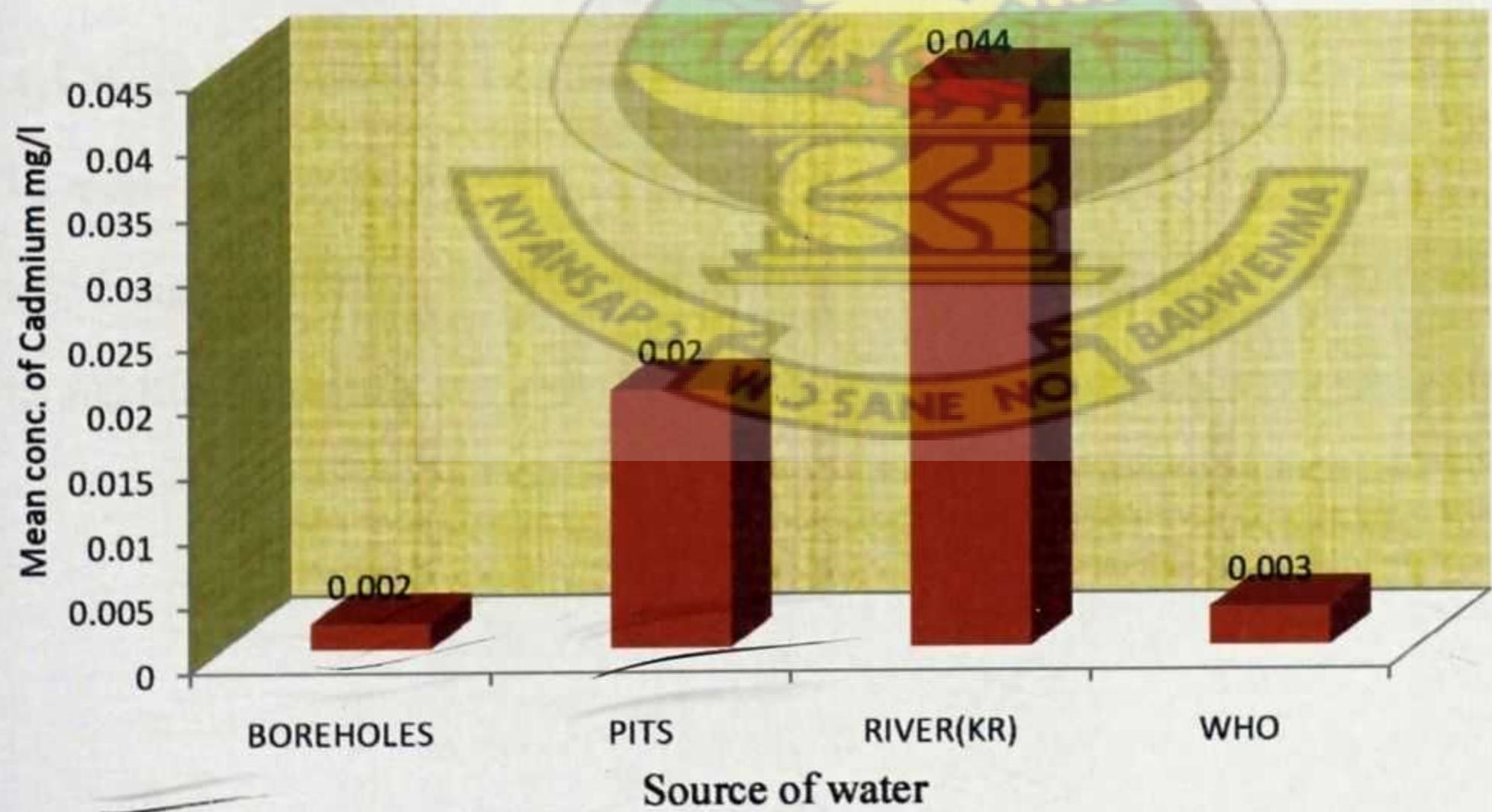
Figure 16: Cadmium concentration in water samples

4.2.4 Copper concentration in water samples

Samples water analysed for copper concentration in Fig.17 from boreholes, pits and river water were 0.001 mg/l, 0.65 mg/l and 0.99 mg/l respectively. But the standard value from WHO guideline was 2.0 mg/l.
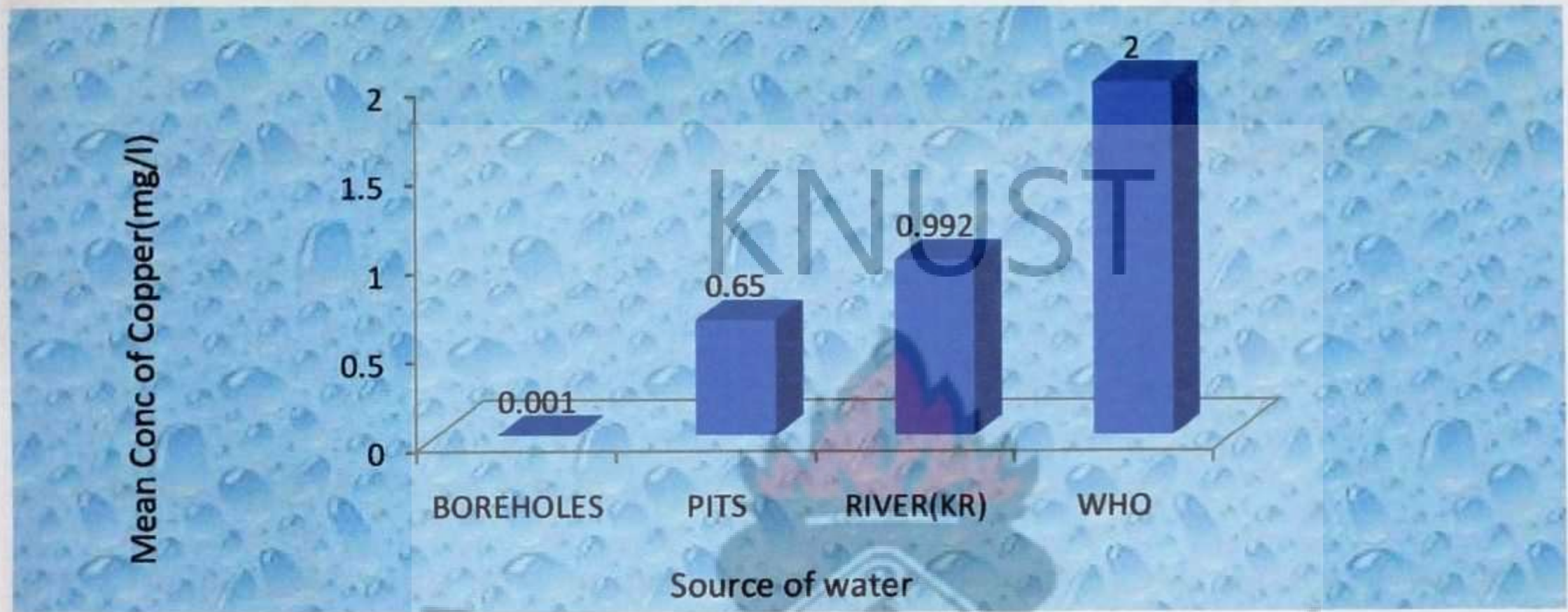
Figure 17: Copper concentration in water samples

4.1.5 Mean levels of Total iron in water from the sampling points

The mean concentration of iron recorded in water from boreholes, pits and river were 0.08 mg/l, 2 mg/l and 11 mg/l respectively in (Fig.18). However, water samples from the Mine Pits and Kulubiliga River recorded values which were far above the WHO value of 0.3 mg/l.
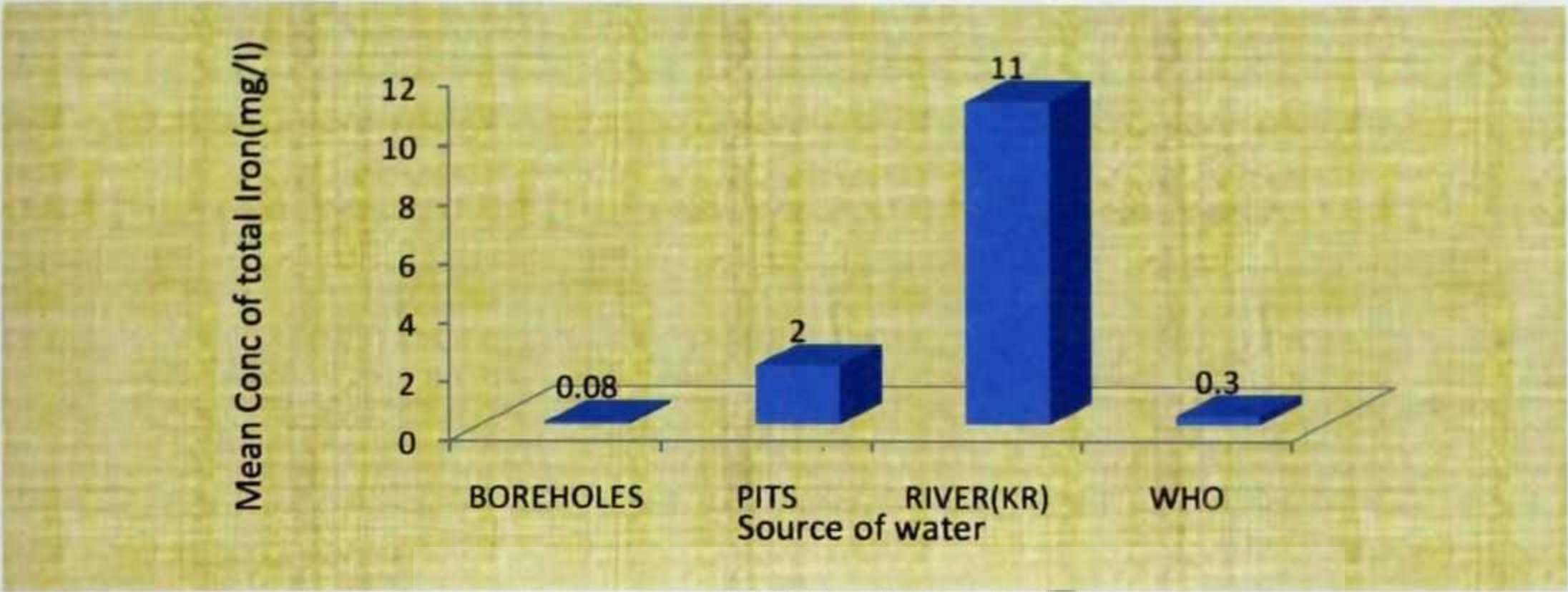
Figure 18: Total iron in water

4.1.6 Mean levels of Manganese in water from the sampling points

In Fig.19, the mean levels of manganese in water from boreholes, pits and Kulubiliga River were 0.007 mg/l, 0.325 mg/ and 0.175 mg/l respectively. WHO guideline was 0.4 mg/l.
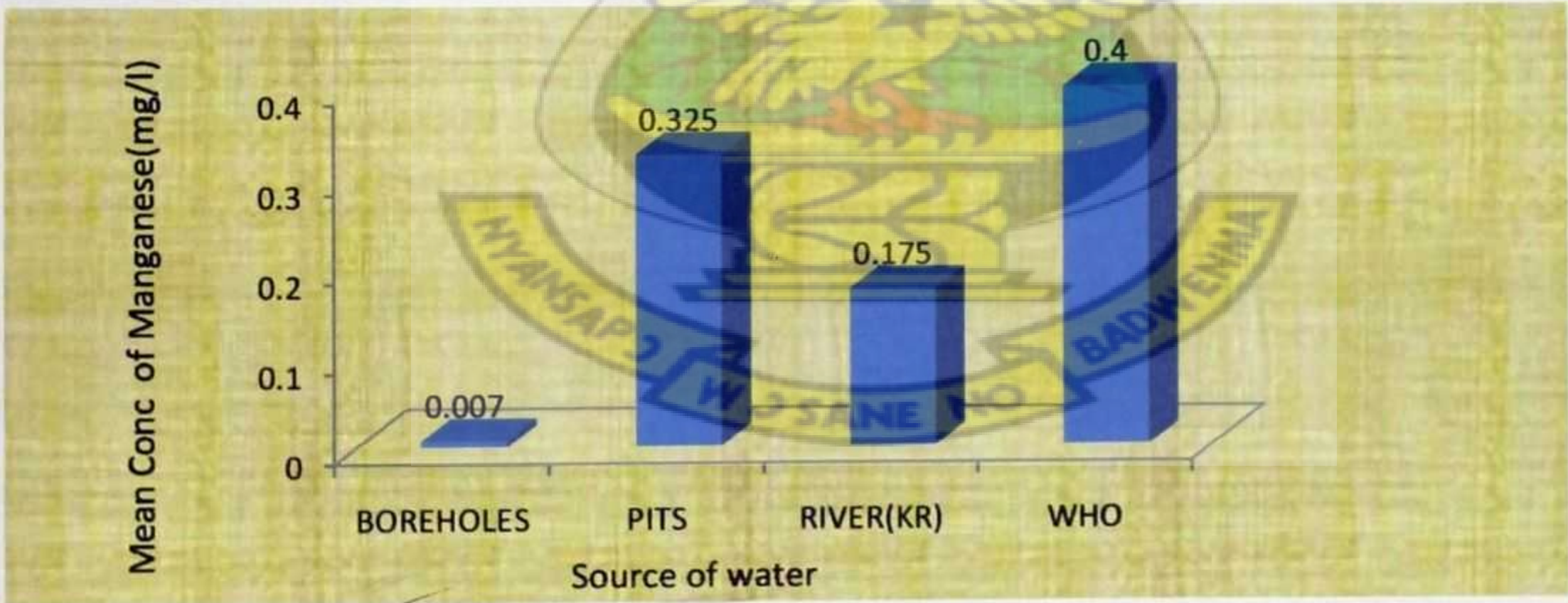
Figure 19: Manganese in water samples

4.2.7 Zinc concentration in water smaples

In Fig.20, sample water recorded concentration of zinc from the boreholes, pits and river water at 0.015 mg/l, 0.454 mg/l and 0.221 mg/l respectively. WHO value was 3 mg/l.
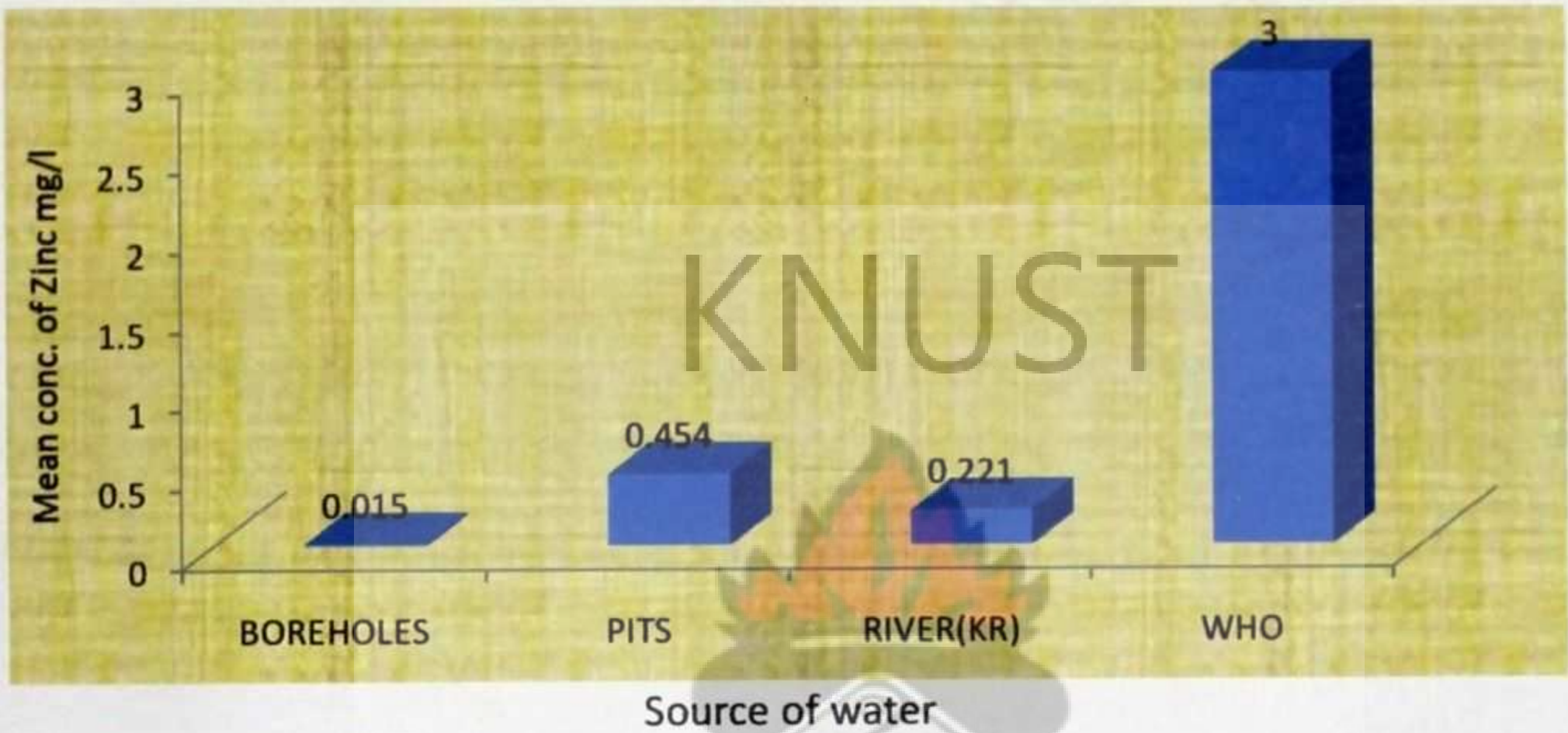
Figure 20: Zinc concentration in water smaples

4.2.8 Arsenic concentration in water samples

Sample water analyzed for the concentration of Arsenic in Fig. 21 from pits and river sources recorded 2.55 mg/l and 1.88 mg/l respectively. While water samples from boreholes recorded 0.001 mg/l lower than WHO guideline of 0.01 mg/l.
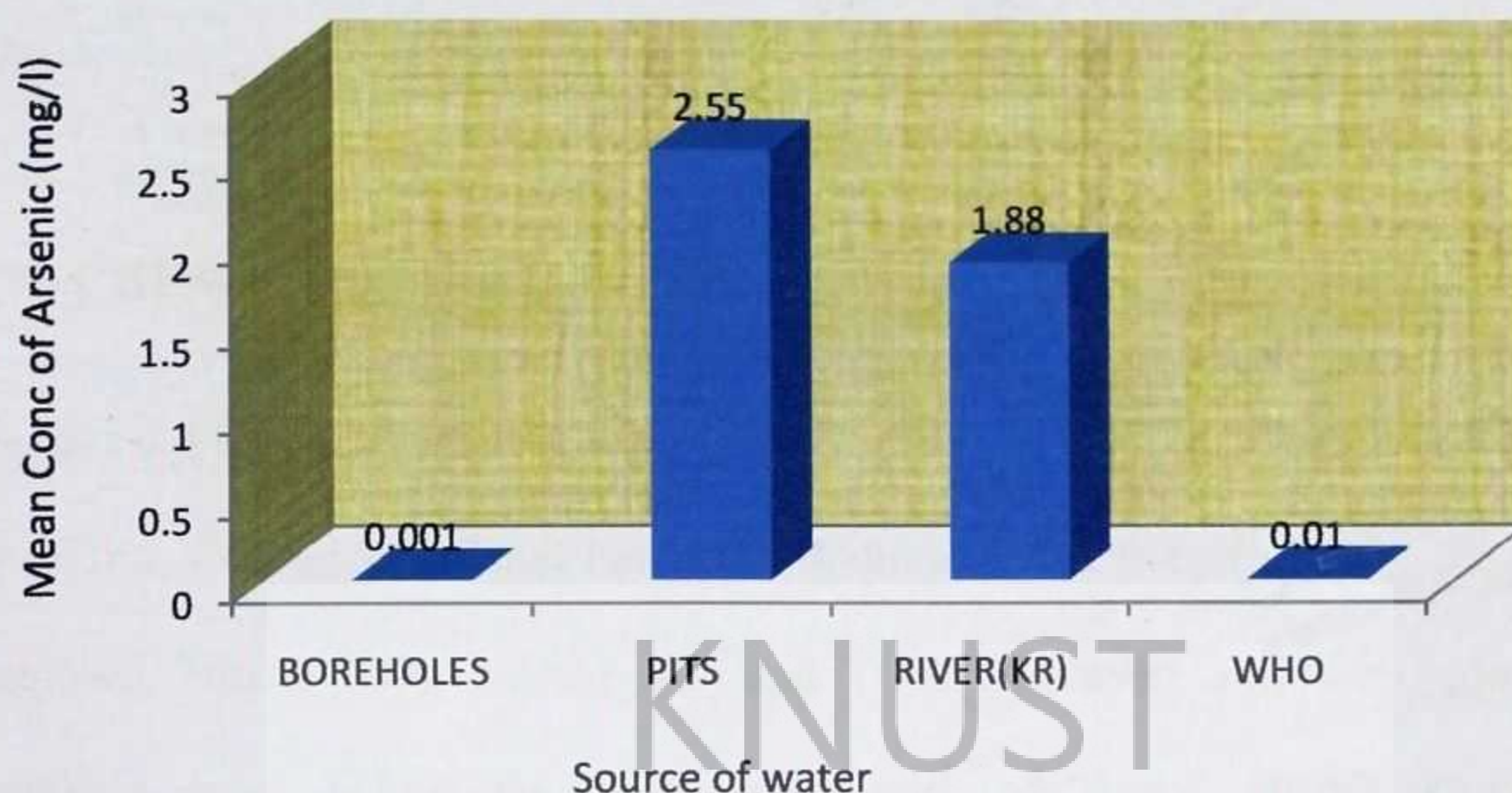
Figure 21: Arsenic concentration in water samples

4.2.9 Mercury concentration in water samples

Water samples analyzed for the concentration of mercury from pits and river water recorded

0.4 ppm and 0.67 ppm respectively, registering higher than the WHO guideline of 0.01 ppm in

(Fig.22).
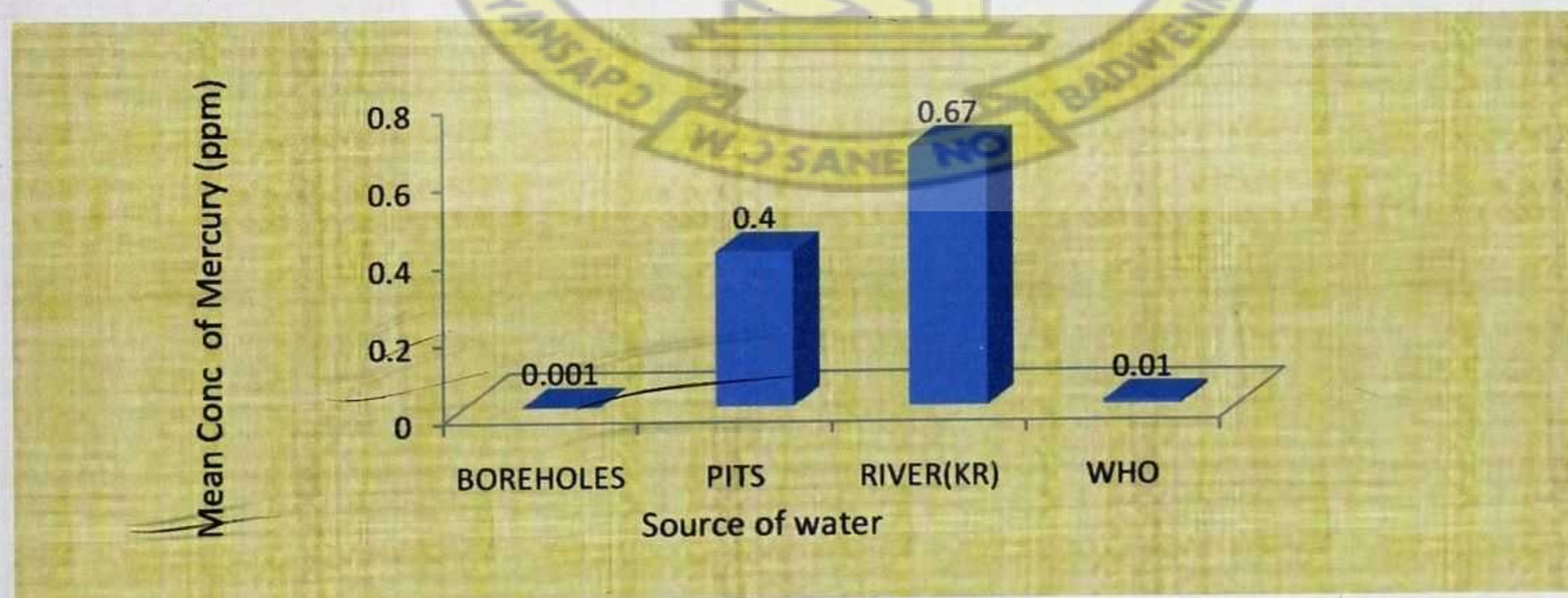
Figure 22: Mercury concentration in water samples

CHAPTER FIVE

DISCUSSION

5.1 PHYSICO-CHEMICAL PARAMETERS

5.1.1 Underground water (Boreholes)

Levels of Turbidity, Colour, pH, Total hardness, Sodium, Potassium, Calcium, Magnesium, Chloride, Sulphate, Nitrite NO_2, Nitrate NO_3 and Total Dissolved Solids recorded in the boreholes samples were below the acceptable limits of World Health Organization (WHO, 2011) and as such could pose no detrimental effects to human health. From the results it was evident that the depths of the boreholes within the mining area are deeper than the mining pits and not affected by the mining activities in the study area.

5.1.2 Underground water (Pits) and Kulubiliga River (Surface Water)

The mean turbidity and colour values of water from the mine pits and Kulubiliga River were recorded above the WHO guideline limits. The high mean levels of turbidity and colour in the pits and Kulubiliga River were caused by the presence of suspended solids in the pits and the river. Suspended solids in the study area such as clay, silt, and finely divided organic and inorganic matter and rock flour from the blast of the rock mass from the mining activities accounted for the significant values of Turbidity and Colour. The study revealed that water sampled from the pits and Kulubiliga River generally recorded physico-chemical parameters (pH, Total hardness, Sodium, Potassium, Calcium, Magnesium, Ammonium, Chloride, Sulphate, Nitrite NO_2, Nitrate NO_3 and Total Dissolved Solids) lower than the acceptable limits by World Health Organization.

5.2 HEAVY METALS IN UNDERGROUND WATER (PITS) AND KULUBILIGA RIVER (SURFACE WATER)

5.2.1 Lead

Lead content in Kulubiliga River and mine pits had mean levels of 0.696 mg/l and 0.185 mg/l respectively. These were significantly higher than the WHO guideline value of 0.01 mg/l. The high level of lead in the study area may be due to weathering and leaching of the metal from waste rocks dumps (AGC, 2001). Other sources of lead are the weathering of the Birimain and Granitiods rocks, which contain high levels of lead (Kuma, 2004). Lead is a neurotoxin metal which affects the central nervous system. Children exposed to high levels of lead contaminated water have low IQs. Other symptoms associated with exposure to lead are behavioural disorders and tremors (WHO, 2011). Lead concentrations can also vary according to the period in which the water has been in contact with the lead-containing materials (Kuma, 2004).

5.2.2 Chromium

From the results, the mean levels of chromium in the river and the pits was 0.01 mg/l. By inference both river water and pit water levels of chromium posed no threat to human health since they registered values below the WHO guideline of 0.05 mg/l. Previous studies around Tarkwa and its environs showed maximum levels of chromium in groundwater to be 0.066 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.49 mg/l (Kuma 2004). The results in table.3 from the study area recorded one mean value of Chromium for the three

water sources from boreholes, mine pits and river as 0.01 mg/l. It is inferred that Chromium in the study recorded lower values compared to the WHO value of 0.05 mg/l.

5.2.3 Cadmium

The presence of Cadmium in the study area was mainly as a by-product due to the presence of refining of lead from the sulphide ores. The mean level of Cadmium in the river was 0.044 mg/l and the samples from the pits recoded 0.22 mg/l. The values were above the WHO value of 0.003 mg/l. Water from either the river or the mine pits could pose a health threat to the inhabitants. Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer (WHO, 2011). Other symptoms include; irritation of upper respiratory tract, metallic taste in the mouth, cough and chest pains (Foulkes, 1986). However, there is no evidence of carcinogenicity by the oral route and no clear evidence for the genotoxicity of cadmium. The kidney is the main target organ for cadmium toxicity WHO (2011).

5.2.4 Copper

Copper is often found near mines, industrial settings, landfills and waste disposals WHO (2011). The mean level of copper in the river was 0.99 mg/l, while that of pits was 0.65 mg/l. The levels of copper in the study area were below WHO guideline (2.0 mg/l). According to WHO (2011), copper is both an essential nutrient and a drinking-water contaminant. In this case, copper concentration in the study area was not a drinking-water

contaminant. The low concentrations of copper in water samples in the study area may be due to the geology of the study area (Kesse, 1985).

5.2.5 Zinc

According to the results the presenec of zinc in the river and pits were within the acceptable WHO values. Both sampling areas registered mean levels below 3.0 mg/l of WHO limit. Since zinc is an essential trace element found in virtually all foods and potable water in the form of salts or organic complexes (WHO, 2004). The concentrations detected in the study posed no health problems to the inhabitants who use the water for domestic purposes. Zinc in surface water and groundwater did not exceed 0.01 and 0.05 mg/l, respectively, drinking-water containing zinc at levels above 3 mg/l may not be acceptable to consumers WHO (2003). Although zinc is an essential element to plants, animals and humans, very high concentrations of it is very toxic, hence harmful to the body. Zinc therefore affects many functions of the body such as reproduction, skin health, sense of smell and taste, brain functions and growth. However, low blood levels of zinc are also associated with hypogeusia, in which there is loss of sense of taste (WHO, 2003).

5.2.6 Iron

Iron is an essential element in human nutrition, particularly in the iron (II) oxidation state (Foulkles, 1986). Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability. An individual requires between 10 and 50 mg/ day. An allocation of 10% of this Provisional Maximum Tolerable Daily Intake (PMTDI) to

drinking-water gives a value of about 2 mg/l, which does not present a hazard to health. The taste and appearance of drinking-water will usually be affected when iron concentration is below this level WHO (2003). It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/l. Iron in the study area is associated with the Birimian and intrusive rock system. The Birimian and the intrusive rock systems contain high levels of iron (Kortatsi, 2004). The concentration of iron in water from Kulubiliga River was 11 mg/l while that from pits was 2 mg/l indicating a higher value compared to WHO guideline of 0.3 mg/l. The high values in the study area may come from the weathering of the Birimian and the intrusive rock system. Iron is one of the major constituents in the lithosphere (i.e. soil or rock) soil as oxides or hydroxides.

5.2.7 Manganese

Although there have been epidemiological studies that report adverse neurological effects following extended exposure to high levels of Mn in drinking-water, there are a number of significant potential factors in these studies, and a number of other studies have failed to observe adverse effects following exposure through drinking water WHO (2011). Manganese is naturally occurring in many surface water and groundwater sources. Humans can consume as much as 20 mg/day without apparent ill effects. Manganese is believed to have a neurotoxic effect; a provisional health-based guideline value of 0.5 mg/l is proposed to protect public health (WHO 1996). However, the mean level of manganese in water from the pits was 0.14 mg/l which was lower than the WHO guidelines of 0.4 mg/l and that of manganese in water from the Kulubiliga River was 1.95 mg/l which was higher than the WHO guideline. Previous

studies show maximum levels in groundwater to be 1.3 mg/l (Kuma, 2004) and maximum levels in surface water to be 2.43 mg/l (Kuma, 2004).

5.2.8 Arsenic

In water, Arsenic is mostly present as arsenate (+5). However, in waters, particularly groundwater, where there were sulphide mineral deposits and sedimentary deposits derived from volcanic rocks, the concentrations can be significantly elevated (Kortatsi, 2004). The mean level of arsenic from pits was 2.55 mg/l. Water samples from the river recorded 1.88 mg/l which was above the WHO standard of 0.01 mg/l. The most dangerous route of As exposure is through drinking-water, including beverages that are made from contaminated water. The high levels of Arsenic could come from the deep bedrock materials as well as the shallow glacial materials in the study area. They are also found alongside the gold ores such arsenopyrites (FeAsS) (Coakley, 1996). According to Tseng *et al.*, (1968), chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high. According to (IARC, 1980), inorganic form of arsenic is classified as a class A Carcinogen (Human Carcinogen). Increased lung cancer mortality was observed in multiple populations exposed to arsenic primarily through drinking of arsenic contaminated water (IARC, 1980).

5.2.9 Mercury

Water from the River and pits were used by the miners to process the gold ore. The high level of mercury in the water demonstrates the fact that in their quest to extract gold from the river

bed and ore from the underground, mercury was the main additive to the ore to amalgamate the gold concentrate. As a result of this some amount of it leaks out in to water body, some escape into the air and others remain in the soil. The results indicated that a mean level of mercury of 0.40 ppm in the water and this can be harmful to the inhabitants since majority of them use the water for domestic purposes including drinking. Comparatively the WHO value of 0.01 ppm was far below the values found in the pits water samples (0.67 ppm). According to (Obiri, 2005) the presence of mercury in the environment may be attributed to the use of mercury in gold recovery processes where the inorganic form of the metal is either washed into rivers. Mercury affects the renal system, nervous system, gastrointestinal tract and the respiratory system. Mercury has been shown to be toxic to human populations because of occupational exposure and accidental ingestion of mercury-contaminated food. The toxic effects of inorganic mercury compounds are seen mainly in the kidney in both humans and laboratory animals following short-term and long-term exposure. In humans, acute oral poisoning results primarily in haemorrhagic gastritis and colitis; the ultimate damage is to the kidney (IARC, 1980). The overall effect is that mercury (II) chloride has the potential to increase the incidence of some benign tumours at sites where tissue damage is apparent and that it possesses weak genotoxic activity but does not cause point mutations WHO (2005).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The physico-chemical parameters such as turbidity, colour, pH, total dissolved solids, sodium, potassium, calcium, magnesium, ammonium, chloride, sulphate, nitrite NO_2^-, nitrate NO_3^- and total hardness from the data analysed from the boreholes indicated that water from the boreholes were good and safe for domestic purposes. All the above parameters recorded values below the WHO standards. Turbidity recorded high levels from the pits and river water samples. The colour recorded high values in the river. This was due to the presence of suspended organ and inorganic matter.

All the heavy metals from the boreholes samples recorded values below the World Health Organization guidelines.

The results showed that groundwater (pits) and the river in the mining area were contaminated with lead, cadmium, mercury and arsenic with their mean values above WHO guideline values for drinking water.

From the study conducted, it is sufficed to conclude that the river and mine pits were contaminated with some heavy metals. Inhabitants who depend on these water bodies for drinking and other domestic purposes could be at health risk.

6.2 RECOMMENDATIONS

It is recommended that;

1. There should be regular follow-up studies to measure the levels of heavy metals and other toxic chemicals in water bodies and food crops in the study areas, especially the Kulubiliga River.

2. A similar study can be conducted in different regions or mining communities to assess the health impacts of toxic chemicals used by the small scale miners and those used by the galamsey operators on the environment and on humans.

3. Miners and the inhabitant's blood, urine and hairs, etc should be sampled for Lead, Mercury, Arsenic, and Cadmium to determine the body's burden of these toxic chemicals.

4. It is recommended that multivariate statistical methods are integrated in future studies on pollution risk assessment of atmospheric, soil and water environment in Ghana

5. There is the need for government and other stakeholders to institute an educational programme on regular bases to inform the small scale miners and their unsuspecting public on the proper handling, use and negative effects of the misuse of the chemicals so as to minimize chemical and heavy metals contamination in the process of extraction.

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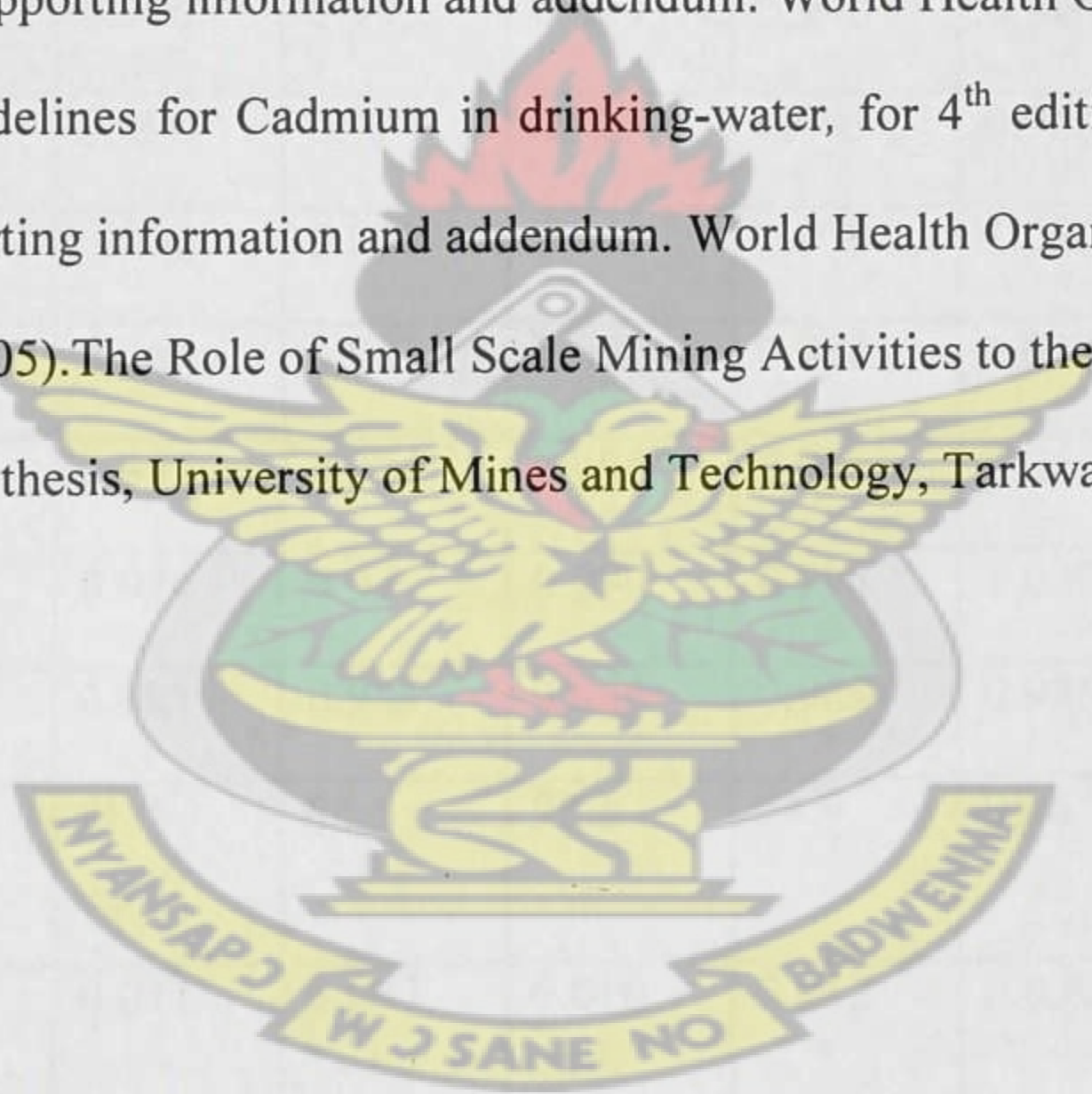
APPENDICES

Appendix 1: Heavy Metals recovered from 1.0mg/l

Replicates	Amount recovered from 1.0 mg/l							
	Pb	Cr	Cd	Cn	Cu	Zn	As	Hg
1	0.993	0.974	0.976	0.995	0.994	0.990	1.002	0.988
2	0.969	0.969	0.982	0.981	0.995	0.990	1.021	0.979
3	0.930	0.978	0.991	0.992	0.991	0.930	0.974	1.003
4	0.978	0.996	0.984	0.974	0.956	0.990	0.991	0.990
5	0.958	0.990	0.995	0.979	0.990	0.980	0.969	1.000
6	0.990	0.990	0.977	0.988	0.993	0.960	0.988	0.996
7	0.996	0.983	0.990	0.969	0.999	1.020	0.994	0.995
8	0.975	0.963	0.983	1.002	0.985	1.010	1.010	0.968
9	0.986	0.992	0.994	0.984	0.985	0.960	1.014	0.985
10	0.977	0.974	0.979	0.990	0.998	1.030	0.995	0.989
Mean	0.975	0.981	0.985	0.985	0.989	0.986	0.996	0.989
Percent recovered	97.5	98.1	98.5	98.5	98.9	98.6	99.6	98.9
Standard deviation	0.019	0.011	0.007	0.010	0.012	0.030	0.017	0.010
Percent coefficient of variation	1.948	1.121	0.711	0.014	1.214	3.043	1.706	1.011
Standard error	0.006	0.003	0.002	0.003	0.004	0.009	0.005	0.003

Appendix 2: Mean levels of Physico-Chemical in Boreholes water

PARAMETER	UNIT	Physic-chemical values in Boreholes water				
		BBH	NBH	CBH	DBH2	DBH1
Turbidity	NTU	4.70	1.25	3.32	4.81	8.91
Colour (apparent)	Hz	2.50	2.50	2.50	2.50	5.00
Odour	-	-	-	-	-	-
pH	pH	7.45	7.39	7.51	7.34	5.81
Conductivity	uS/cm	548	521	575	758	120
Tot Susp. Solid (SS)	mg/l	<1.00	<1.00	<1.00	<1.00	<1.00
Tot Dis Solids (TDS)	mg/l	301	287	316	417	66.0
Sodium	mg/l	3.50	2.00	3.10	7.00	5.00
Potassium	mg/l	1.00	1.20	1.00	1.60	1.80
Calcium	mg/l	26.6	29.8	31.8	28.1	5.00
Magnesium	mg/l	20.0	19.9	25.2	21.9	4.10
Total Iron	mg/l	0.076	<0.010	<0.010	0.077	0.231
Ammonium (NH_4-N)	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	2.00	4.00	5.00	6.00	6.00
Sulphate (SO_4)	mg/l	7.00	15.0	12.0	50.0	9.00
Phosphate (PO-P)	mg/l	20.001	<0.001	0.900	1.30	0.900
Manganese	mg/l	0.014	<0.005	0.006	<0.005	0.005
Nitrite (NO_2-N)	mg/l	0.001	<0.001	0.002	<0.001	<0.001
Nitrite (NO_3-N)	mg/l	<0.001	<0.001	<0.001	0.026	7.30
Total Hardness ($CaCO_3$)	mg/l	223	181	233	342	29.4
Total Alkalinity ($CaCO_3$)	mg/l	146	129	144	168	15.6
Calcium Hardness ($CaCO_3$)	mg/l	141	99.4	130	170	12.4
Mag Hardness ($CaCO_3$)	mg/l	82.3	81.8	103	172	17.0
Fluoride	mg/l	0.297	0.329	0.127	0.453	0.349
Bicarbonate ($CaCO_3$)	mg/l	178	158	176	205	19.0
Carbonate	mg/l	0.00	0.00	0..00	0.00	0.00

Appendix 3: Mean levels of Physico-Chemical in Pits water

PARAMETER	UNIT	Physic-chemical values in Pits				
		RVLD	RVUD	RVND	CNS	PT
Turbidity	NTU	5.90*	4.70	4.30	27.6*	59.0*
Colour (apparent)	Hz	5.00	7.50	2.50	2.50	50.0*
Odour	-	-	-	-	-	-
pH	pH	6.75	6.76	6.77	7.48	8.22
Conductivity	uS/cm	502	498	490	615	579
Tot Susp. Solids (SS)	mg/l	1.00	1.00	1.00	7.00	18.0
Tot Dis Solids (TDS)	mg/l	276	274	270	338	318
Sodium	mg/l	8.00	7.30	9.00	34.2	41.0
Potassium	mg/l	2.40	1.60	1.80	3.40	3.20
Calcium	mg/l	48.1	45.7	35.7	52.9	32.1
Magnesium	mg/l	22.1	25.0	25.5	23.0	28.6
Total Iron	mg/l	0.114	0.102	0.089	0.391*	9.26*
Ammonium (NH_4-N)	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	9.90	9.90	9.90	39.7	39.7
Sulphate (SO_4)	mg/l	29.1	24.5	18.4	59.9	41.6
Phosphate (PO-P)	mg/l	0.221	0.157	0.114	0.067	0.147
Manganese	mg/l	0.062	0.051	0.056	0.211	0.742*
Nitrite (NO_2-N)	mg/l	0.022	0.043	0.039	0.842	0.041
Nitrite (NO_3-N)	mg/l	0.178	0.144	0.095	3.68	0.133
Total Hardness ($CaCO_3$)	mg/l	211	217	219	227	198
Total Alkalinity ($CaCO_3$)	mg/l	166	173	169	164	211
Calcium Hardness ($CaCO_3$)	mg/l	120	144	144	132	80.2
Mag Hardness ($CaCO_3$)	mg/l	90.8	103	105	94.7	118
Fluoride	mg/l	0.321	0.324	0.279	0.422	0.463
Bicarbonate ($CaCO_3$)	mg/l	203	211	207	200	258
Carbonate	mg/l	0.00	0.00	0.00	0.00	0.00

Appendix 4: Mean levels of Physico-Chemical in Kulubiliga River (KR) water

PARAMETER	UNIT	Physic-chemical values in KR					
		UQ1	UQ2	UQ3	UQ4	UQ5	RVW
Turbidity	NTU	136*	26.0*	56.0*	94.0*	400*	23.9*
Colour (apparent)	Hz	75.0*	7.50	10.0	10.0	150*	20.0*
Odour	-	-	-	-	-	-	-
pH	pH	7.82	8.32	6.01	7.82	8.00	6.67
Conductivity	uS/cm	937	1178	594	1620	1254	396
Tot Susp. Solid (SS)	mg/l	4.00	7.00	5.00	11.0	21.0	5.00
Tot Dis Solids (TDS)	mg/l	515	648	327	891	690	218
Sodium	mg/l	193	268	165	19.0	358	47.0
Potassium	mg/l	3.40	4.30	3.20	2.10	3.10	2.80
Calcium	mg/l	58.1	18.8	36.2	40.0	79.4	24.8
Magnesium	mg/l	20.6	14.9	24.3	29.6	20.1	8.70
Total Iron	mg/l	16.7*	0.411*	7.28*	9.27*	28.3*	4.23*
Ammonium (NH4-N)	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chloride	mg/l	149	201	203	27.8	338	53.6
Sulphate (SO_4)	mg/l	288	168	150	21.0	332	47.6
Phosphate (PO-P)	mg/l	0.222	0.115	0.167	0.277	0.155	0.115
Manganese	mg/l	3.28*	0.129	0.911*	0.644*	6.21*	0.519*
Nitrite (NO_2-N)	mg/l	0.058	0.035	0.013	0.065	0.030	0.048
Nitrite(NO_3-N)	mg/l	0.100	0.106	0.069	0.096	0.082	0.270
Total Hardness ($CaCO_3$)	mg/l	230	108	190	247	281	98.0
Total Alkalinity ($CaCO_3$)	mg/l	203	174	131	188	202	98.4
Calcium Hardness ($CaCO_3$)	mg/l	145	46.9	90.6	125	198	62.1
Mag Hardness ($CaCO_3$)	mg/l	84.7	61.3	99.8	122	82.6	35.9
Fluoride	mg/l	0.194	0.411	0.473	0.367	0.512	0.417
Bicarbonate ($CaCO_3$)	mg/l	249	212	161	229	247	120
Carbonate	mg/l	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 5: Mean levels of Heavy Metals for Pits

Parameter	UNIT	Concentrations for Heavy Metals for Pits				
		RVLD	RVUD	RVND	CNS	PT
Lead	mg/l	0.062	0.054	0.003	0.350	0.454
Chromium	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/l	0.015	0.030	0.012	0.031	0.011
Cyanide	mg/l	<0.001	<0.001	<0.002	<0.001	<0.001
Copper	mg/l	0.655	<0.002	0.323	0.031	2.220
Zinc	mg/l	0.843	0.140	0.322	0.514	0.449
Arsenic	mg/l	1.752	1.401	1.960	2.512	5.120
Mercury	ppb	0.045	0.073	0.825	0.318	0.730

Appendix 6: Mean levels of Heavy Metals for Kulubiliga River (KR)

Parameter	UNIT	Concentrations for Heavy Metals for KR					
		UQI	UQ2	UQ3	UQ4	UQ5	RVW
Lead	mg/l	1.580	0.622	0.921	0.500	0.001	0.550
Chromium	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/l	0.003	0.220	<0.002	<0.001	0.017	0.019
Cyanide	mg/l	<0.015	<0.002	<0.001	0.020	0.120	0.004
Copper	mg/l	1.635	1.455	0.879	0.612	0.015	0.895
Zinc	mg/l	0.012	0.313	0.881	<0.005	0.110	<0.005
Arsenic	mg/l	0.953	1.590	1.644	4.310	0.863	1.897
Mercury	ppb	0.020	1.623	0.368	0.514	1.324	0.200

Appendix 7: Mean levels of Heavy Metals for Boreholes

PARAMETER	UNIT	Concentrations for Heavy Metals for Boreholes				
		BBH	NBH	CBH	DBH1	DBH2
Lead	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	mg/l	<0.010	<0.010	<0.010	<0.010	<0.010
Cadmium	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002
Cyanide	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/l	<0.020	<0.020	<0.020	<0.020	<0.020
Zinc	mg/l	0.010	<0.005	0.015	<0.005	0.038
Arsenic	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	ppm	<0.001	<0.001	<0.001	<0.001	<0.001
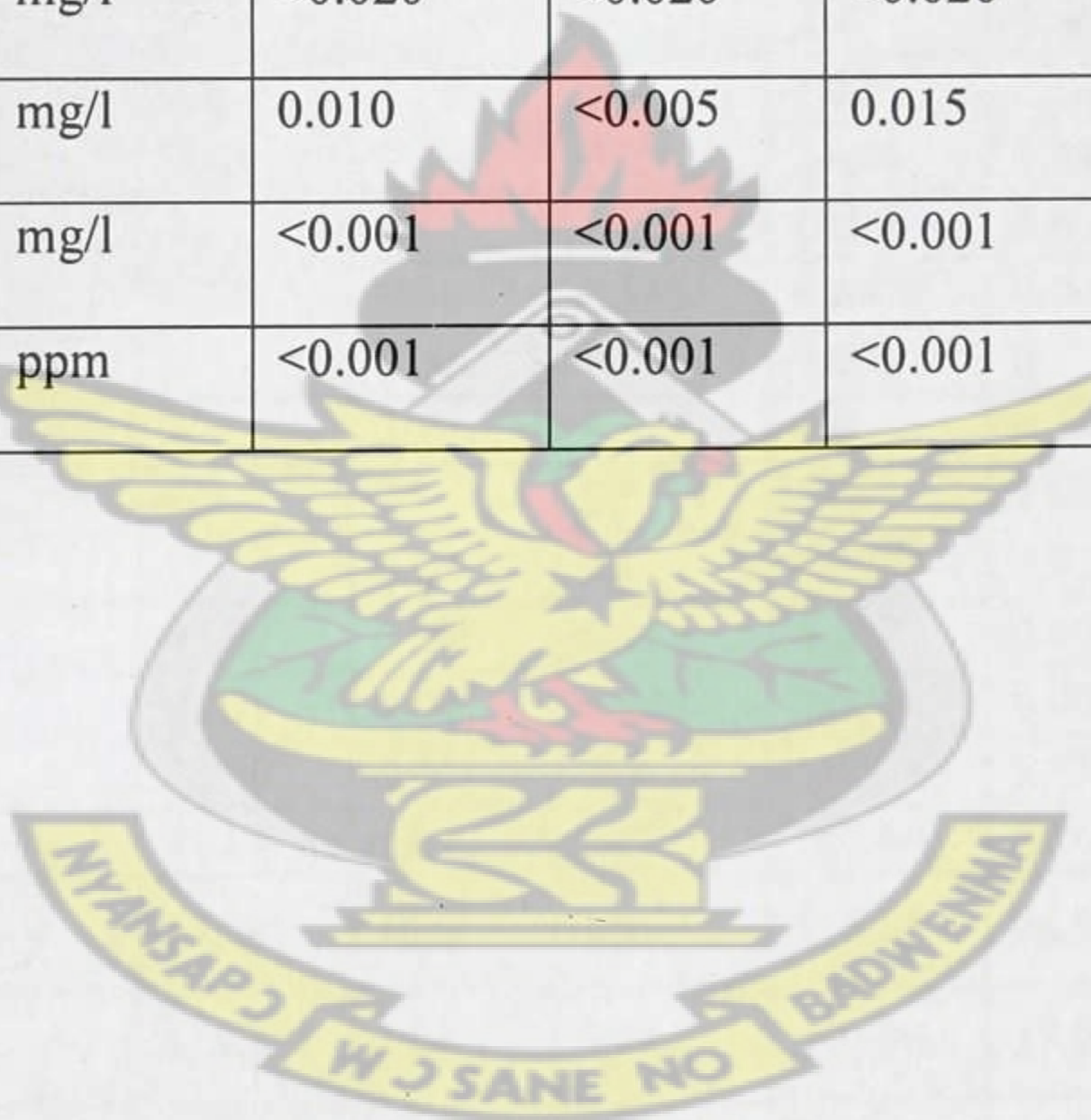
Appendix 8: Descriptive statistics of underground water for controls (boreholes)

Parameter	N	Range	Min	Max	Mean		Std. Deviation	WHO Guidelines
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Value
Turbidity	5	7.66	1.25	8.91	4.598	1.254812	2.805846	5
Colour	5	2.5	2.5	5	3	0.5	1.118034	15
Odour	5	0	0	0	0	0	0	Inoffensive
Ph	5	1.7	5.81	7.51	7.1	0.323759	0.723948	6.5-8.5
Conductivity	5	638	120	758	504.4	104.6989	234.1139	-
Tot Susp. Solids SS	5	0	1	1	1	0	0	-
Tot Dis. Solids TDS	5	351	66	417	277.4	57.5835	128.7606	1000
Sodium	5	5	2	7	4.12	0.865679	1.935717	200
Potassium	5	0.8	1	1.8	1.32	0.162481	0.363318	30
Calcium	5	26.8	5	31.8	24.26	4.892402	10.93974	200
Magnessium	5	21.1	4.1	25.2	18.22	3.65806	8.17967	150
TotalIron	5	0.221	0.01	0.231	0.0808	0.040387	0.090309	0.3
Ammonium NH4	5	0	0.001	0.001	0.001	0	0	0.0-1.5
Chloride	5	4	2	6	4.6	0.748331	1.67332	250
Sulphate	5	43	7	50	18.6	7.966179	17.81292	250
Phosphate	5	20	0.001	20	4.6204	3.851036	8.611178	-
Manganese	5	0.009	0.005	0.014	0.007	0.001761	0.003937	0.4
NitriteNO2	5	0.001	0.001	0.002	0.0012	0.0002	0.000447	1.0
NitriteNO3	5	7.299	0.001	7.3	1.4658	1.458558	3.261435	10
Total Hardness CaCO3	5	312.6	29.4	342	201.68	50.61287	113.1738	500
Total Alkalinity CaCO3	5	152.4	15.6	168	120.52	26.95831	60.28061	-
Calcium Hardness CaCO3	5	157.6	12.4	170	110.56	27.01625	60.41016	-
Mag Hardness	5	155	17	172	91.22	24.84058	55.54522	-
Fluoride	5	0.326	0.127	0.453	0.311	0.052907	0.118305	1.5
BicarbonateCaCO3	5	186	19	205	147.2	32.91717	73.60503	-
Carbonate	5	0	0	0	0	0	0	-
Valid N (listwise)	5							

Appendix 9: Descriptive statistics of underground water (pits)

| Parameter | Underground water | | | | | | | WHO |
| | N | Range | Min | Max | Mean | Std. Error | Std. Deviation | Guidelines |
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	
Turbidity	5	54.7	4.3	59	20.3	10.62474	23.75763	5
Colour	5	47.5	2.5	50	13.5	9.171968	20.50914	15
Odour	5	0	0	0	0	0	0	Inoffensive
pH	5	1.47	6.75	8.22	7.196	0.291524	0.651867	6.5-8.5
Conductivity	5	125	490	615	536.8	25.30099	56.57473	-
Tot Dis Solid SS	5	17	1	18	5.6	3.310589	7.402702	-
Tot Dis Solid TDS	5	68	270	338	295.2	13.79275	30.84153	1000
Sodium	5	33.7	7.3	41	19.9	7.31054	16.34687	200
Potassium	5	1.8	1.6	3.4	2.48	0.361109	0.807465	30
Calcium	5	20.8	32.1	52.9	42.9	3.894612	8.708616	200
Magnesium	5	6.5	22.1	28.6	24.84	1.128982	2.52448	150
Total Iron	5	9.171	0.089	9.26	1.9912	1.818068	4.065323	0.3
Ammonium	5	0	0.001	0.001	0.001	0	0	0.0-1.5
Chloride	5	29.8	9.9	39.7	21.82	7.299479	16.32213	250
Sulphate	5	41.5	18.4	59.9	34.7	7.361182	16.4601	250
Phosphate	5	0.154	0.067	0.221	0.1412	0.025394	0.056782	-
Manganese	5	0.691	0.051	0.742	0.3252	0.138988	0.310787	0.4
NitriteNO2	5	0.82	0.022	0.842	0.1974	0.161193	0.360439	1.0
NitriteNO3	5	3.585	0.095	3.68	0.846	0.708624	1.584531	10
Total Hardness CaCO3	5	29	198	227	214.4	4.833218	10.8074	500
Total Alkalinity CaCO3	5	47	164	211	176.6	8.732697	19.5269	-
Calcium Hardness CaCO3	5	63.8	80.2	144	124.04	11.82885	26.4501	-
Mag Hardness CaCO3	5	27.2	90.8	118	102.3	4.713173	10.53898	-
Floride	5	0.184	0.279	0.463	0.3618	0.034507	0.07716	1.5
Bicarbonate CaCO3	5	58	200	258	215.8	10.71168	23.95204	-
Carbonate	5	0	0	0	0	0	0	-
Valid N (listwise)	5							

94

Appendix 10: Descriptive statistics of Kulubiliga River

surface water

Parameter	N Statistic	Range Statistic	Min Statistic	Max Statistic	Mean Statistic	Std. Error	Std. Deviation Statistic	WHO Guidelines
Turbidity	6	376.1	23.9	400	122.65	58.15413	142.4479	5
Colour	6	142.5	7.5	150	45.4167	23.38462	57.28038	15
Odour	6	0	0	0	0	0	0	inoffensive
pH	6	2.31	6.01	8.32	7.44	0.365814	0.896058	6.5-8.5
Conductivity	6	1224	396	1620	996.5	183.8611	450.366	-
Tot Dis Solid SS	6	17	4	21	8.83333	2.638392	6.462714	-
Tot Dis Solid TDS	6	673	218	891	548.167	101.1011	247.6461	1000
Sodium	6	339	19	358	175	52.68839	129.0597	200
Potassium	6	2.2	2.1	4.3	3.15	0.29524	0.723187	30
Calcium	6	60.6	18.8	79.4	42.8833	9.174254	22.47224	200
Magnesium	6	20.9	8.7	29.6	19.7	2.967491	7.268838	150
Total Iron	6	27.889	0.411	28.3	11.0318	4.109197	10.06544	0.3
AmmoniumNH4	6	0	0.001	0.001	0.001	0	0	0.0-1.5
Chloride	6	310.2	27.8	338	162.067	46.22668	113.2318	250
Sulphate	6	311	21	332	167.767	50.90017	124.6795	250
Phosphate	6	0.162	0.115	0.277	0.17517	0.025998	0.063682	-
Manganese	6	6.081	0.129	6.21	1.94883	0.96722	2.369196	0.4
NitriteNO2	6	0.052	0.013	0.065	0.0415	0.00786	0.019254	1.0
NitriteNO3	6	0.201	0.069	0.27	0.1205	0.030395	0.074452	10
TotalHardnessCaCO3	6	183	98	281	192.333	30.70577	75.21347	500
TotalAlkalinityCaCO3	6	104.6	98.4	203	166.067	17.32795	42.44463	-
CalciumHardnessCaCO3	6	151.1	46.9	198	111.267	22.9759	56.27922	-
MagHardnessCaCO3	6	86.1	35.9	122	81.05	12.21034	29.90911	-
Floride	6	0.318	0.194	0.512	0.39567	0.045349	0.111081	1.5
BicarbonateCaCO3	6	129	120	249	203	21.18333	51.88834	-
Carbonate	6	0	0	0	0	0	0	-

Appendix 11: Descriptive statistics of heavy metals for Controls (Boreholes)

Element	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Mean Std. Error	Std. Deviation Statistic	WHO Guidelines
Lead	5	.000	.005	.005	.00500	.000000	.000000	0.01
Chromium	5	.000	.010	.010	.01000	.000000	.000000	0.05
Cadmium	5	.000	.002	.002	.00200	.000000	.000000	0.003
Cyanide	5	.000	.001	.001	.00100	.000000	.000000	0.07
Cooper	5	.000	.020	.020	.02000	.000000	.000000	2.0
Zinc	5	.033	.005	.038	.01460	.006137	.013722	3.0
Arsenic	5	.000	.001	.001	.00100	.000000	.000000	0.01
Mercury	5	.000	.001	.001	.00100	.000000	.000000	0.01
Valid N (listwise)	5							

Appendix 12: Descriptive statistics of heavy metals for underground water (pits)

Element	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Mean Std. Error	Std. Deviation Statistic	WHO Guidelines
Lead	5	.451	.003	.454	.18460	.090829	.203100	0.01
Chromium	5	.000	.010	.010	.01000	.000000	.000000	0.05
Cadmium	5	.020	.011	.031	.01980	.004420	.009884	0.003
Cyanide	5	.001	.001	.002	.00120	.000200	.000447	0.07
Copper	5	2.218	.002	2.220	.64620	.410783	.918538	2.0
Zinc	5	.703	.140	.843	.45360	.116397	.260272	3.0
Arsenic	5	3.719	1.401	5.120	2.54900	.667512	1.492602	0.01
Mercury	5	.780	.045	.825	.39820	.162663	.363726	0.01
Valid N (listwise)	5							

Appendix 13: Descriptive statistics of heavy metals for Kulubiliga River

Element	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Mean Std. Error	Std. Deviation Statistic	WHO Guidelines
Lead	6	1.579	.001	1.580	.69567	.214500	.525417	0.01
Chromium	6	.000	.010	.010	.01000	.000000	.000000	0.05
Cadmium	6	.219	.001	.220	.04367	.035413	.086745	0.003
Cyanide	6	.119	.001	.120	.02700	.018861	.046200	0.07
Copper	6	1.620	.015	1.635	.91517	.238991	.585407	2.0
Zinc	6	.876	.005	.881	.22100	.140639	.344493	3.0
Arsenic	6	3.447	.863	4.310	1.87617	.514410	1.260041	0.01
Mercury	6	1.603	.020	1.623	.67483	.264243	.647260	0.01
Valid N (listwise)	6							