

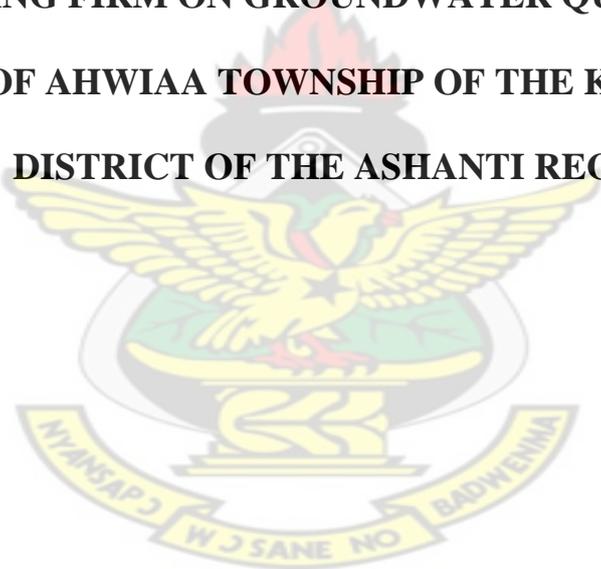
KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

KUMASI, GHANA

**IMPACT OF THE ACTIVITIES OF THE AHWIAA TIMBER
PROCESSING FIRM ON GROUNDWATER QUALITY: A CASE
STUDY OF AHWIAA TOWNSHIP OF THE KWABRE EAST
DISTRICT OF THE ASHANTI REGION.**



BY

KAMPELGE YOROSE DAVID

NOVEMBER, 2013

**IMPACT OF THE ACTIVITIES OF THE AHWIAA TIMBER PROCESSING
FIRM ON GROUNDWATER QUALITY: A CASE STUDY OF AHWIAA
TOWNSHIP OF THE KWABRE EAST DISTRICT OF THE ASHANTI
REGION.**

A Thesis submitted to the Department of Theoretical and Applied Biology,

Kwame Nkrumah University of Science and Technology in partial

Fulfillment of the requirement for the award of

Master of Science degree

(MSc. Environmental Science).



By

Kampelge Yorose David

November, 2013

DECLARATION

I hereby declare that this thesis document submitted to the Board of Postgraduate study, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana is the result of my own research work towards the MSc. Degree and to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the Kwame Nkrumah University of Science and Technology or any other university, except for references to other people works which have been acknowledgement.

KNUST

KAMPELGE YOROSE DAVID

(Student ID-PG4984410)

Signature

Date

Certified By:

PROF. K. OBIRI DANSO

(Supervisor)

Signature

Date

REV. S. AKYEAMPONG

(Head of Department)

Signature

Date

ABSTRACT

It is perceived that wood preservatives when used close to water bodies eventually contaminate them. The effect of a wood (teak) preservation factory that uses chemicals with high heavy metal content on water resources within the Kwabre East District of Ghana was assessed on wells. Wells, selected randomly from four locations using a hand-held Global Positioning System Device, were analysed for the heavy metals As, Cu, Cr and Zn using Atomic Absorption Spectrophotometer (AAS). Arsenic (As) and Chromium (Cr) levels in the water samples were less than 0.01 mg/l. Zinc (Zn) content ranged between 0.10mg/l to 0.26mg/l. Copper (Cu) content was between 0.05mg/l to 0.08mg/l. The ground waters were slightly acidic (pH = 5.36 to 6.51). Significant differences were observed in pH, conductivity (65 μ S/cm to 362 μ S/cm), TDS (39.6mg/l to 206.5mg/l) and TSS (1.60mg/l to 5.10mg/l) were observed among the water samples. However, the water samples did not differ in terms of temperature (27.90°C to 28.09°C), turbidity (0.01NTU to 0.21NTU) and colour (0.01PCU to 0.76 PCU). Nitrate content of the water samples ranged from 0.0035 mg/l to 0.0083 mg/l and for phosphate (PO₄) between 0.02mg/l to 0.32 mg/l. Biochemical Oxygen Demand (BOD) of the water sampled ranged between 0.04mg/l and 0.09mg/l. Significant differences were observed for nitrate and phosphate content in the water samples but no significant differences were observed for BOD. All parameters studied were within WHO guideline limits. Generally, the well water sources in the Kwabre East district were not affected by the wood preservatives being used by the factory and are safe for consumption.

DEDICATION

I dedicate this thesis to the late Beatrice Kane Bawa, my mother Adagine Kosewo, my uncle Michael Adagine and the Wodah family for taking care of me throughout my education.

KNUST



AKNOWLEDGMENT

I wish to register my heartfelt appreciation and gratitude to my supervisor, Prof. Kwasi Obiri Danso, for his immense guidance, support and constructive suggestions in the preparation of this research work particularly reading through my work and making useful comments despite his busy schedules. This work would not have been successful without the help of Mr. Napoleon of the Department of the Renewable Natural Resources KNUST who in diverse ways assisted me throughout my work. My profound gratitude also goes to Mr. Odame Emmanuel for his assistance in the analysis of my results. I am also thankful to all friends especially Gerard Ataogye, Matthew Angbanyere, Maxwell Kubi, Kenneth Agbemehia, Felix Adechie and Kwarteng Romeo who contributed in diverse ways to this work.

Finally, I wish to indicate my outmost appreciation and recognition to the Almighty God for the guidance, sustenance and blessings bestowed on me to make this work successful.

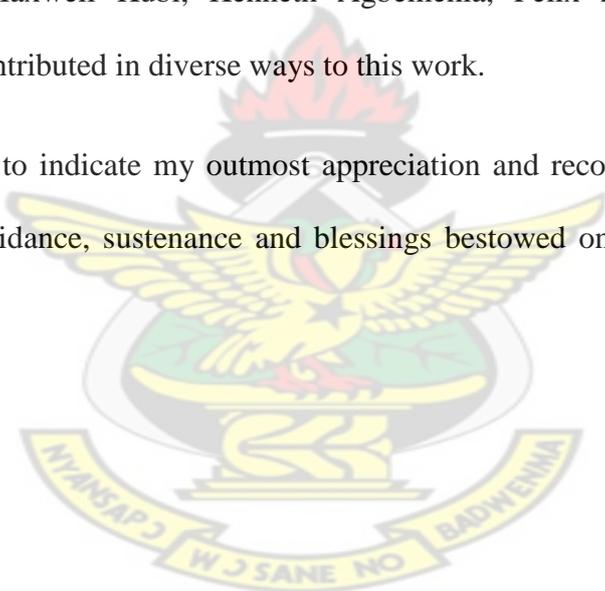


TABLE OF CONTENTS

TITLE	PAGE
DECLARATION.....	ii
ABSTRACT.....	iii
DEDICATION.....	iv
AKNOWLEDGMENT	v
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xi
CHAPTER ONE	1
1. INTRODUCTION	1
1.1 BACKGROUND	1
1.2 PROBLEM STATEMENT	6
1.3 GENERAL OBJECTIVE.....	8
1.3.1 SPECIFIC OBJECTIVES.....	8
2.0 LITERATURE REVIEW	9
2.2 GHANA WATER POLICY	9
2.3 GROUNDWATER	10
2.4 GROUND WATER QUALITY	11
2.5 WATERBORNE PRESERVATIVES (CHROMATED COPPER ARSENATE (CCA)).....	13
2.6 PHYSICO-CHEMICAL INDICATORS FOR WATER QUALITY	15
2.7 NUTRIENTS	17
2.7.1 NITRATES	17
2.7.2 PHOSPHATES	19
2.7.3 BIOCHEMICAL OXYGEN DEMAND	20
2.7.4 TOTAL DISSOLVE SOLIDS	21
2.7.5 TOTAL SUSPENDED SOLIDS	23

2.7.6 TURBIDITY	23
2.7.7 COLOUR	24
2.7.8 CONDUCTIVITY	24
2.7.9 pH.....	25
2.7.10 TEMPERATURE	26
CHAPTER THREE.....	27
3.0 MATERIALS AND METHODS.....	27
3.1 STUDY AREA	27
3.2 CLIMATE AND VEGETATION.....	28
3.3 RELIEF AND DRAINAGE	29
3.4 SOIL AND AGRICULTURE USE	29
3.5 GEOLOGY AND MINERALS	29
3.6 POPULATION	30
3.7 WATER AND SANITATION	30
3.7.1 WATER	30
3.7.2 SANITATION	30
3.8 DRAINAGE.....	31
3.9 SAMPLING SITES	31
3.10 SAMPLING	32
3.11 PHYSICAL PARAMETERS ANALYSIS.....	33
3.11.1 TOTAL DISSOLVED SOLIDS (TDS).....	33
3.11.2 TOTAL SUSPENDED SOLIDS	33
3.11.3 MEASUREMENT OF pH	33
3.11.4 CONDUCTIVITY	34
3.11.6 COLOUR BY SPECTROPHOTOMETER	34
3.12 NUTRIENT ANALYSIS.....	35
3.12.1. NITRITE CONCENTRATION	35

3.12.2. NITRATE CONCENTRATION	35
3.12.3. PHOSPHATE	36
3.12.4 BIOCHEMICAL OXYGEN DEMAND (BOD ₅).....	36
3.12.5 DETERMINATION OF METALS CONCENTRATION (Cr, Cu, As and Zn).....	38
3.12.6 DATA ANALYSES.....	39
CHAPTER FOUR.....	40
4.0 RESULTS	40
4.1 HEAVY METAL CONCENTRATION OF WATER SAMPLES FROM THE FOUR SAMPLING LOCATIONS	40
4.2 HEAVY METAL CONCENTRATION OF WATER SAMPLES FROM THE TWEENTY SAMPLING POINTS	40
4.3 NUTRIENT CONCENTRATIONS OF WATER SAMPLES FROM DIFFERENT SAMPLING LOCATIONS	46
4.4 CORRELATION MATRIX OF PARAMETERS	48
CHAPTER FIVE	50
5.0 DISCUSSION	50
6.0. CONCLUSION AND RECOMMENDATIONS	58
6.1. CONCLUSION.....	58
6.2. RECOMMENDATION	58
REFERENCE.....	60
APPENDICES	86

LIST OF TABLES

Table 4.1: The Mean values for Metal concentration in water from the four different sampling locations of Ahwiaa Township, 2000.	40
Table 4.2: Metal concentration in water from all the 20 sampling points of Ahwiaa Township, 2010.	41
Table 4.3: Correlation matrix of parameters measured	48

KNUST



LIST OF FIGURES

Figure 3.1:Map of District	28
Figure 4.1: Temperature variations in water samples from the different sampling locations.	42
Figure 4.2: pH variations in water samples from the different sampling locations.....	42
Figure 4.3: Turbidity variations in water samples from the different sampling locations	43
Figure 4.4: Conductivity variations in water samples from the different sampling locations	43
Figure 4.5: Total Dissolved Solids variations in water samples from the different sampling locations.....	44
Figure 4.6: Total Suspended Solids variations in water samples from the different sampling locations.....	44
Figure 4.7: Colour variations in water samples from the different sampling locations	45
Figure 4.8: Nitrate concentrations in water samples from the different sampling locations	46
Figure 4.9: .Phosphate concentrations in water samples from the different sampling locations.	47
Figure 4.10:.BOD concentration in water samples from the different sampling locations	47

LIST OF ABBREVIATIONS

APHA	-	American Public Health Association
CSIR	-	Council for Scientific and Industrial Research
DA	-	District Assembly
DANIDA	-	Danish Development Agency
DHMT	-	District Health Management Team
EDTA	-	Ethylenediaminetetraacetic acid
EPA	-	Environmental Protection Agency
GIS	-	Geographical Information System
GMA	-	Ghana Meteorological Agency
GNWP	-	Ghana National Water Policy
GOG	-	Government of Ghana
GPRS	-	Ghana Poverty Reduction Strategy
GPRSII	-	Growth and Poverty Reduction Strategy
GPS	-	Global Positioning System
GWCL	-	Ghana Water Company Limited
GWSC	-	Ghana Water and Sewerage Corporation
LI	-	Legislative Instrument
MDGs	-	Millennium Development Goals
MMSD	-	Milwaukee Metropolitan Sewerage District
MWRWH	-	Ministry of Water Resources, Works and Housing
NEPAD	-	New Partnership for African Development
SPSS	-	Statistical Package for the Social Sciences
TDS	-	Total Dissolved Solids
U.S.A	-	United States of America

UNEP	-	United Nations Environment Programme
UNESCO	-	United Nations Educational, Scientific and Cultural Organisation
WHO	-	World Health Organisation
WRC	-	Water Resources Commission
WRI	-	Water Research Institute

KNUST



CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND

The combination of chromium, copper and arsenic salts known as chromate copper arsenate (CCA) is a commonly used biocide to preserve wood. Chromate copper arsenate (CCA) has been used for years as a preservative to treat woods to extend the life of wood products. It is efficient in reducing bacterial, fungal and insect decay in wood (Warner and Solomon, 1990). Pentachlorophenol, creosote, chromate copper arsenate (CCA) and ammoniacal copper arsenate (ACA) are the most widely used wood preservatives throughout the world. CCA is the mostly used in aquatic environments (Hingston *et al.*, 2001). CCA, an inorganic wood preservative was developed by an Indian scientist, Dr. Sonti Kamesam in 1933 (Lahiry, 1997) and since then has been used extensively throughout the world, although recently its use has been phased out in the United States (Rahman *et al.*, 2004). In Germany, more than 1000 tons of chromium and 600 tons of copper are used annually for preservation of wood (Stephan *et al.*, 1996).

The viticulture industry is one of the largest users of CCA timber in South Africa and consequently generates significant quantities of waste CCA timber requiring management and disposal (Merz, 1999). Waste CCA timber posts generated by these industries are being stockpiled at various sites and in increasing volumes; the quantity can be expected to continue increasing in the short to midterm, with exponential growth in the longer term. Waste poles, furniture and sawdust are stockpiled in every timber processing firm in Ghana and possibility of disposal problems is glooming. Research has shown that components of CCA leach from wood surface to elevated

concentration of As, Cr and Cu in the soil and groundwater (Carey *et al.*, 1996; Lebow, 1996; Cooper and Ung, 1997; Solo-Gabriel *et al.*, 2000) and aqueous environment to the detriment of soil and aquatic organisms (Weis and Weis, 1996). Arsenic (As) and copper (Cu) act as the insecticides and fungicides respectively, while chromium (Cr) is used to fix the other two elements to the cellulose and other components of the wood (Dawson *et al.*, 1991). Timber utility poles in North America are treated with preservatives to reduce bacteria, fungi and insect attack and increase their life expectancy. The recent switch from CCA to other form of wood preservatives for many treated wood products (US EPA, 2002) results from over impact on human health and the environment. In the past decades, questions were raised with respect to human exposure to CCA treated wood products during manufacturing and use, contamination of soils underneath or adjacent to treated structures and impact on water supplies and aquatic organisms (cooper, 199; Weis *et al.*, 1993; Breslin, 1996; Stilwell and Gorny, 1997; Adler-Ivanbrook,1998;Lebow *et al.*, 1999; Solo-Gabriele *et al.*, 2003; Lebow *et al.*, 2003; Townsend *et al.*,2003a; Townsend *et al.*, 2003b).The management of discarded CCA-treated wood at the end of its useful life has also been raised as an issue of possible concern(McQueen and Stevens,1998; Solo-Gabriele and Townsend, 1999). In Ghana a number of wood preservatives are used in sawmills to treat wood and due to differences in environmental conditions and species of wood high concentrations of these preservatives are used to treat wood creating problems of contamination of ground and surface water (Oteng-Amoako, 1989). The wood preservatives are either organic (and oil based) or inorganic (and waterborne). CCA or CCB treated wood has an expected service life of approximately 20-50 years, depending on the method of treatment and conditions of service (Cooper, 1994). After the service life, the wood is removed and discarded as waste. It has been estimated by

Felton and DeGroot (1996) that by the year 2020, about $1.9 \times 10^6 \text{m}^3/\text{year}$ of copper treated wood will be removed from service world-wide and be available for disposal. In Europe, volumes of CCA treated wood wastes in the order of 3 to 4 million m^3 per year are expected by the year 2020 (Connell, 1999) while in Canada, this number was expected to increase from about 180,000 m^3 at present to about 2.5 million m^3 by the year 2010 (Stephens *et al.*, 1996). Common management practices for discarded CCA-treated wood include disposal in landfills and combustion in waste-to-energy systems. Potential adverse effects posed by these practices include elevated metal concentrations in landfill Leachate and groundwater (Jang and Townsend, 2001; Townsend *et al.*, 2001; Weber *et al.*, 2002; Jang and Townsend, 2003a; and Jambeck *et al.*, 2003) and WTE combustion ash (Solo-Gabriele *et al.*, 2001). In Ghana large proportion of waste wood are used as particleboard and fuels. CCA-treated wood has attracted much attention in recent years mainly due to the adverse health impacts resulting from arsenic. Arsenic-contaminated groundwater poses a threat to human health if the contaminated groundwater is used as a drinking water supply without adequate treatment (Smith *et al.*, 2002). Arsenic is a known human carcinogen, and consumption of arsenic-contaminated groundwater is association with much adverse health effects including cancer of the skin and internal organs. The use of CCA-treated wood extends from playgrounds, fences, yards and general-purpose decks to public utility poles throughout Florida (Chirenje *et al.*, 2003). Townsend *et al.* (2000) estimated that, in Florida, CCA-treated decks impact approximately 10000 ha or 60 million tons of soil and the volume of CCA-treated utility poles in use is $7 \times 10^5 \text{m}^3$.

Elevated metal concentrations were observed in soils near CCA-treated decks in Connecticut where As, Cr and Cu concentrations were 76, 43 and 75 mg/kg compared to background concentration of 3.7, 20 and 17mg/kg, respectively (Stilwell and

Gormy, 1997). Due to the intensive use of CCA to treat wood, it is expected that CCA would be found in the ground water sources of the study area. Cooper and Ung (1997) determined As, Cu and Cr concentrations in the vicinity of utility poles to be as high as 550, 200, and 1,000 mg /kg, respectively. (Oteng-Amoako, 1999) determined the presence of wood preservatives in selected sawmills in Koforidua and Kumasi. Townsend *et al.* (2000) also determined the leaching of As, Cr and Cu from CCA-treated decks in public access areas in Florida and showed that the mean As, Cr and Cu concentrations below the decks were 28, 34 and 40 mg/kg compared to background concentration of 1.5, 10 and 10 mg /kg, respectively. The extensive used of wood preservative to treat wood in the area could possibly leach heavy metals into the ground water sources. The United States Environmental Protection Agency (USEPA) soil screening levels (SSL) for As and Cr are 0.4mg/kg and 390mg/kg, respectively for direct exposure (no Federal SSL value for Cu). The soil cleanup target levels (SCTL) for As, Cr⁵⁺ and Cu in Florida are 0.8, 210 and 110 mg/ kg for residential areas, and 3.7mg/kg, 420 and 76 000 mg/kg, for commercial areas, respectively (FDEP, 1999).

In recent years due to the extensive use of organic and inorganic preservatives (containing toxic metals) for protection of timber and other structural materials, there have been considerable problems with groundwater pollution (Zagury *et al.*, 2008). Chromated Copper Arsenate (CCA) is extensively used throughout the world due to its wide range of effects on target (bacteria, fungi, termites, marine borers, etc.,) organisms. Although, it is very effective, its usage is under increasing public and regulatory pressure to move away from chromium and arsenic based preservatives. This is due to the fact that individual elements of CCA have been found to be toxic to non target organisms. Earlier studies have shown that metals of copper, chromium and arsenic are released from CCA treated timber into ground and surface water upon

getting in contact with the water. The metals lost from treated wood enter into the surrounding water. Soil contamination problems with one or more of these chemicals can often be expected at wood preservation sites, particularly at old sites. The chemicals used for wood preservation are chosen for several reasons, one being that they are toxic to microorganisms and fungus, which can degrade wood. Meanwhile the toxicity is not specific for these organisms and thus these chemicals can cause serious problems, when spread to the environment. The use of CCA and other As-based chemicals as wood preservatives in Sweden (Bhattacharya *et al.*, 2002) have caused widespread metal contamination in soil around the wood preservation sites due to raw material handling, spills, deposition of sludge and dripping from freshly impregnated wood or due to leaching from the piles of impregnated wood at these sites by rain water especially under low pH conditions (Solomon, 1990; Lund and Fobian, 1991; Warner and Andersen *et al.*, 1996; Bhattacharya *et al.*, 1996). Because CCA leaches out of the treated timber over time there can be residues of arsenic, copper and chromium on the surfaces of the wood and it can be washed off by rain to accumulate in the soil or water below. All three metals pose a potential threat to the environment. According to the USEPA, 'the amount and rate at which arsenic leaches, varies considerably depending on numerous factors, such as local climate, acidity of rain and soil, age of the wood product, and how much CCA was applied' (USEPA, 2002), Older wood preserver sites contain widespread soil, sediment, and sludge contamination generated by processes, practices, equipment leaks, storage, and waste treatment. Often, these primary sources lead to secondary contamination of underlying soil, which leads to groundwater pollution. Copper originating at the wood preservation plant leaches to the groundwater by infiltrating rainwater. Moreover, leakage of process liquors including very high concentrations of copper from wood

preservation plant products contributes to rainwater leaching. There are four major routes through which pesticides reach the water: it may drift outside of the intended area when it is sprayed, it may percolate, or leach, through the soil, it may be carried to the water as runoff, or it may be spilled, for example accidentally or through neglect. They may also be carried to water by eroding soil. Many of the chemicals used in pesticides contain heavy metals which are persistent soil contaminants, whose impact may endure for decades and adversely affect soil and water conservation. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, including non-target species, air, water and soil (FAO, Government of Puducherry)

Pesticides containing heavy metals are one of the causes of water pollution, and some pesticides are persistent organic pollutants and contribute to soil and groundwater contamination. While microbiological contamination is the largest public health threat, chemical contamination (heavy metals) can also be a major health concern as it will contain arsenic, fluoride, nitrate, heavy metals, phosphates and pesticides. Water of poor physical quality does not directly cause disease, but it may be aesthetically unacceptable to consumers, and may force them to use less safe sources.

1.2 PROBLEM STATEMENT

The timber processing firm in Ahwii processes plywood, veneer, planks, window and door frames, furniture and electric poles. This has created jobs for over a thousand youth in the District. To ensure longevity, the timber products are treated with chemical preservatives to protect them from insect and microbial (bacteria and fungi) attack. Wood preservatives can extend the life of wood and reduce the need to over exploit our forest resources. It is established that most of these chemicals are pesticides

(organophosphates and organochlorines) and when released into the environment, become toxic, persistent and bioaccumulate in tissues of organisms and water bodies.

One of the most serious environmental issues in the world today is ground water contamination (Vodela *et al.*, 1997). Indiscriminate release of toxic wastes and even carcinogenic substances from industrial units may result in these toxic substances slowly trickling down through the earth surface and mixed with the groundwater. This problem is very serious in areas where the water table is high. Drinking this contaminated water over many years may lead to bioaccumulation of toxic metals in the body. These metals are difficult to metabolize and are stored in the fatty tissues of the body. Their concentration in the body over a long period may reach dangerous levels and may cause severe damage to vital human organs and even bring nervous disorder. Chronic exposure to chemicals in drinking water may also affect cognitive development (Tsai *et al.*, 2003; Wasserman *et al.*, 2004). Cognitive impairment can last a lifetime and contributes to a vicious cycle. In developing countries, the incidence of diarrhoeal diseases attributed to water consumption varies substantially between communities because of varying water quality and other behavioural and socio-economic factors (Esrey *et al.*, 1991). Population increase in Kumasi has led to limited supply of potable water by the Ghana Water Company. Few areas have access to pipe-borne water (GOG, 2007). Some do not even have service lines in their area, especially, the peri-urban communities. This has resulted in individuals drilling wells for potable water. Those who cannot afford the cost of drilling wells tend to buy water from those who have it. The activities of this timber processing firm can cause contamination of the ground water. This is possible because chemicals (heavy metals) can leach into the ground water and cause health problems when the water is used for drinking purposes. The wide diversity of contaminants affecting water resources including heavy metals has

received particular concern considering their strong toxicity even at low concentrations (Marcovecchio *et al.*, 2007). According to Mateu *et al.* (1996) trace metal levels can be indicators of the concentrations of other pollutants to which they are potentially related. Wood waste from construction, renovation and demolition work may be regulated as dangerous waste due to the fact that, they are treated with pesticide.

1.3 GENERAL OBJECTIVE

To evaluate the extent of chemical contamination of the groundwater resources in the Ahwiaa township by measuring the concentrations of CCA and ammonical copper zinc arsenate in the water resources of the area.

1.3.1 SPECIFIC OBJECTIVES

- To determine the concentration of chromium, copper, arsenic and zinc in well water sources.
- To determine phyco-chemical parameters (pH, temperature, colour, turbidity, total dissolved solids, total suspended solids) in well water sources.
- To determine the level of Biological Oxygen Demand in well water sources.
- To determine the concentration of nutrients (nitrates and phosphates) in well water sources
- To assess the presence of sawdust in well water.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Water is the most important natural resource in the world and without it life cannot not probably exist, industries cannot operate and there is no substitute in many of its uses (Aidoo, 2003).

Ground water is the most important source of the domestic, industrial and agricultural water supply in the world and this preference to surface water could be due to the purification of ground water prior to distribution (Adeyeye and Abulude, 2004).

Groundwater is increasingly becoming the source of drinking water for inhabitants of both rural and urban settlements in Ghana due to intermittent water shortage which has been hitting most parts of cities and only 30 percent have access to safe drinking water with over 50 percent relying on “unprotected” source of water (Ministry of Health, 1999). The United Nations declared 1981-1990 a water-and-sanitation decade (WHO, 1987). It has been estimated that lack of clean drinking water and sanitation services leads to water-related diseases globally and between five to ten million deaths occur annually, primarily of small children (Snyder and Merson, 1982).

2.2 GHANA WATER POLICY

The Ghana Water Company Limited (GWCL) is responsible for overall planning, managing and implementation of urban water supply. However, only 41.4 % of people living in the urban areas have piped water in their homes whilst 42.6% purchase water from a public tap or neighbor’s residence (GOG, 2007). This shows that urban water supply by GWCL is insufficient for the urban community and there must be

adjustments in policy implementation of urban water supply to ensure sustainable development as spelt out in Growth and Poverty Reduction Strategy II, New Partnership for African Development and the Millennium Development Goals, to which Ghana is signatory.

2.3 GROUNDWATER

Groundwater occurs in many different geological formations. Nearly all rocks in the upper part of the Earth's crust possess openings called pores or voids. In unconsolidated, granular materials the voids are the spaces between the grains which may become reduced by compaction and cementation. In consolidated rocks, the only voids may be the fractures or fissures, which are generally restricted but may be enlarged by solution. The volume of water contained in the rock depends on the percentage of these openings or pores in a given volume of the rock. This is termed the porosity of the rock. More pore spaces result in higher porosity and more stored water (UNESCO/WHO/UNEP, 1996). A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a significant quantity of water. In Ghana, a rock unit or unconsolidated medium which can yield up to 13 litres per minute constitutes an aquifer (Harvey, 2004). The limit to which soil pore spaces or fractures and voids in rock become fully saturated with water is called the water table. The phenomenon by which water seeps down from the land surface adding to the ground water is called recharge. Ground water is recharged from rain water and snowmelt or from water that leaks through the bottom of lakes and rivers. Ground water may be obtained by drilling or digging wells and may also appear on the surface as spring. A well is usually an opening created to be able to gain access to groundwater. This may be in the form of a tube or bore lined with protective material or a shaft created by digging into the earth until the water table is reached. This water can then be brought to the land surface by a

pump or a bucket and a rope. Ground water can run out if more water is discharged than recharged. For example, during periods of dry weather, recharge to the aquifers decreases. If too much ground water is abstracted during these times, the water table can fall and wells may go dry.

2.4 GROUND WATER QUALITY

Water quality refers to the physical, chemical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to assess water quality relate to health of ecosystems, safety of human contact and drinking water. Water quality can be thought of as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. Water quality is a reflection of the source environment and the activities of man, including the use and management term that is most frequently used. However, the desirable properties of water quality should include: adequate amount of dissolved oxygen at all time, a relatively low organic content, pH value near neutrality, moderate temperature, and freedom from excessive amount of infectious agents, toxic substances and mineral matter (Adeniyi, 2004). There is a difference between “pure water” and “safe drinking water.” Pure water does not contain any minerals or chemicals, and does not exist naturally (EPA 1999). Safe drinking water may contain naturally occurring minerals and chemicals such as calcium, potassium, sodium or fluoride which are actually beneficial to human health (UNEP 2008). In general, good quality drinking water is “free from disease-causing organisms, harmful chemical substances and radioactive matter, tastes good, is aesthetically appealing and is free from objectionable colour or odour” (Life Water Canada 2007). To determine

water quality, scientists first measure and analyze characteristics of the water such as temperature, dissolved mineral content and number of bacteria. Selected characteristics are then compared to numeric standards and guidelines to decide if the water is suitable for a particular use. Groundwater is actually a complex, generally dilute, chemical solution. The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the aquifers (Zuane, 1990). The chemical alteration of the groundwater depends on several factors including interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallord and Edmond, 1983; Dethier, 1988; Faure, 1998; Umar and Absar, 2003; Umar *et al.*, 2006).

Groundwater in its natural state is generally of good quality. This is because rocks and their derivatives such as soils act as filters. However, not all soils are equally effective in this respect and therefore pathogens contained in human excreta such as bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Lewis *et al.*, 1982). Rainfall is a dilute chemical solution and contributes significant proportions to some constituents in groundwater, especially in regions with little soil cover where hard compact rocks occur at or near the surface. As water flows through the ground, the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater is saline, with concentrations ranging up to ten times the salinity of the sea. Groundwater can become unpotable if it becomes polluted and is no longer safe to drink. In areas

where the material above the aquifer is permeable, pollutants can seep into groundwater. This is particularly so in a fractured aquifer.

2.5 WATERBORNE PRESERVATIVES (CHROMATED COPPER ARSENATE (CCA))

The base ingredients from which CCA treating solutions are made are hexavalent chromium, cupric oxide, arsenic pentoxide and water. Arsenic, copper and chromium occur naturally in both soil and water but at certain concentrations all three compounds are toxic. Of these elements, arsenic causes the greatest concern due to its toxicity even at very low levels (Nriagu and Pacyna, 1988). Background levels depend on the local conditions and independent of this there is a geographical variation. On a global scale the natural background for arsenic is less than 10 mg/kg soil (Nriagu, 1990). Because of the high concentrations of metals in the CCA-solution, relatively small leaks or spills may result in high concentrations of the metals in soil that are potentially harmful to human health and the environment (Jang *et al.*, 2002). At wood preservation sites, extremely high soil concentrations can be found and these concentrations are high as 20.000 mg/kg in impregnation plants (Nordic Council of Ministers, 2000). To assess the environmental impact of contaminated soils and water, knowledge of the total concentration of a specific metal without considering its speciation is not sufficient. The physicochemical properties of soil and water can widely influence metal speciation and, consequently, its mobility, bioavailability and toxicity. Especially knowledge of As and Cr speciation is very important, since their toxicity is associated with changes in oxidation state. Dependent on pH and redox potential of the soil and water environment, As can occur in two stable oxidation states that form oxyanions: As (V) as arsenate species ($H_xAsO_4^{x-3}$) and As (III) as arsenite species ($H_xAsO_3^{x-3}$). In general, trivalent arsenic is of more environmental concern,

because it is more mobile and more toxic. Cr mainly exists in two stable oxidation states (hexavalent and trivalent) in soils and water, the hexavalent form being far more toxic than the trivalent. An investigation of a Norwegian wood preservation site showed that even 7 years after the preservation activities were ended at the site high concentrations of As was still found in the soil solution (as high as 50 mg/l). Meanwhile Cu was not detectable in the soil solution, not even at hot spots with a total soil concentration of 67000 mg/kg. As was also found to be far most mobile in the soil (Andersen *et al.* 1996). Cu is normally regarded as strongly adsorbed to the soil and Kelsall *et al.*, (1999) reported that Cu was immobile in an acid sandy soil of South West Victoria. Meanwhile there are examples of Cu being mobile example migration into depths of up to 6 meters under a Danish wood preservation site in Hammel which was placed on glacial till (Boutrup and Clement, 1990). In another Danish site, Cu was found in very high concentrations in the depth of 2.3 m below surface. The high concentration was connected to a calcareous zone (Lund and Fobian, 1991). The immediate leaching potential of the initial ionic species was found to increase in the following order $\text{Cu}^{2+} < \text{HAsO}_4^{2-}/\text{H}_2\text{AsO}_4^- \ll \text{Cr}_2\text{O}_7^{2-}$ in spiking experiments (Carey *et al.*, 1996) and this finding was supported by another investigation by Kelsall *et al.*, (1999) who found that Cu was immobile, arsenic somewhat mobile whilst chromium had a significant mobility. Findings from real sites do meanwhile show a different order: $\text{Cr} < \text{Cu} < \text{As}$ (Lund and Fobian, 1991; Boutrup and Clement, 1990). The difference may be related to the fact that even though Cr is present as Cr (VI) in the impregnation solution Cr is readily reduced to Cr (III) at the soil surface and this form is less mobile. Not only problems with groundwater quality has been reported in connection to wood preservation sites, example investigations have shown that

contamination of river has occurred from Norwegian impregnation sites (Andersen *et al.*, 1996; Rasmussen and Andersen, 1996).

2.6 PHYSICO-CHEMICAL INDICATORS FOR WATER QUALITY

Heavy metals contribute significantly to environmental pollution as a result of anthropogenic activities such as mining, energy and fuel production, power transmission, intensive agricultural practices, sludge and industrial effluent dumping, timber treatment and military operations (Foy *et al.*, 1978; Salt *et al.*, 1998; Orcutt and Nilsen, 2000; Cseh, 2002; Pilon and Smits, 2005). Metals such as aluminum, arsenic, cadmium, cobalt, chromium, copper, lead, manganese, mercury, nickel, selenium and zinc have been considered as the major environmental pollutants and their toxicity has already been established (Ross, 1994; Kochian, 1995; Orcutt and Nilsen, 2000; Cseh, 2002; Fodor, 2002). Contamination of groundwater with heavy metals (i.e., zinc, arsenic, copper, chromium, nickel, cadmium, lead and mercury) could come from several sources, including industrial discharges from chemical and metallurgic factories or leakage from landfills and wood treatment sites. The sediments, both suspended and precipitated substances stored on the water bottom, form a reservoir for many pollutants and trace substances of low solubility and low degree of degradability (Biney *et al.*, 1994; Barbour *et al.*, 1998). A characteristic feature of heavy metals in general regardless of whether they are biologically essential or not is that they may exert toxic effects to plants and animals in low concentrations compared to macro nutrients and these metals are considered to be cytotoxic and mutagenic although a few of them are essential for metabolic processes (Alloway, 1990; Shaw, 1995; Hadjiliadis, 1997; Salt *et al.*, 1998; Orcutt and Nilsen, 2000; Kabata-Pendias and Pendias, 2001; Fodor, 2002). In New Zealand and Australia, timbers have been preserved with formulations of Cu, Cr, and As (CCA), and there are now many derelict sites where

soil concentrations of these elements greatly exceed background concentrations. Such contamination has the potential to cause problems, particularly to groundwater. In Ghana, timber species have been preserved with formulations of CCA but no deleterious effects have reported. Elevated concentrations of both essential and non-essential heavy metals in the soil and water can lead to toxicity symptoms and growth inhibition in most organisms (Grant *et al.*, 1998; Jindal and Kaur, 2000; Hall, 2002). The dissolved constituents in ground water, include calcium, magnesium, sodium, potassium, bicarbonate, nitrate, phosphates, sulphate, chloride, iron, manganese, fluoride, zinc, chromium, arsenic, copper and lead. Soils receiving repeated applications of organic manures, fungicides and pesticides from wood treatment sites have exhibited high concentration of extractable heavy metals, thereby increasing their concentration in runoff (Moore *et al.*, 1998). These added substances may be arbitrarily classified as biological, chemical (both organic and inorganic), physical and radiological impurities. These impurities may give water a bad taste, color, odor or turbidity and cause hardness, corrosiveness, staining or frothing. The pH measures the acidity or alkalinity of the water while the conductivity is the ability of the groundwater to conduct an electrical current. Conductivity is a function of temperature, types of ions present and the concentrations of the ions. The total dissolved solids (TDS) an index of conductivity, has a direct relationship to salinity and high total dissolved solids limits the suitability of water for potable use (Davis and DeWiest, 1966). Generally, chemicals occurring in drinking-water are of health concern only after extended exposure for years. The only exception is nitrate. Nitrate and nitrite in water has been associated with methaemoglobinaemia, especially in bottle-fed infants. With a methaemoglobin level of 3-15%, skin can turn to a pale gray or blue. The nitrite ion contains nitrogen in a relatively unstable oxidation state.

Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (Anon, 1987). Because of its solubility and its anionic form, nitrate is very mobile in groundwater (Fytianos and Christophoridis, 2003). It tends not to adsorb or precipitate on aquifer solids (Hem, 1985). Changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies, such as, contaminated landfill and wood processing sites.

Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption.

2.7 NUTRIENTS

2.7.1 NITRATES

Nitrate contamination of ground and surface waters is of serious concern in many countries including Ghana. Providing high quality ground and surface water resources is essential for human use and consumption and to help secure the stability of dynamic environmental systems. Nitrate is considered one of the most widespread ground water contaminants in the United States (Petrovic, 1990) and researchers in many disciplines, have addressed this concern. Nitrogen occurs in three forms in groundwater; nitrate, ammonium and nitrite (Apello and Postma, 1996). According to Hem (1985), nitrogen occurs in water as nitrate or nitrite anions, as ammonium cations, and in a variety of organic compounds. Nitrite and the organic species are unstable in aerated water. Ammonium cations are strongly adsorbed on mineral surfaces, but the anionic species are readily transported in water and are stable over a wide range of conditions. Other sources of contamination include deposits from airborne nitrogen compounds emitted

by industry and automobiles (Nolan and Stoner, 2002). In developing countries, inorganic fertilizers, septic tanks and domestic animal manure from feedlots are the common forms of nitrate contamination. Nitrates-N, level above 3 mg /l is generally being related to anthropogenic activities (Madison and Brunett 1995). Perhaps the greatest environmental concern regarding nitrogen fertilization is potential nitrate loss via leaching and runoff. Nitrate is inherently mobile in the soil and nitrate is considered the most widespread groundwater contaminate (Petrovic, 1990). Potential sources of nitrate pollution include effluent from cesspools and septic tanks, animal and human wastes, urban runoff, and losses of nitrogen from agricultural land uses (Pye *et al.*, 1983, Keeney, 1986). Major concerns of nitrate contamination of ground and surface waters arise because nitrogen poses major human health and environmental risks. Nitrate does not pose threat to an adult's health in general. However, excessive ingestion of nitrate by infants can cause low oxygen levels in blood and is potentially fatal (US EPA, 2006). Health concerns over nitrate contamination result when nitrate in drinking water supplies are elevated. Groundwater provides 50 percent of our drinking water and as much as 95 percent in rural areas; therefore, protecting groundwater from pollution is essential if we are to have safe drinking water in all areas (Petrovic, 1990). When there are high levels of nitrate in drinking water supplies, in combination with conditions favorable for nitrate reduction to nitrite, toxic effects are produced (Keeney, 1982). Nitrate is reduced to nitrite in the gastrointestinal tract and subsequently moves into the bloodstream and reacts with hemoglobin to produce methemoglobin (USEPA, 1976). This causes the transport of oxygen to be altered and can cause methemoglobinemia or "blue-baby syndrome" in infants. Primarily, methemoglobinemia only occurs in infants under three months old and can result in serious or fatal poisonings (USEPA, 1976). Because of this concern,

the EPA has set 10 mg NO₃-N/l as the maximum concentration limit (MCL) for drinking water. According to Groover *et al.* (1997) this MCL was based on clinical studies but remains somewhat controversial. Petrovic (1989) states the lowest level recorded to cause health problems were 20 mg/l; however, very few cases of methemoglobinemia have been documented recently. Other documented potential health effects from excess nitrate in drinking water include birth defects, cancer, and nervous system impairment (Petrovic, 1989). Nitrate contamination of ground and surface waters also pose major environmental threats. Because nitrogen and phosphorus are limiting in aquatic systems, these nutrients increase the biological productivity of aquatic ecosystems. This can be desirable in low productivity water bodies, but can cause major problems through excess plant and organism growth (Keeney, 1986).

2.7.2 PHOSPHATES

In natural water system, phosphorus is gradually released from rocks due to weathering. Phosphates generally exist in three forms: orthophosphate, metaphosphate and organically bound phosphate. The primary sources of phosphate from anthropogenic activities are sewage, agricultural run-offs and detergents (Wangness 1994). Phosphates concentrations are seldom measured in groundwater, but available data suggest concentrations usually range from 0.01 to 0.1mg/l, with levels higher than 1 mg/l suggesting contamination (Hitchon *et al.*, 1990). However some exceptions do occur. For example, 8.5 mg/l PO₄-P was measured in the uncontaminated Milk River Sandstone Aquifer in southern Alberta (Hitchon *et al.*, 1990). Phosphorus leaching is enhanced by soils that are low in clay, organic carbon, iron and aluminum and in soils where preferential flow occurs through macropores (cracks formed by shrink-swell, root holes and worm burrows) (Culley and Bolton, 1983; Beauchemin *et al.*, 1998;

stamm *et al.*, 1998). Phosphorus leaching tends to increase significantly once binding sites in soil become saturated (Mozaffari and Sims, 1994; Simard *et al.*, 1995), but substantial phosphorus leaching can occur when saturation is reached (Heckrath *et al.*, 1995). Phosphorus concentration also turned to increase under reduced conditions when phosphorus is more mobile and sorption complexes dissolve (Moore and Reddy, 1994; Zilkey, 2001). Kjeldstrup *et al.*, (1992) found higher phosphate concentrations in shallow wells, dug wells and unconfined sand aquifers. Phosphorous is of concern because it can cause algal blooms and subsequent eutrophication to receiving water bodies where P is the limiting nutrient (Mihelcic, 1999). Sources of phosphorus include motor oil (Pitt *et al.*, 1999), animal wastes and remains, plant material, and fertilizers. Orthophosphate is the form of P most readily available (U.S. EPA, 1999) to aquatic life and is the most common form occurring in stormwater. It has been found that phosphorous loading is correlated to intensity of urban land use. Phosphorous was found to increase logarithmically with impervious surface area in construction using curb-and-gutter style stormwater management. No such trend was observed for a comparable LID development (Dietz and Clausen, 2008).

2.7.3 BIOCHEMICAL OXYGEN DEMAND

Biochemical Oxygen Demand (BOD) is a measure of the oxygen used in bacteria mediated oxidation of organic substances in water and wastewater. Theoretically an infinite time is required for complete biochemical oxidation of organic matter.

Respirometry is a versatile method for measuring the degradation and the oxygen uptake characteristics of a wide variety of domestic and industrial wastewaters (Young and Cowan, 2004). Multiorder BOD data from Hewitt *et al.*, (1979) encouraged Adrian *et al.*, (1999) to develop a DO sag equation for the three-halves order BOD reaction

and a multiorder BOD reaction (Adrian *et al.*, 2004).BOD can be used to measure organic matter content in water.

DO is essential for aquatic life . A low DO (less than 2mg/l) would indicate poor water quality and thus would have difficulty in sustaining many sensitive aquatic life. The amount of oxygen in water, to a degree, shows its overall health. That is, if oxygen levels are high, one can presume that pollution levels in the water are low. Conversely, if oxygen levels are low, one can presume there is a high oxygen demand and that the body of water is not of optimal health.

2.7.4 TOTAL DISSOLVE SOLIDS

Total dissolved solids (TDS) include dissolved, suspended and settleable solids in water (EPA, 2006). In fresh water, dissolved solids usually consist of calcium, chlorides, nitrate, phosphorus, iron, sulfur arsenic, chromium, zinc, copper and other ions particles that is small enough to pass through a filter with pores of two microns width (EPA, 2006). Total Dissolved Solids (TDS) is a measure of all constituents dissolved in water. Total Dissolved Solids measures the solids remaining in a water sample filtered through a 1.2 μm filter. According to the World Health Organization (WHO, 1996), the compounds and elements remaining after filtration are commonly calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, silica and nitrate-n. High TDS affects the taste and odor of water and in general, levels above 300 mg/l become noticeable to consumers. As TDS increases, the water becomes increasingly unacceptable. Although the SMCL for TDS is 500 mg/l, levels above 1200 mg/l are unacceptable to most consumers. Because TDS measurements may include a variety of parameters which can be naturally occurring or anthropogenic, its value as an indicator of nonpoint source pollution is limited. Particulate matter such as silt and clay particles, plankton, algae, and fine organic

debris will not pass through a 2micron filter (EPA, 2006). TDS is an important water quality parameter in regions with discharges from sewage treatment plants, industrial plants or extensive crop irrigation. The common sources of TDS include industrial discharges, sewage, fertilizers, and road runoff and soil erosion. Electrical conductivity (EC) is also known as specific conductance. It is a measure of the solution's ability to transmit electrical current. EC in water is closely related to the concentration of ionized substances. Ions that have a major influence on the conductivity of the water are H^+ , Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} and HCO_3^- . Other ions such as Zn^{2+} , Cr^{4+} , Cu^{2+} , Fe^{2+} , Mn^{2+} , Al^{3+} , NO_3^- , HPO_4^{2-} , $H_2PO_4^-$ and dissolved gases have a minor influence on the conductivity. Conductivity increases with increasing mineral content of a water sample. There are three major reasons to analyze total dissolved solids content. First, the concentration of total dissolved solids affects the water balance in the cells of aquatic organisms (EPA, 2006). Toxics can easily attach to suspended solids. A higher concentration of suspended solids implies that there are more solid particles to serve as "toxics carriers" (EPA, 2006). Due to the intensive agricultural practices in Kuttanad, it is especially important to analyze the TDS. A high TDS level makes drinking water unpleasant and unsuitable for human consumption. With higher TDS, less sun-light can penetrate through the depth of water, reducing the rate of photosynthesis by aquatic plants. As a result, TDS also leads to less dissolved oxygen supply in the water. EPA recommends drinking water to have a TDS level no more than 500 mg/l (EPA, 2008). TDS are correlated fairly well to the total mineral content of the water (deposits left after evaporation of a water sample), primarily salts, carbonates and metals. Organic compounds may also be dissolved solids. A high concentration of TDS is an indicator of possibly high volume contamination and further investigation may be recommended.

2.7.5 TOTAL SUSPENDED SOLIDS

Total Suspended Solids (TSS), also known as non-filterable residue, are those solids (minerals and organic material) that remain trapped on a 1.2 μm filter (U.S.EPA, 1998). Suspended solids can enter groundwater through runoff from industrial, urban or agricultural areas. Elevated TSS (MMSD, 2002) can “reduce water clarity, degrade habitats, clog fish gills, decrease photosynthetic activity and cause an increase in water temperatures.” TSS has no drinking water standard. Therefore, data in this report are compared to the KPDES surface water discharge permit requirement for sewage treatment plants of 35 mg/l. Suspended solids, which are almost always found in stormwater runoff samples, can degrade water quality (US EPA, 1999). Construction and land-disturbing activities are the leading source of suspended solids in stormwater (US EPA, 1999). Because metals, pesticides, and petroleum hydrocarbons often are sorbed to solid surfaces, solids provide a means of transport and accumulation of pollutants (US EPA, 1999). In general, TSS is not usually considered a good indicator for nonpoint source pollution in groundwater. However turbidity and TSS vary with change in flow. Poor management practices associated with activities such as construction and agricultural tillage can strip vegetation and allow the quick influx of sediment into groundwater via overland flow. Typically, given the nature of the activities that introduce sediments into groundwater, these impacts are transient.

2.7.6 TURBIDITY

Solids particles suspended in water absorb or reflect light and cause the water to appear “cloudy”. These particles are suspended inorganic minerals or organic matter picked up over or under the ground. Since the earth acts as an excellent filter, the water from deep well is usually clear without significant amounts of turbidity. This problem is more common in the water from surface supplies. The major problem with turbidity

is aesthetic, but in some cases suspended matter can carry pathogens with it. Large amounts of organic matter can also produce stains on sinks, fixtures, and laundry (WHO, 1985). Higher turbidity can be caused by human activity like cutting trees and removing vegetation next to a body of water. Trees provide shade to keep the water cooler, and trees and other plants help block mud and soil from washing into the water. When roads and parking lots are constructed without the proper silt fencing, more soil and mud are likely to reach the water.

2.7.7 COLOUR

Colour in drinking water may be due to the presence of coloured material in the water, example, humic substances, metals, wood preservative or highly coloured industrial wastes. The appearance of colour is caused by the absorption of certain wavelength of light by coloured substances (true colour) and by the scattering of light by suspended particles, together those are termed apparent colour. Treatment removes much of the suspended matter and, generally speaking, drinking water should be colourless. Sources high in true water should be true colour can be treated to remove colour by oxidation with ozone and adsorption onto activated carbon. Changes in colour from that normally seen provide warning of possible quality changes or maintenance issues should be investigated. They may, for example reflect degradation of the sources water.

2.7.8 CONDUCTIVITY

Conductivity indicates the presence of ions in the water, usually due to in majority, saline water and in part leaching. It can also indicate industrial discharges. Electrical conductivity (EC) is also known as specific conductance. It is a measure of the solution's ability to transmit electrical current. EC in water is closely related to the concentration of ionized substances. Ions that have a major influence on the

conductivity of the water are H^+ , Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^- and HCO_3^- . Other ions such as Zn^{2+} , Cu^{2+} , Cr^{4+} , Fe^{2+} , Mn^{2+} , Al^{3+} , NO_3^- , $H_2PO_4^-$, HPO_4^{2-} and dissolved gases have a minor influence on the conductivity. Conductivity increases with increasing mineral content of a water sample.

2.7.9 pH

pH is a measure of the acidity or alkalinity of water. It is usually measured by using a colorimetric test - litmus paper changes colour with increased acidity or alkalinity. pH varies naturally within streams as a result of photosynthesis. The acidity of a solution is expressed as the pH which is defined as $pH = -\log [H^+]$. In other words, the concentration of hydrogen ion $[H^+]$ in a solution determines the pH value. As the pH value is the negative exponent to the base 10 of $[H^+]$, there is an inverse relationship between $[H^+]$ and the pH value. The lower the pH, the more acidic is the sample; the higher the pH, the more basic. In natural water bodies, $[H^+]$ usually comes from carbon dioxide in the air dissolving in the water, forming carbonic acid. The reaction is shown in the following equation, $CO_2 + H_2O = H_2CO_3$. Acidity can also be caused by acid rain from industrial pollutants, such as sulfur dioxide emissions from power plants (Eby, 2004). On the other hand, alkalinity is the solution's capacity to resist changes in pH. This capacity is commonly known as "buffering capacity." When acid is added to a solution, the presence of hydroxide (OH^-) absorbs the excess H^+ ions and inhibits a rapid decrease in the solution's pH. Alkalinity of natural water is determined by the soil and bedrock in contact with the water. The main sources for natural alkalinity are bedrocks which contain carbonate, bicarbonate and hydroxide compounds such as limestone. A pH of 6.5 - 8.5 is the range with the maximum environmental and aesthetic benefits (EPA, 2008).

2.7.10 TEMPERATURE

Temperature of a waterway is significant because it affects the amount of dissolved oxygen in the water. The amount of oxygen that will dissolve in water increases as temperature decreases. Water at 0^oc will hold up to 14.6 mg of oxygen per litre, while at 30^oC it will hold only up to 7.6 mg/l. Temperature also affects the rate of photosynthesis of plants, the metabolic rate of aquatic animals, rates of development, timing and success of reproduction, mobility, migration patterns and the sensitivity of organisms to toxins, parasites and disease. Life cycles of aquatic organisms are often related to changes in temperature. Temperature ranges for plants and animals can be affected by manmade structures such as dams and weirs and releases of water from them.



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

Ahwiaa is a suburb of the Kwabre East District of the Ashanti Region. The District was part of the former Kwabre District, which was carved out of the former Kwabre Sekyere District in 1988. It became Kwabre East District after the creation of Afigya Kwabre District in 2008. It is located almost in the central portion of the Ashanti region. It is within latitudes $6^{\circ}45'$ and $6^{\circ}50'$ North and longitudes $1^{\circ}30'$ and $1^{\circ}35'$ West.

The District in figure 3.1 shares common boundaries with Sekyere South District to the North; Kumasi Metropolitan Assembly to the South; Ejisu Juaben District to the East and Afigya Kwabre District to the West. The District has a total land area of 148 square kilometers constituting about 0.6% of the total land area of Ashanti Region. Kwabre East District is part of the Greater Kumasi City region, which is made up of Kumasi Metropolitan Area and the surrounding Districts. The District capital, Mampong, is approximately 14.5 kilometers from Kumasi to the north east. There are 42 settlements, 1 parliamentary constituency, 2 Town Councils, 4 Area Councils and 27 Electoral Areas (DMTP Kwabre East, 2010-2011).

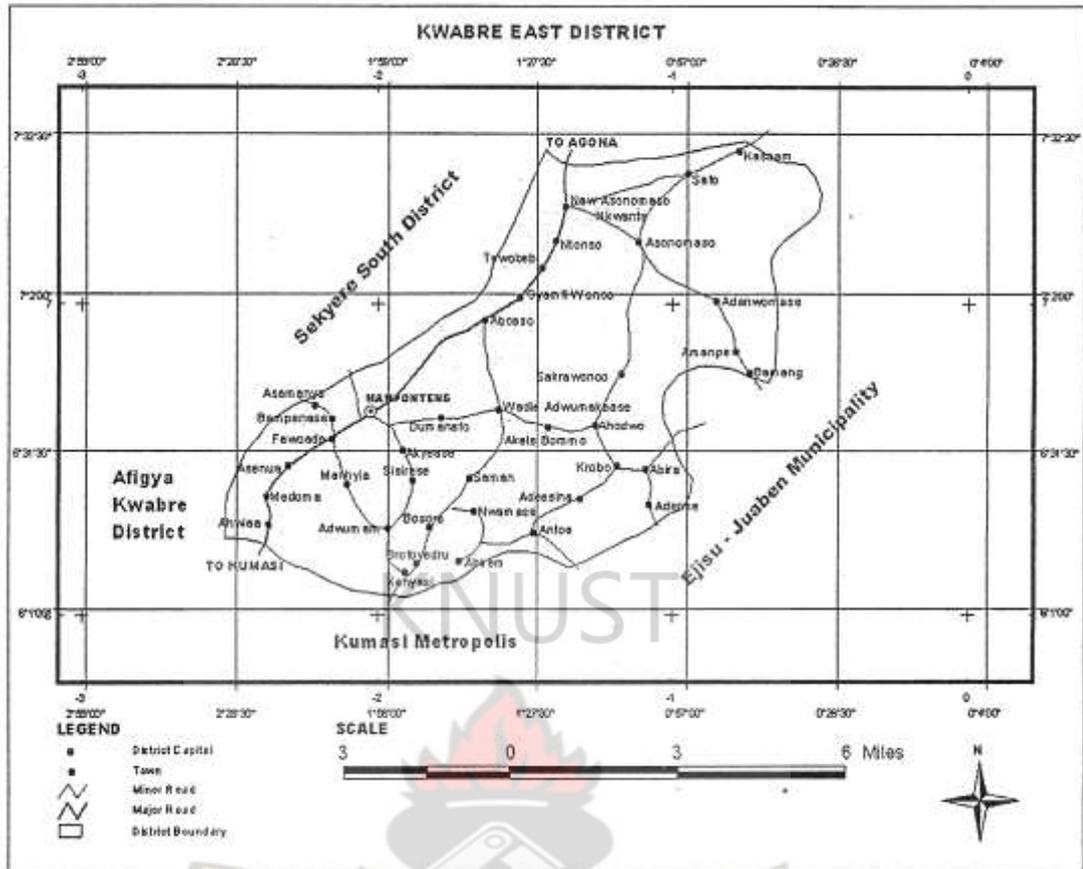


Figure 3.1: Map of District

Source: DMTP Kwabre East District 2010-2011

3.2 CLIMATE AND VEGETATION

The District is located within the wet semi-equatorial climatic region with double rainfall regimes. The major raining season is from April to June with the heaviest rainfall occurring in June. The minor raining season is from September to October. The dry season begins in November and ends in February. The average annual rainfall is between 12.5cm and 17.5cm with relative humidity of 75 – 80 percent during the rainy season and 70 – 72 percent during the dry season. The mean annual temperature is about 30°C with the lowest about 26.1°C. The rainfall regimes and adequate sunshine are suitable for food and cash crop production. The major vegetation types

are semi-deciduous forests and grasslands. Indiscriminate felling of trees, continuous cultivation of crops, the bush fires of 1983 and the increasing proportion of land for settlement purposes have left very little of the original forest to be found only along the river courses and northern fringes of the District. That notwithstanding, all the vegetation types are cultivable and thus useful for agricultural purposes.

3.3 RELIEF AND DRAINAGE

The topography exhibits diverse patterns with land heights ranging between 305 meters and 335m above sea level in the eastern portion with large isolated hilly outcrops, whilst the western boundary is generally undulating with areas below 290m above sea level. The district is well drained with a number of streams taking their source from the eastern highland flowing southeast and the rocky lulls of the west and depicting dendritic patterns. Notable streams are Akawsua, Anyinasu, Daku Wiwi, Ayiresua, Owai, Atonsu, Akasu, Krowa and Afiam almost all of which are perennial.

3.4 SOIL AND AGRICULTURE USE

Soils of varied complex associations found in the District include the Kumasi - Offin and Bomso-Offin compound associations, Boaman Simple Associations and Nyanoa - Tinkong Simple Association. The Kumasi Offin compound Association supports food crops like plantain, cocoyam and maize. The Boaman Simple Association supports cocoa and other tree crops. Finally, the Nyanoa – Tinkong Simple Association is not very good for agriculture but may support cocoa while having a dense forest and a lot of moisture.

3.5 GEOLOGY AND MINERALS

The main rock types found in the District are biotite, granite and grandiotites whose weathered products are fine textured granitic soils found in areas like Antoa, Abira,

Sakoro Wonoo, Wadie Adwumakase and Kenyase. Biotite gneiss and granites biotites have formed a number of large rocky outcrops in Kenyase and Aboaso. Low-grade alluvial gold deposits have been sited at Sakoro Wonoo. Diamonds have also been located at Safo and Kasaam in the northeast. Clay and sand deposits are found in the central areas of the District.

3.6 POPULATION

According to the 2000 population census, Kwabre East District has a population of 102,310 comprising 52,230 males (51%) and 50,080 females (49%). Some of the major communities and their population are as follows: Ahwiaa-19,729; Mampong-9,121; Ntonso-7,489; Aboaso-7,493. The rural-urban split is 65:35 which implies that 65% of the settlements are rural and 35% urban (Ghana Statistical Service, 2000).

3.7 WATER AND SANITATION

3.7.1 WATER

Potable water coverage in the District is about 70%. Almost all the 42 communities have access to potable water. The problem, however, is the adequacy especially in the peri-urban communities and the small towns where small town water systems would be needed. Currently, the District in collaboration with the Community Water and Sanitation Agency is constructing 200 boreholes under the Rural Water and Sanitation Initiative with financial support from the Government of Ghana and the African Development Bank, to increase access to potable water for a greater proportion of the population.

3.7.2 SANITATION

The practice of good sanitation and sound environmental practices ensure the quality of health of the people. Unfortunately, the sanitation situation in the District is still

deplorable. Toilet facilities available in the district are KVIPs, aqua privy, pit and VIP (household) latrines. Majority of the people (54%) depend on public toilet facility while the remaining (20%) have access to private places of convenience. The inadequacy of public toilet facilities compels some of the people to dispose of human excreta in bush (5%) while a good number of them use to bury their human waste behind their houses while the remaining (21%) use pit latrine. In view of the above, the Assembly in collaboration with the Community Water and Sanitation Agency (CWSA) is promoting the construction of over 2000 household latrines in the District under the Rural Water Supply and Sanitation Initiative (RWSSI). So far 800 household latrines have been constructed.

3.8 DRAINAGE

Most communities do not have properly constructed drainage system. Waste water from households gathers in gullies or flows into the streets and become breeding grounds for mosquitoes and other disease vectors. About 82% use the free flow method to get rid of their wastewater, 12% use the drains and 6% uses soak-a-ways.

3.9 SAMPLING SITES

The sample size was estimated to achieve a 95% confidence level, with an expected frequency of wells in houses being 20% and at 7% margin of error.

Using the formula for sample size, $n = \frac{Z^2 pq}{d^2}$

For 95% Confidence level, the value of $Z = 1.9$

The proportion of boreholes in houses, $p = 0.2$

$$q = 1 - p = 1 - 0.2 = 0.8$$

Margin of error, $d = 0.07$

Sampling size, $n = 126$

Houses were chosen for the study by systematic random sampling to ensure that there was equal likelihood of choosing the houses for the study in the study area. The selection interval was determined by dividing the total number of houses (19,729) by the estimated sample size (126), giving an interval of 25. A random start point was selected by spinning a pen in the centre of Ahwiaa and the direction of pen dictated the choice of house to sample first. We then went to the nearest house in the direction of the spun pen for sample collection, likewise for every 25th house in the right direction.

A total of 120 houses with wells were selected. 20 houses with wells were sampled from the 4 sampling locations thus Zongo, Overseas, Aboam and Ashanti line. In each sampling location, 5 sampling points were selected making a total of 20 wells.

3.10 SAMPLING

Monthly water samples were collected from the four locations in plastic sample bottles washed with acid and well rinsed with distilled water. Sampling began in February 2011 and ended in June 2011).

Two samples of groundwater were collected at each sampling point into two types of clearly labeled bottles, one for physical parameters analyses (1500 ml) and the other for the heavy metals analyses (500 ml). The samples were collected directly from the groundwater sources, without going through the overhead tank. Each sample collected was preserved in a light-proof insulated box containing ice-packs to prevent possible alteration of parameters by light and temperature. Samples were then transported to the Natural Resources Faculty, KNUST, for analyses.

To every one litre of sample for metal analysis, 5 ml of Conc. HNO₃ was added. This treatment was used to minimize adsorption of metals on the container walls. The acidified samples were then refrigerated at 4°C immediately on arrival.

3.11 PHYSICAL PARAMETERS ANALYSIS

3.11.1 TOTAL DISSOLVED SOLIDS (TDS)

TDS was measured *in situ* using a JENWAY 40710, model HI 9032 (0.01 degree of accuracy). One hundred milliliters of the sample was poured into a 250 ml beaker. The probe was then immersed into the sample and the value read on the digital screen.

3.11.2 TOTAL SUSPENDED SOLIDS

Absorbent Method

The Spectrometer was set to a wavelength of 630 nm.

The sample was shaken to ensure even distribution of dissolved solids and 25 ml aliquot was taken and put in the sample holder. The results were displayed digitally in mg/l.

3.11.3 MEASUREMENT OF pH

pH was measured *in situ* using a pH meter JENWAY 3071, model pH 82 (degree of accuracy 0.01) equipped with a temperature probe. The pH meter was initially calibrated by dipping the electrode into a buffer solution of known pH (pH 4). The asymmetric potential control of the instrument altered until the meter read the known pH value of the buffer solution. The standard electrode after rinsing with distilled/deionised water was then immersed in a second buffer solution (pH 9) and the instrument adjusted to read the pH value of this buffer solution. With the pH meter calibrated, it was immersed in the water sample, allowed to stabilize and the pH value read from the instrument. The beaker and the electrode were washed in between

samples with deionised water in order to prevent contamination by other samples. Duplicate pH values were taken.

3.11.4 CONDUCTIVITY

The conductivity was determined by means of a field conductivity meter. The conductivity cells and beaker were rinsed with a portion of the sample. Then the beaker was filled completely. The cell was then inserted into the beaker. The temperature control was adjusted to that of the sample and the probe was then inserted into the vessel and the conductance read.

The conductance was equilibrated to 25°C before the sample measurement (APHA 1998).

3.11.5 MEASUREMENT OF TURBIDITY

Turbidity of the water samples was measured *in situ* with a microprocessor turbidimeter JENWAY 3071, model HI93703 (0.0001 degree of accuracy). The instrument was first calibrated by dipping the probe into standard solution with turbidity values of 0.00 and 10.00 Nephelometric Turbidity Unit (NTU) and calibrated before using the turbidity values of the samples.

3.11.6 COLOUR BY SPECTROPHOTOMETER

The cell containing the blank (distilled water) in the sample compartment with the transparent sides was placed facing the light source. The sample compartment lid was then closed. The auto zero key was pressed to set the zero absorbance. The distilled water was discarded and the sample water placed in the cell. The apparent and true colour of the sample was then determined by pressing the start key.

3.12 NUTRIENT ANALYSIS

3.12.1. NITRITE CONCENTRATION

Diazotization method

The sample was filtered in the field through a 0.45 µm membrane filter and preserved at 4°C. The sample aliquot was reacted with sulphanilamide to form a diazo compound. This compound was then reacted with N-(1-naphthyl) ethylenediamine dihydrochloride to form an azo dye. The azo dye intensity, proportional to the nitrite concentration, was determined colourimetrically at 540 nm with the aid of an Ultra Violet Spectrophotometer (Wagtech, Jenway 6505) and compared to identically-prepared 0.001 mg/l standard and blank solutions (Environment Canada, 1974). The method detection limit was 0.001mg/l.

3.12.2. NITRATE CONCENTRATION

Hydrazine reduction method

The sample was filtered in the field through a 0.45 µm membrane filter and stored at 4°C. Nitrates, from the sample aliquot were reduced to nitrites with hydrazine sulphate. The resulting nitrites, together with the original nitrites, were then reacted with sulphanilamide to form a diazo compound. This compound was then reacted with N-(1-naphthyl) ethylenediamine dihydrochloride to form an azo dye. The azo dye colour intensity proportional to the nitrate + nitrite concentration was determined colourimetrically at 520 nm and compared to identically-prepared standard and blank solutions. The nitrate concentration was obtained by subtracting the original nitrite concentration, determined from a duplicate sample (Environment Canada, 1979). The method detection limit was 0.005 mg/l.

3.12.3. PHOSPHATE

Stannous chloride method

One drop of phenolphthalein indicator was added to 100 ml of sample. The sample was discharged by adding an acid, drop wise until it turned pink. 4 ml of molybdate reagent I and 10 drops of stannous chloride reagent I was added and mixed thoroughly. Absorbance was then read after 10 minutes at a wavelength of 690 nm on a spectrometer.

3.12.4 BIOCHEMICAL OXYGEN DEMAND (BOD₅)

In the presence of oxygen, manganous oxide (MnO_2) is oxidized to higher oxides of manganese. Upon acidification and in the presence of iodide this is reduced back to manganese liberating equivalent amount of the oxygen originally dissolved in the sample. The free iodine is titrated with thiosulphate, with starch as indicator as follows

1. Dilution water was prepared considering the number of samples under analysis. Suitable dilutions containing appropriate amounts of sample in volumetric flasks with the dilution water were prepared.
2. Careful mixing was done to avoid violent agitation which leads to formation of minute air bubbles.
3. Two BOD (300 ml) bottles with the dilution water were filled with diluted samples.
4. Two other BOD bottles with the dilution water but without sample were also set up as control.
5. The dissolved oxygen concentration was determined on one of the two bottles of diluted sample using the Winkler Method. The same was done on one of the blanks, within 15 minutes of its preparation.

6. The remaining bottles were stored in an incubator at 20 °C for 5 days.
7. Dissolved oxygen concentration in the incubated samples was determined at the end of the fifth day.

3.12.4.1 The Winkler Method for Dissolved Oxygen Determination

1. Two millilitres of Manganous sulphate followed with 2ml of alkaline-iodide azide agent were added to the filled BOD bottles (the tip of the pipette was always placed just below the surface of the liquid).
2. The bottles were stoppered without trapping any air bubbles. The content was mixed by inverting the bottles several times.
3. The precipitate was allowed to settle at least at the lower half of the bottle leaving a clear supernatant liquid above the manganese hydroxide flocs. Mixing was repeated as above.
4. The precipitate was allowed to settle again leaving at least 100 ml clear supernatant liquid.
5. The stopper was carefully removed and immediately 1 ml of concentrated sulphuric acid (H_2SO_4) was added allowing the acid to run down the neck of the bottle.
6. The bottle was re-stoppered and mixed by gentle inversion until a completely mixed solution was obtained. The iodine is ensured to be uniformly distributed throughout the bottle as seen by a uniform colour.
7. 203 ml of the liquid was decanted and titrated with N/40 Sodium thiosulphate to pale straw colour.
8. 1-2 ml of freshly prepared starch solution was then added.
9. Titration was continued to the first disappearance of the blue colour.

3.12.4.2 Calculating for the dissolved oxygen

1ml of N/40 or 0.024 M sodium thiosulphate is = 0.2 mg O₂. 203 ml of sample taken for titration corresponds to 200 ml of original sample. Therefore each ml of titrant used corresponds to 1mg/l of dissolved oxygen in the original sample. The results were expressed in mg/l.

$$\text{Mg/l BOD} = D1 - D2P$$

D1 = D. O. of diluted sample 15 minutes within preparation

D2 = D. O. of diluted sample after incubation

P = Decimal fractions of sample used (1/dilution factor)

3.12.5 DETERMINATION OF METALS CONCENTRATION (Cr, Cu, As and Zn)

Fifteen milliliters (15 ml) of concentrated HNO₃ was added to 50 ml of sample collected. The mixture was heated slowly to evaporate to a lower volume of 15 – 20 ml after which 5 ml of concentrated HNO₃ was again added to the 15 ml of the mixture obtained. The mixture was then diluted to 50 ml with distilled water. This was then heated slowly to obtain a gentle refluxing action. Further heating continued until digestion was complete (a light coloured solution). The sample was then transferred to a 50 ml volumetric flask and diluted to the mark after allowing it to cool for about 30 minutes. The levels of the individual metals were then determined using an Atomic Absorption Spectrophotometer (AAS) (Parkin Elmer 5100 PC). The absorbance of the standards and samples as well as the blank solution were read at 193.7 nm. Sensitivity for 1% absorption was 2.5 µg/l a calibration curve was constructed and the concentration equivalent to absorbent of was read from the curve and was recorded accordingly.

3.12.6 DATA ANALYSES

The data were entered in Microsoft Excel and transported to SPSS 12.0 2004 for analyses. The summary statistics such as mean, range and standard deviation were generated. The patterns of the variation of the water quality parameters in relation to the wells sites were also generated.

KNUST



CHAPTER FOUR

4.0 RESULTS

4.1 HEAVY METAL CONCENTRATION OF WATER SAMPLES FROM THE FOUR SAMPLING LOCATIONS

Arsenic, copper, and chromium concentration in water samples from all the four different sampling locations; Ashanti line, Overseas, Aboam and Zongo were below the WHO standard limits. However the concentration of zinc was very high at all sites but below the WHO standard limit (Table 4.1).

Table 4.1: The Mean values for Metal concentration in water from the four different sampling locations of Ahwiaa Township, 2000.

Location	As (mg/l)	Cu (mg/l)	Cr (mg/l)	Zn (mg/l)
Ashanti line	<0.01	0.076	<0.01	0.264
Overseas	<0.01	0.068	<0.01	0.101
Aboam	<0.01	0.060	<0.01	0.199
Zongo	<0.01	0.051	<0.01	0.239
WHO limit	0.01	2	0.05	3000
LSD _(0.05)	-	0.05	-	0.20

4.2 HEAVY METAL CONCENTRATION OF WATER SAMPLES FROM THE TWENTY SAMPLING POINTS

Arsenic and chromium content from all the sampling points were below 0.01 mg/l.

Copper content was high in the sampling point AB in Ashanti line (0.180mg/l) and low in CM in Overseas (0.042 mg/l), AA in Aboam (0.046 mg/l) and PK in Zongo (0.035 mg/l).Zinc concentration was however high in all the sampling points with PK recording highest in Ashanti line (0.788 mg/l) followed by KA in Zongo (0.070), AB

in Aboam (0.042 mg/l) and ABD in Overseas (0.027 mg/l). No statistically significant differences were observed in arsenic, copper, Chromium and Zinc concentrations in the water samples from all the sampling points ($P>0.05$).

Table 4.2: Metal concentration in water from all the 20 sampling points of Ahwiaa Township, 2010.

Sampling points	As (mg/l)	Cu (mg/l)	Cr (mg/l)	Zn (mg/l)
AB	<0.01	0.180	<0.01	0.042
MG	<0.01	0.060	<0.01	0.233
PK	<0.01	0.035	<0.01	0.788
CM	<0.01	0.046	<0.01	0.125
KS	<0.01	0.058	<0.01	0.131
EA	<0.01	0.059	<0.01	0.077
KA	<0.01	0.063	<0.01	0.070
ML	<0.01	0.080	<0.01	0.192
SK	<0.01	0.072	<0.01	0.077
OG	<0.01	0.068	<0.01	0.091
BK	<0.01	0.096	<0.01	0.269
YA	<0.01	0.046	<0.01	0.221
ABD	<0.01	0.056	<0.01	0.027
EO	<0.01	0.047	<0.01	0.239
DD	<0.01	0.055	<0.01	0.240
AA	<0.01	0.042	<0.01	0.312
CH	<0.01	0.047	<0.01	0.293
IY	<0.01	0.065	<0.01	0.071
MM	<0.01	0.047	<0.01	0.230
AKM	<0.01	0.054	<0.01	0.287
WHO limit	0.01	2	0.05	3000
LSD _(0.05)	-	0.05	-	0.20

4.2 PHYSICO-CHEMICAL PROPERTIES OF WATER SAMPLED FROM THE DIFFERENT SAMPLING LOCATIONS

Water temperatures at the different locations ranged between 27.90°C at Overseas to 28.09°C at Zongo (Figure .4.1).

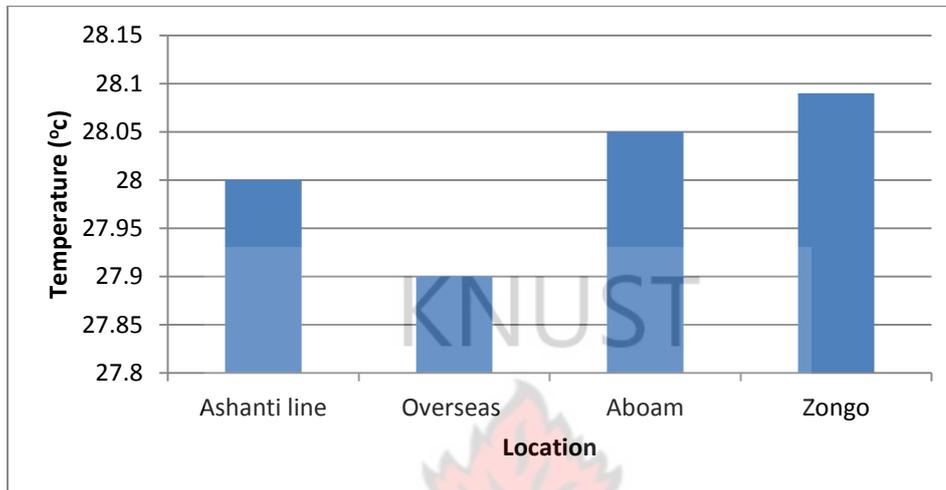


Figure 4.1: Temperature variations in water samples from the different sampling locations.

pH of the water samples were highest in Overseas (6.51) and lowest in Zongo (5.36) (Figure 4.2).

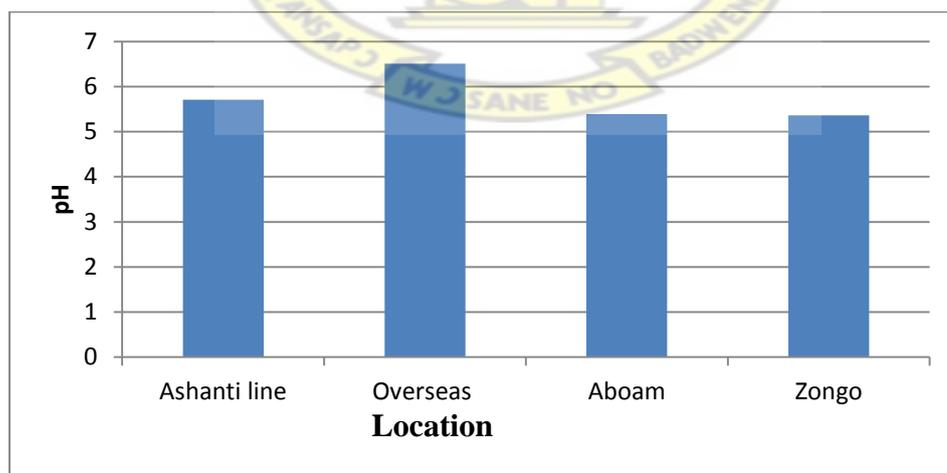


Figure 4.2: pH variations in water samples from the different sampling locations

Turbidity of the water samples in Zongo were high (0.21NTU) and low in Ashanti line, Overseas and Aboam with a recording of 0.01NTU, respectively (Figure.13). Most of the wells in Zongo are not mechanized and are many people fetch from these wells. This could account for the differences in the turbidity values.

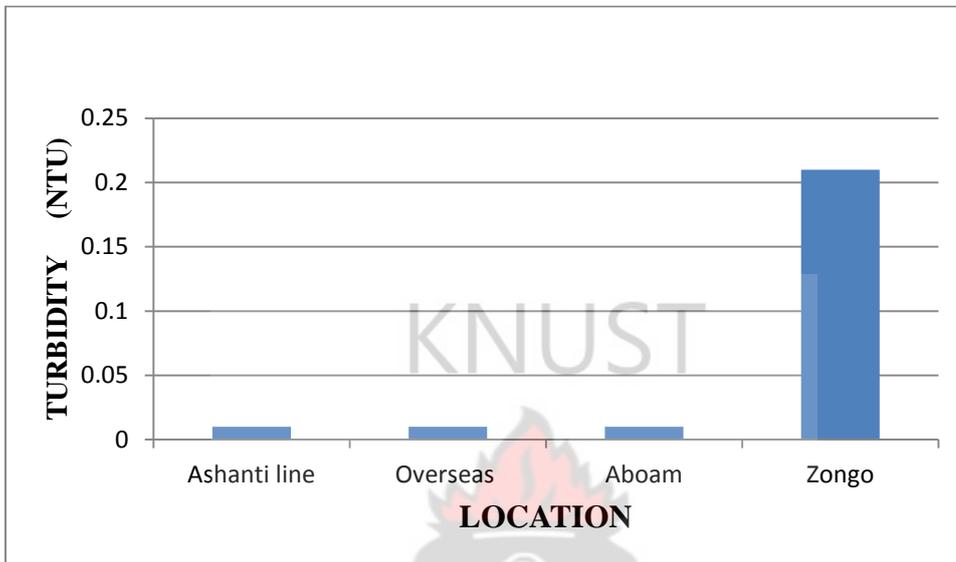


Figure 4.3: Turbidity variations in water samples from the different sampling locations

Conductivity of the water samples from Overseas were high (362 μ S/cm) with the lowest at Ashanti line (65 μ S/cm) (Figure .4.4).

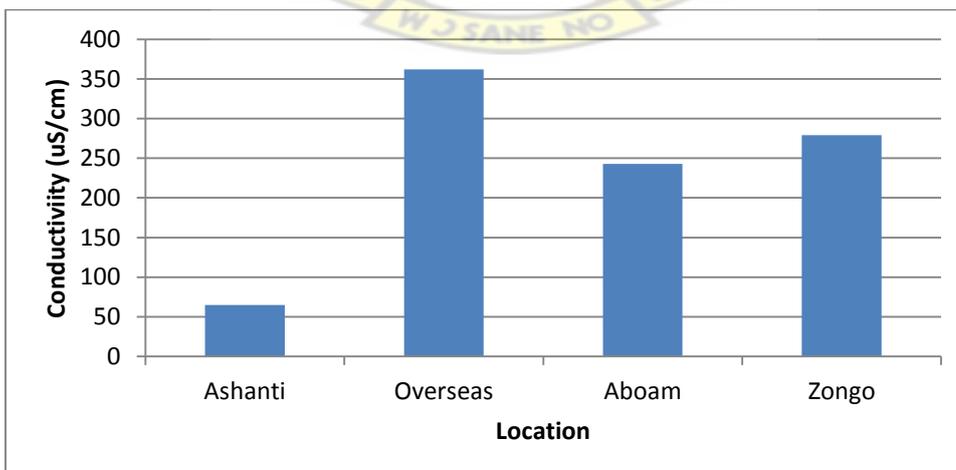


Figure 4.4: Conductivity variations in water samples from the different sampling locations

Total dissolved solids (TDS) in the water samples were high in Overseas (206.5 mg/l) and low in Ashanti line (39.6 mg/l) (Figure 4.5).

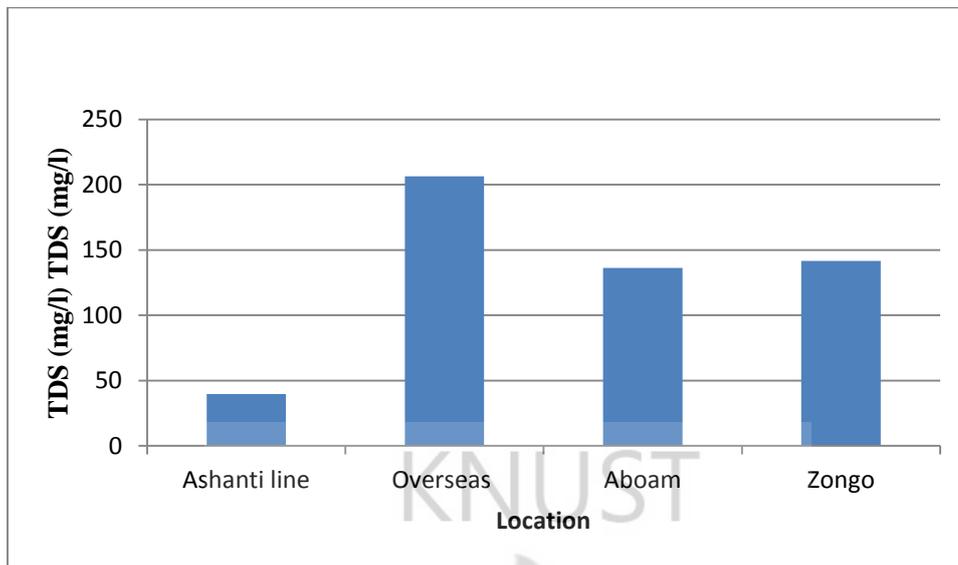


Figure 4.5: Total Dissolved Solids variations in water samples from the different sampling locations

For the Total suspended solids (TSS) of the water samples, Zongo recorded the highest TSS of 5.10 mg/l with Ashanti line recording the lowest value of 1.60 mg/l (Figure 4.6).

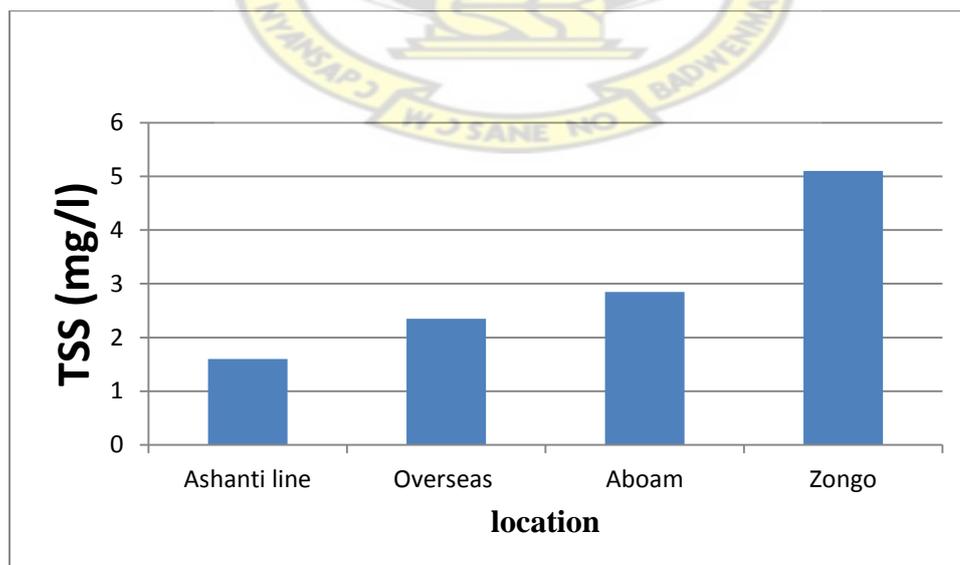


Figure 4.6: Total Suspended Solids variations in water samples from the different sampling locations

The colour of the water samples ranged between 0.01 Hz in Ashanti line and Overseas and 0.76 Hz in Zongo communities (Figure 4.7).

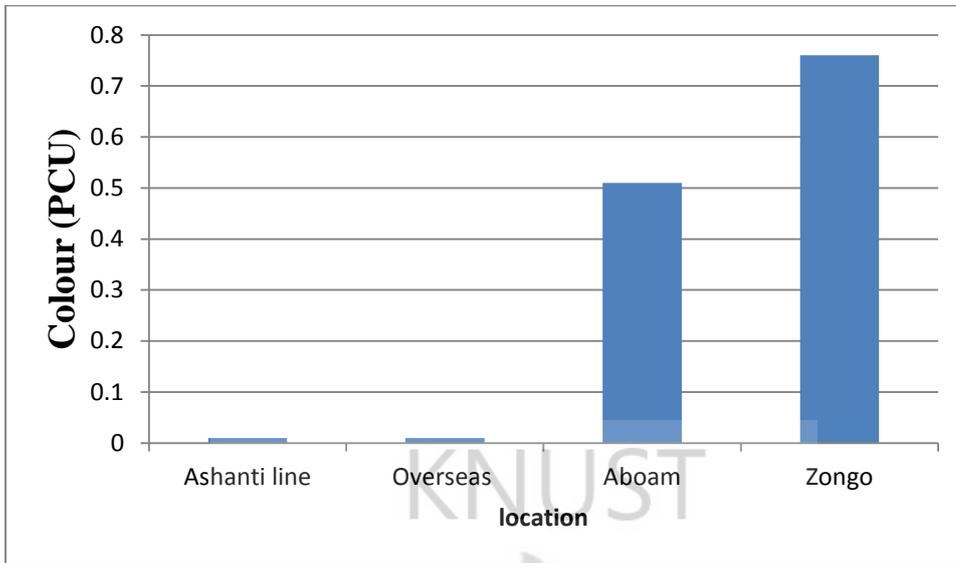


Figure 4.7: Colour variations in water samples from the different sampling locations

Significant differences were observed in pH, conductivity, and TSS of the water samples obtained from the different locations ($P < 0.05$). However, no significant differences were observed in the temperature, turbidity and colour ($P > 0.05$).

4.3 NUTRIENT CONCENTRATIONS OF WATER SAMPLES FROM DIFFERENT SAMPLING LOCATIONS

Table 4.4 shows the nutrient concentration of water sampled from four different locations.

The results showed that nitrate content of the water samples collected from Ashanti line, Overseas, Aboam and Zongo ranged from 0.0035 mg/l to 0.0083 mg/l.

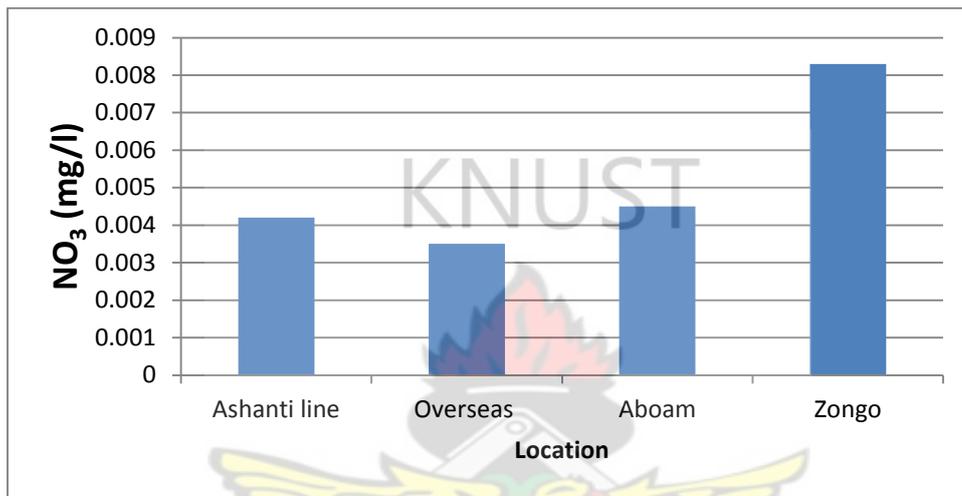


Figure 4.8: Nitrate concentrations in water samples from the different sampling locations

Phosphate (PO₄) content of the water was high in water samples from Ashanti line (0.32 mg/l) with Aboam recording the lowest, 0.02 mg/l.

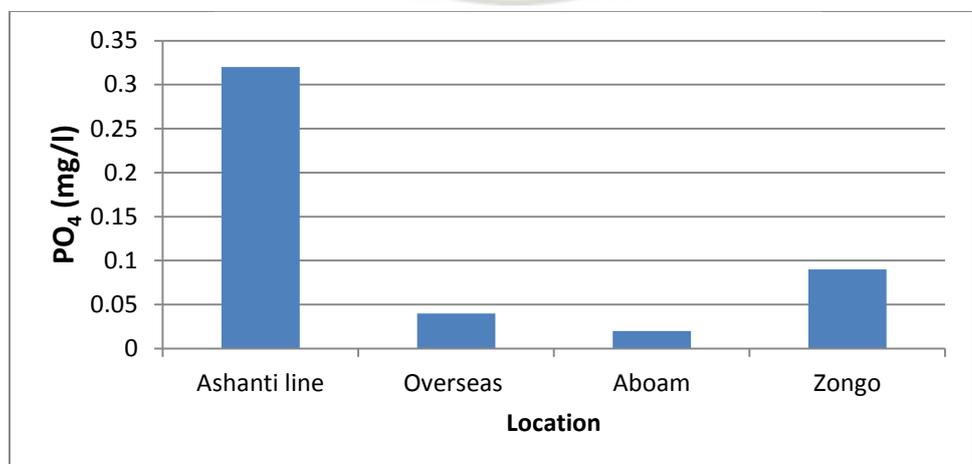


Figure 4.9: Phosphate concentrations in water samples from the different sampling locations.

BOD content of the water sampled was high in Aboam (0.06mg/l) with Ashanti line, Overseas and Zongo recording a BOD of 0.05mg/l.

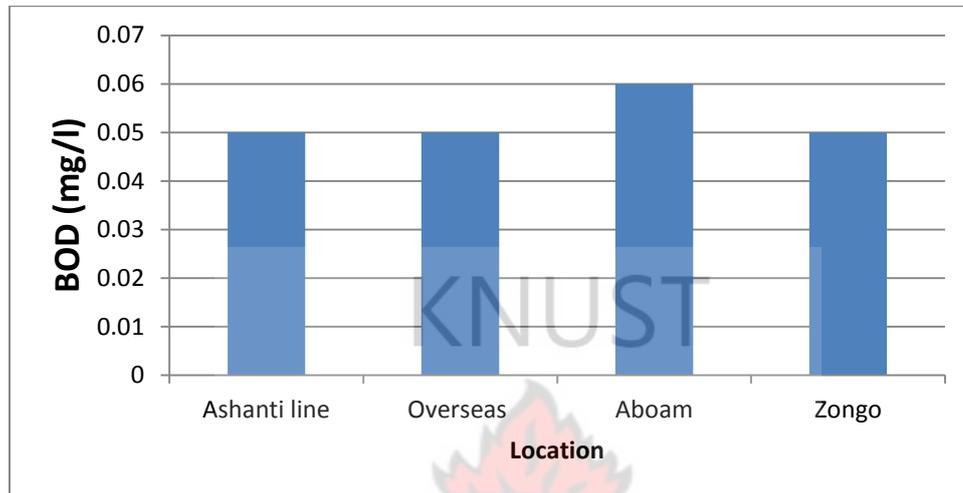


Figure 4.10: BOD concentration in water samples from the different sampling locations

Significant differences were observed in nitrate and phosphate concentrations in water samples obtained from the different locations ($P < 0.05$). However, no significant differences were observed in BOD of the water samples from the different locations ($P > 0.05$).

4.4 CORRELATION MATRIX OF PARAMETERS

Table 4.3: Correlation matrix of parameters measured

Location	As	Cu	Cr	Zn	Turbidity	TSS	Colour	TDS	pH	Temp	Conductivity	NO ₃	PO ₄
Cu		-											
Cr		-	-										
Zn		0.11	-	-									
Turbidity		-0.07	-	-0.06	-								
TSS		0.03	-	0.01	0.05	-							
Colour		-0.13	-	-0.10	0.32	0.11	-						
TDS		-0.01	-	-0.08	0.09	0.08	-0.05	-					
pH		0.11	-	-0.22	-0.12	-0.25*	-0.06	0.28**	-				
Temp		-0.16	-	0.18	0.29**	-0.04	0.35**	-0.09	-0.06	-			
Conductivity		-0.04	-	-0.04	0.12	0.18	-0.02	0.04**	0.22	0.03	-		
NO ₃		-0.09	-	-0.06	0.69**	0.23*	0.36**	0.18	-0.24*	0.09	0.18	-	
PO ₄		-0.21	-	-0.11	-0.01	-0.16	0.02	-0.26*	-0.08	0.30**	-0.25*	-0.16	-
BOD		0.29**	-	-0.03	0.03	0.14	-0.11	0.21	-0.21	-0.42**	0.19	0.09	-0.23*

** - significant at P=0.01

* - significant at P=0.05

Table 4.3 shows the correlation matrix of the parameters studied. pH was significantly correlated with TSS and TDS but showed a weak negative correlation with TSS (-0.25) and a weak positive correlation with TDS (0.28). Temperature was significantly correlated with turbidity and colour but had a weak positive correlation with turbidity (0.29) and colour (0.35). Conductivity had a weak positive correlation with TDS (0.04).

Similarly, nitrate was significantly correlated with turbidity, TSS, colour and pH. Nitrate had a strong positive correlation with turbidity (0.69), a weak correlation with TSS (0.23) and colour (0.36). Nitrate also had a weak negative correlation with pH (-0.24). Phosphate was significantly correlated with TDS and conductivity. Phosphate had a weak negative correlation with TDS (-0.226) and conductivity (-0.25). However, there was a weak positive correlation between phosphate and temperature.

BOD was significantly correlated with copper, temperature and phosphate. BOD had a weak positive correlation with copper (0.29) and a weak negative correlation with temperature (-0.42) and phosphate (-0.23).

CHAPTER FIVE

5.0 DISCUSSION

The study has shown that arsenic, copper and chromium concentrations in water samples from all the four different sampling locations; Ashanti line, Overseas, Aboam and Zongo within the Kwabre East District of the Ashanti region were all below the WHO standard limit (WHO, 2011). Chromium and arsenic concentration in the water samples from the four locations were less than 0.01 mg/l. Copper is naturally found in surface waters, groundwater, seawater and drinking water, but it is primarily present in complexes or as particulate matter (ATSDR, 2002). Karikari and Ansa-Asare (2006) also reported low levels of copper between 0.028 and 0.220 mg/l for the Densu River which were below the WHO limit for drinking water. It is known that at levels above 5 mg/l, copper imparts colour and an undesirable bitter taste to water (WHO, 2004). However, the concentration of zinc was slightly high at all sites but below the WHO standard limit (Table 1). Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. Drinking-water containing zinc at levels above 3 mg/l may not be acceptable to consumers. Excess zinc, however, produces aesthetic effect (metallic taste) on the water and for this reason the WHO (1993) recommended a limit of 3000.00 mg/l for drinking water. Ramesh *et al.* (1995) in their study on groundwater for eight ultra-trace elements (Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn), showed that the mobility, concentration and geoaccumulation of these metals are important indices to quantify pollution levels. The elements Mn, Cr and Zn exceeded the maximum permissible limits in certain locations of lake kolavoi in India. Pelig- Ba, (1998) in their study of mercury, lead, copper, zinc, cadmium, iron, manganese, chromium and arsenic in ground waters from the upper west and upper east region and the Accra plains in Ghana found that

the mean Cd, Mn and Cu concentrations for all the study areas fell within the WHO limits, whereas the values of Pb, Cr and Fe exceeded the WHO limits for drinking water. They concluded that the chemical composition of the rocks in the area could be the dominant source of the trace elements. Nkansah *et al.* (2011) also showed that all elements except iron, lead and nickel were well within WHO limits in groundwater samples from the Kwahu west district of Ghana and attributed this to the low levels of industrialization. The low levels of Cr, As, Cu and Zn in the ground water could be attributed to the geology and the low industrialization of the study area.

Indiscriminate dumping of solid waste has also been cited as a key source of heavy metals pollution of many underground water bodies because of seepage of heavy metals from their leachate (Rajkumar *et al.*, 2010). Most of the wells in Ashanti line, Aboam and Overseas are mechanized reducing pollutions of the ground water through run off from dumping site and the wood processing firm. Most of the wells in Zongo are not mechanized hence high turbidity.

Temperature and pH are known to influence the solubility and concentration of heavy metals in groundwater resources. Tsai *et al.* (2003) showed that As, Cu, Zn and Cr are soluble in water at 37°C. In general, as temperature increases, solubility of a given solute increases and solubility of heavy metals is high at low pH. At a pH of above 8, heavy metals rather precipitate reducing their concentration and availability in water and most heavy metals have a field of minimum solubility somewhere between pH 7 and 11 (Crawford, 1999). According to Chapman (1992), pH value for most natural waters is between 6.0 and 8.5 making them suitable for drinking and domestic purposes. However, water samples from Ashanti line, Aboam and Zongo were acidic and therefore not suitable for drinking (Water Resource Commission, 2003; Stumm and Morgan, 1981). High water temperature and low pH also enhance the growth of

microorganisms and may increase problems related to taste, odour, colour and solubility. The presence of heavy metals (Zn, As, Cr, Cu), nutrients (phosphates and nitrates), inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates), domestic wastes and organic matter (sawdust, humus, plants and animals) have a significant effect on TDS, TSS, conductivity, colour, BOD, phosphates and nitrates of groundwater resources (Ravichandran and Pundarikanthan, 1991; Singh, 2006; Tyagi *et al.*, 2000). The low levels of heavy metals, nutrient, organic salts and inorganic matter in the ground water resources is the reason for the low levels of TDS, TSS, conductivity, colour, BOD, phosphates and nitrates.

Concentration and availability of heavy metals and sawdust in groundwater contribute to the levels of TDS and TSS thus reducing clarity and increasing temperature of groundwater (Jensen, 2009). High levels of TDS and TSS concentration affect turbidity and transparency of groundwater which also affect the conductivity of water. Chapman (1992) reported that conductivity has a direct relationship with the concentration of TDS and major ions in water. Dissolved ions (Ca^{2+} , Zn^{2+} , Mg^{2+} , Cu^{2+} , Cr^{3+} , As^{2+}) in groundwater increase the conductivity of water. Transition metals (Zn^{2+} , Cu^+ , Cu^{2+} , Fe^{2+} , Fe^{3+} , Cr^{3+} , Cr^{5+} , As^{2+}) have a distinct tendency of forming ion complex with neutral water molecules resulting in colouration. The colour in natural water also results from the leaching of organic materials and is primarily the result of dissolved and colloidal humic substances, primarily humic and fulvic acids. The concentration is so low that colour, TDS, TSS, and BOD values are also low. Concentration of heavy metals in groundwater determines the number of microbes which will use metals as a source of food nutrients and will have a correlation on BOD. Most of the wells are mechanized preventing the contamination of the

groundwater resources by runoff hence the low values of TDS and TSS. The clarity of the groundwater resources is also an indication of low turbidity. Water conductivity is a function of the concentration of dissolved metal ions. The low conductivity values show low metal contamination of groundwater resources.

WHO (2011) reports that drinking-water should ideally have no visible colour and that colour in drinking-water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products (University of Florida, 2004). It may also result from the contamination of the water source with industrial effluents and may be the first indication of a hazardous situation. The colour of the water samples obtained from the locations was within the range of 0.01-0.76 PCU and 0.01-2.51 PCU for the water from the sampling points. These colour ranges were below the WHO recommended limits of 15 PCU. Thus concentration of heavy metals did not impact on the colour of the groundwater resources. Turbidity in water is caused by suspended particles or colloidal matter that obstructs light transmission through the water. High concentrations of phosphate and nitrate indicate the presence of pollution and are largely responsible for eutrophic conditions. Under eutrophic condition, the demand for oxygen by algae and bacteria is very high. BOD gives indication of the level of pollution of water sources. The mean BOD values obtained from my results ranged from 0.05mg/l to 0.06mg/l and comparing to Sangodoyin and Sanyalou (1995) who reported that for unpolluted waters, BOD values must range from about 1-3 mg/l. These low BOD values from my findings attest to the fact that the groundwater resources in the study area are not polluted by nutrients (phosphates and nitrates) from the wood processing factory.

The results indicated that nitrate concentration from the wells were within the WHO permissible limits of 10mg/l. Similar research was conducted by Nkansah *et al.* (2010) from hand-dug wells in the Kumasi Metropolis and found out that, nitrate levels ranged from 0.001mg/l to 0.968 mg/l. Both findings are below WHO limits which imply that, nitrates do not pose significant threat to the Ahwiaa community. Dallas and Day (1993) reported that nitrate and nitrite were considered to be non-cumulative toxin but at high concentrations, may give rise to potential health risks such as the 'blue-baby-syndrome' particularly in pregnant women and bottle-fed infants. Nitrate at elevated concentrations is also known to result in cyanosis in infants (Kempster *et al.*, 1997). Kelter *et al.* (1997) reported that where nitrite poisoning occurs, livestock could be at risk when given such waters to drink. Phosphate levels measured from the wells showed a range of 0.02 mg/l and 0.32 mg/l. A similar work was done by Nkansah *et al.* (2010) in waters from hand-dug wells in the Kumasi Metropolis where the phosphate levels were between 0.33mg/l and 9.30mg/l. Whereas phosphate levels in Ahwiaa are within WHO limits, literature showed that, certain areas within Kumasi metropolis have phosphates level above WHO limits of 2.2mg/l. Phosphorus is a limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Chapman (1992) reported phosphorus ranges from 0.005mg/l to 0.020mg/l for most natural surface waters. Nitrate (NO_3^-) and phosphates (PO_4^{3-}) are found naturally in the environment and are important plant nutrients. The results recorded for TDS in the study area ranged between 39.6 mg/l and 206.5 mg/l and were within the maximum acceptable limits of 1000 mg/l for drinking waters (WHO, 1993). A study also conducted by Kempster *et al.* (1997) reported that total dissolved solids concentrations in water that exceeds the maximum acceptable limits could in the long-term result in health problems. All the sampling

points measured low levels and health problems in Ahwiaa could not be attributed to TDS concentration in groundwater. According to WHO (2011) the palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS and TSS levels greater than about 1000 mg/l. This implies that, the well water can be described as good for drinking according to the levels of TDS and TSS recorded from the study area. A mean turbidity value of 0.01 NTU was recorded for the sampling locations Ashanti line, Aboam and Overseas except for Zongo which had a turbidity value of 0.21 NTU. The water samples from the current study were found to be within the no effect range of 0 -1 NTU for drinking (Water Resource Commission, 2003). WHO (2011) indicated that turbidity in some groundwater sources is a result of inert clay or chalk particles or the precipitation of non-soluble reduced iron and other oxides when water is pumped from anaerobic waters, whereas turbidity in surface waters may be the result of particulate matter of many types and is more likely to include attached microorganisms that are a threat to health. Turbidity in distribution systems can occur as a result of the disturbance of sediments and bio-films but is also from the ingress of dirty water from outside the system. Turbidity can also have a negative impact on consumer acceptability of water as a result of visible cloudiness. Although turbidity per se is not necessarily a threat to health, it is an important indicator of the possible presence of contaminants that would be of concern for health, especially from inadequately treated or unfiltered surface water. Conductivity of the water sampled from the locations ranged between 65 μ S/cm to 362 μ S/cm. The WHO permissible limit for electrical conductivity (EC) of water is 300 μ S/cm. With the exception of water samples from Overseas, which recorded conductivity values higher than the WHO limit, the rest had conductivity values lower

than the WHO limit. This means that the conductivity of the water samples were within the limits of acceptable standards for drinking and domestic water. In a study by Nkansah *et al.* (2010) on dug out wells from residential areas in the Kumasi Metropolis, conductivity values ranged between 46 μ S/cm to 282 μ S/cm, which were below the WHO permissible limit and therefore safe for drinking and domestic use. The concentrations of arsenic and chromium in the wells were less than 0.01 mg/l which are far below WHO limits and could not be attributed to contamination by the wood processing firm. Ashanti line recorded the highest mean values of 0.076 mg/l and 0.264 mg/l for copper and zinc respectively which are far below WHO limits of 2.0 mg/l for copper and 3000 mg/l for zinc and these concentrations could not be caused by contamination from the wood processing firm. The geology and low industrial activities in the study area could account for the low levels of these heavy metals. This is supported by a work done by Pelig-Ba *et al.*, (1998) in the upper regions of Ghana on heavy metals that the availability of trace elements in ground water could be attributed to the chemical composition of the rocks. Levels of TDS, TSS, turbidity and conductivity of the groundwater in the study area were also within the WHO limits and could partly be attributed to the low levels of the heavy metals and sawdust. However, the high conductivity values recorded could be attributed to the nature of the soil at the water source. The groundwater sources available in the study area were within the limits of acceptable standards prescribed for drinking water and therefore pose no health issue to consumers and therefore safe for drinking and domestic uses. According to Smedley *et al.* (1995), arsenic is a known carcinogen (an agent producing and exciting cancer) and a toxin. Skin cancer has also been associated with long-term, low-level exposure to arsenic through drinking water (WHO, 1993). There is also suggestive evidence of increasing risk of bladder, kidney,

liver and lung tumours. According to WHO (2011), arsenic has not been demonstrated to be essential in humans. The acute toxicity of arsenic compounds in humans is predominantly a function of their rate of removal from the body. Arsine is considered to be the most toxic form, followed by the arsenites, the arsenates and organic arsenic compounds. Acute arsenic intoxication associated with the ingestion of well water containing very high concentrations (21.0 mg/l) of arsenic has been reported. The results of the study shows that people living in the communities where water was sampled are at no risk of contracting diseases associated with long-term low-level of arsenic ingestion. WHO (1988) and IARC (1980) reported that chromium and its salts are used in the leather tanning industry, the manufacture of catalysts, pigments and paints, fungicides, the ceramic and glass industry, and in photography, and for chrome alloy and chromium metal production, chrome plating, and corrosion control. These activities could increase the availability and concentration of chromium in ground water through leaching and run off. The low levels of chromium in the wells in the study area could be linked to the low number of artisans using chromium for manufacturing purposes which could possibly cause contamination through leaching.

The study showed a very low concentration of heavy metals in the groundwater resources. There are also low levels of TDS, TSS, BOD, nitrates, phosphates, turbidity, colour, and conductivity. Ground water in the study area can be described as slightly acidic with temperature variations due to different times of sampling as the ambient temperature influenced the temperatures of the samples. The ground water resources are therefore safe for consumption.

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

Generally, the groundwater resources (well water) in Ahwiaa were slightly acidic. The study also revealed that the concentration of arsenic, copper, zinc, and chromium were all below the WHO guideline limits. The water temperatures were above the normal room temperature of 25 °C. Turbidity, TDS, TSS, conductivity and colour were within the WHO guideline limits. The nutrients (PO₄, NO₃ and BOD) concentration of the water samples were within WHO guideline limits. The well waters in Ahwiaa can generally be considered safe for human consumption with reference to WHO guidelines for drinking water.

6.2. RECOMMENDATION

From the research conducted in the study area, the following recommendations are for the Governments, NGO's and other stakeholders.

- The Ministry of Health should organize health talk and screening programmes in the area where metal concentration is high to find out if there is toxicity related diseases in the area to introduce the appropriate interventions.
- Opinion leaders such as assemblymen, resources persons, teachers, chiefs should educate the community on the effect of using water which is not of good quality.
- Work should be done on oil borne wood preservatives (creosote and pentachlorophenol)

- Work should also be done on microbial contamination of ground water in the area
- The timber firm should be monitor to ensure that they comply with WHO regulations on the use of wood preservatives.

KNUST



REFERENCE

- Abdul-Razak, L.A., Asiedu, A. B., Entsua-Mensah, R. E. M. and deGraft-Johnson, K. A. A. (2009). Assessment of the Water Quality of the Oti River in Ghana. *West African Journal of Applied Ecology* 15: 45-60.
- Abdul, J. and Zahir, H. A. (2011). *Environ Monit Assess.* 183:103.
- Abdul, J. and Sirajudeen, J. (2006). *Environ Monit Assess.*; 123, 299.
- Adeniyi, I.F. (2004). The Concept of Water Quality In: Ife Environmentalist, *Official Bulletin of Nigerian Society for Environmental Management (NISEM) O.A.U.*, 1(1): 2.
- Adeyeye E. I, and Abulude F. O., (2004). Analytical assessments of some surface and ground water resources in Ile-Ife, Nigeria. *J. chem.. Soc. Nig.* Ed 29: 98- 103
- Adrian, D .D., Roider, E. M. and Sanders, T. G. (2004). Oxygen sag models for multiorder biochemical oxygen demand reactions. *Journal of Environmental Engineering.* 130(7): 784-791.
- Adrian, D .D., Sanders, T. G. and Roider, E.M. (1999). Oxygen sag equation for three halves order BOD reaction, *Journal of the American Water Resources Association*, 35(5): 1191-1200.
- Aidoo Sylvester. (2003). Quality of surface, River Birim as a case study. *Department of Chemistry*, KNUST. P23
- Allinson, G., Turoczy, N. J., Kelsall, Y., Allinson, M., Stagnitti, F., Lloyd-Smith, J. (2000). Mobility of the constituents of chromated copper arsenate in a shallow sandy soil. *New Zealand Journal of Agricultural Research* 43: 149- 156.
- Alloway, B.J. (1990) Heavy metals in soils. John Wiley and Sons, Inc. New York, ISBN 0470215984 EC (1999) Integrated Pollution Prevention and Control

(IPPC) Best available techniques reference document on the production of iron and steel. Publ: EC European IPPC Bureau 370 pp.

AMAP (2002). Arctic Pollution 2002. Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health, Changing Pathways. Arctic Monitoring and Assessment Programme, Oslo. Nordic Council of Ministers, Copenhagen.

Andersen, S., Rasmussen, G., Snilsberg, P., Amundsen, C.E., Westby, T. (1996). Assessing toxicity and mobilization of impregnation salts at a contaminated site. *Fresenius' J Anal Chem* 354: 676-80.

Anon (1987). Drinking Water Criteria Document on Nitrate/Nitrite. Washington, DC, US 1987. ICAIR Life Systems, Inc.

Ansa-Asare, O. D. and Asante, K. A. (2000). The Water Quality of Birim River in South-East Ghana. *West African Journal of Applied Ecology* 1: 23–34.

Antwi, L. A. K. and Ofori-Danson, P. K. (1993). Limnology of a Tropical Reservoir (The Kpong Reservoir in Ghana). *Trop. Ecol.* 34: 75–87.

APHA. (1998). *Standard methods for the examination of water and wastewater*. 18th ed. American Public Health Association, Washington, DC.

Appello, C.A.J. and Postma, D. (1996). *Geochemistry, groundwater and pollution*. A. A. Balkema. Holanda.

Asante, K. A., Quarcoopome, T. and Amevenku, F. Y. K. (2008). Water quality of the Weija Reservoir after 28 years of impoundment. *West African Journal of Applied Ecology* 13: 25-28.

- Asiamah, R. D. (1995). Soils of Ho-Keta Plains, Volta Region, Ghana. Memoir No. 10. Soil Research Institute. Advent Press, Osu, Ghana.
- ATSDR (2002). Toxicological profile for copper (draft for public comment). Atlanta, GA, US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (Subcontract No. ATSDR-205-1999-00024).
- Balasoïu, C., Zagury, G.J.; Deschênes (2001) Partitioning and speciation of chromium, copper, and arsenic in CCA-contaminated soils: influence of soil composition. *The Science of the Total Environment* **280**, 239-255.
- Baldwin, W.J., Pasek, E.A. and Osborne, P.D. (1996). Sediment toxicity study of CCA-C treated marine pile, *Forest Products Journal*, 4: 42-50.
- Balogh, J. C., and W. J. Walker, eds. (1992). Golf Course Management and Construction: Environmental Issues. Chelsea, Mich.: Lewis Publishers, Inc.
- Balogh, J. C., Leslie, A.R., Walker, W.J. and Kenna, M.P. (1992). Development of integrated management systems for turfgrass. In *Golf Course Management and Construction: Environmental Issues*, 355–439. J. C. Balogh and W. J. Walker, eds. Chelsea, Mich.: Lewis Publishers, Inc.
- Beauchemin S, Simard RR & Cluis D (1996) Phosphorus sorption desorption kinetics of soil under contrasting land uses. *J Environ Qual* 25: 1317–1325
- BARBOUR, M. T. & GERRITSEN, J. (1996). Subsampling of benthic samples: a defense of the fixed-count method. *J. N. Am. Benthol. Soc.*, 15(3): 386-391.
- BARBOUR, M. T.; GERRITSEN, J.; SNYDER, B. D. & STRIBLING, J. B. (1999). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers:*

Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. US EPA; Office of Water; Washington, D.C.

Basberg-Pahlsson, A. M. (1989) Toxicity of heavy metals to vascular plants. *Water air soil pollut.* 47: 287-319.

Bhattacharya, P., Mukherjee, A.B., Jacks, G., Nordqvist, S. (2002). Metal contamination at wood preservation site: characterization and experimental studies on remediation. *Science of Total Environment* 290(1-3):165–180.

Biney, C., Amuzu, A.T., Calamari., D., Kaba, N., Mbome, I.L., Naeve, H., Ochumba, P.B.O., Osibanjo, O., Radegonde, V., and Saad, M.A.H. (1994). Review of heavy metals in the African aquatic environment. *Ecotoxicology and Environmental Safety* 13:134-159

Boutrup, S., and Clement, P. (1990). Forurening med tungmetaller i parcelsumråder (contamination with heavy metals in residential areas) vng og Miljø 3: 102-105(in Danish)

Breslin, V. and Adler-Ivanbrook, L. (1996) Release of Copper, Chromium and Arsenic from CCA-C Treated Lumber in Estuaries. *Estuarine, Coastal and Shelf Science* 46, 111-125.CCR, C. C. O. R. *California Code of Regulations, Title 22 Chapter 11, Article 5, Appendix II*. 1998.

Bull, D.C., (2001). The Chemistry of Chromated Copper Arsenate II; Preservative Wood Interactions, *Wood Science and Technology*, 34(6):450-466.

Carey, P.L., McLaren, R. and Adams, J. A., (1996). Sorption of Cupric, Dichromate, and Arsenate Ions in some New Zealand Soils, 2006, 87: 189-203.

- CCME (Canadian Council of Ministers of the Environment). 2007. Canadian water quality guidelines: Imidacloprid. Scientific Supporting Document. Winnipeg, Manitoba.
- Chapman, D. (1992). Water Quality Assessment; A guide to the use of biota, sediments and water in environmental monitoring. University Press, Cambridge, 585 pp.
- Chirenje, T., Ma, L.Q., Clark, C. and Reeves, M. (2003). Cu, Cr and As distribution in soils adjacent to pressure-treated decks, fences and poles. *Environmental Pollution*. 124:407-417.
- Chirenje, T., Rivero, C. and Ma, L.Q. (2002). Leachability of Cu and Ni in wood ash amended soil columns as affected by humic and fulvic acid. *Geoderma* 108:31- 47.
- Cloern, J. E. (1987). Turbidity as a Control on Phytoplankton Biomass and Productivity in Estuaries. *Continental Shelf Res.* 7(11/12): 1367–1381.
- Connell, M. (1999). Waste management options in the wood protection industry. *J. I. Wood Sci.* 15(1): 51–58.
- Cooper, P.A., (1994). Leaching of CCA: Is it a problem? Environmental Considerations in the Manufacture, Use and Disposal of Pressure Treated Wood, Forest Products Society, Madison, Wisconsin pp. 45-57.
- Cooper, P.A., Ung, Y. T. and Aucoin, J.P. (1997). “Environmental impact of CCA poles in service”, in Proceedings of the 28th Annual meeting of the Int. Res. Group on Wood Preservation, Whistler, B.C, Canada, Section 5: Environmental Aspects, pp. 1-20.

- Cooper, P. and Ung, Y.T. (1997). The Environmental Impact of CCA Poles in Service. Paper Number IRG/WP 97-50087. International Research Group, Stockholm, Sweden.
- Crawford, J. and Neretnieks, I. (1999). Simulation of the redox buffer depletion rate in landfills of combustion residue waste materials.
- Crawford J., Bellander C., and Neretnieks I. (1999). Acid neutralising kinetics of slags and combustion residue waste materials.
- Cseh, E. (2002) Metal permeability, transport and efflux in plants. In: M. N. V. Prasad and Strzalka, (Eds.). *Physiology and Biochemistry of Metals Toxicity and Tolerance in Plants*. Kluwer Academic, Dordrecht i-36.
- Culley, J. L. B., Bolton, E. F. and Bernyk, V. (1983) Suspended solids and phosphorus loads from a clay soil: I. Plot studies. *J Environ Qual* 12: 493–498
- Dallas, H. F. and Day, J. A. (1993). The Effect of Water Quality Variables on River and Ecosystem. Water Research Commission Report No. TT 61/93. South Africa.
- Davis, S.N. and DeWiest, R.J. (1966). *Hydrogeology*, New York: Wiley.
- Dawson, B.S.W., Parker, G.F., Cowan, F.J. and Hong, S.O., (1991). Inter-laboratory determination of copper, chromium, and arsenic in timber treated with wood preservative. *Analyst* 116, 339–346. EPA, “Treatment Technology Performance and Cost Data for the Remediation of Wood Preserving Site, EPA- 625/R- 97/009,” Office of Research and Development, Washington, DC (1997).

Department of Fisheries and Aquatic Sciences, Institute of Food and Agricultural Sciences, University of Florida, 2004, A beginner's guide to water management.

Dethier, D. P. (1988). A hydrochemical model for stream chemistry, cascade range, Washington U.S.A. *Earth Surface Processes Land Forms* 13: 321–333.

Dietz, M.E. and Clausen, J.C. (2008). Stormwater runoff and export changes with development in a traditional and low impact subdivision. *Journal of environmental Management* 87:560-566.

DMTP Kwabre East (2010- 2011)

Eby, G. N. 2004, Principles of Environmental Geochemistry. Thomson-Brooks/Cole.

EPA. 2008. National Primary Drinking Water Regulations & National Secondary Drinking Water Regulations. From <http://www.epa.gov/safewater/contaminants/index.html#primary>

EPA.1999, Drinking Water and Health: What you need to know. From [http://www.epa.gov/safewater/dwh/dw – health](http://www.epa.gov/safewater/dwh/dw-health). Pdf. Retrieved on October 19, 2012.

EPRI, 1997. Pole preservatives in soils adjacent to in-service utility poles in the United States. EPRI Research Projects W02879 and W09024. EPRI Report TR-108598. Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, California 94304.

Esrey, S.A., Potash, J.B., Roberts, L. and Shiff, C. (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bull. WHO* 69(5): 609-621.

FAO (1988). Salt Affected Soils and their Management. FAO Soils Bull. 39. FAO, Rome, Italy. 131 pp.

FOA Government of Puducherry

Faure, G. (1998). *Principles and applications of geochemistry, 2nd ed.* Englewood Cliffs, NJ: Prentice-Hall.

FDEP (Florida Department of Environmental Protection). 1999. Contaminant Cleanup target levels. Chapter 62-777. Tallahassee, FL.

Felton, C.C. and DeGroot, R.C. (1996). The recycling potential of preservative-treated wood. *Forest Products Journal* 46(7/8): 37-46.

Florida Department of Environmental Protection (FDEP), (1999). Technical Guidance: Determination of Natural Background Concentrations.

<http://www.dep.state.fl.us/dwn/programs/csf/focus/natural>.

Fodor, F. (2002) Physiological responses to vascular plants to heavy metals. In: M. N. V. Prasad and Strzalka (Eds.) *Physiology and Biochemistry of Metal Toxicity and Tolerance in Plants*. Kluwer Academic. Dordrecht. 149- 177.

Foy, C. D. Chaney, R. L. and White, M. C. (1978) The physiology of metals toxicity in plants. *Annu. Rev. Plant Physiol.* 29: 511- 566.

Fytianos, K. and Christophoridis, C. (2003). Nitrate, Arsenic and Chloride Pollution of Drinking Water in Northern Greece. Elaboration by Applying GIS. *Environmental Monitoring and Assessment*, 1–13.

Ghana Statistical service (2000)

- GOG (2007). Ghana National Water Policy. Ministry of Water Resources, Works and Housing, Ghana.
- Grant, C. A., Buckley, W. T., Bailey, L. D. and Selles, F. (1998) Cadmium accumulation in crops. *Can. J. Plant Sci.* 78: 1- 17.
- Groover, V.A., R.B. Reneau, D.R. Chalmers, R.E. Schmidt, N.R. Rudy, and H.L. Slattery. 1997. Nitrogenous Fertilizers in Turfgrass Systems: Impact on Water Quality. Virginia Tech Department of Environmental Sciences and The Chesapeake Research Consortium, Inc. Virginia Tech, Blacksburg, Virginia.
- Guidelines for drinking-water quality, fourth edition World Health Organization 2011
- Hadjiliadis, N. D. (1997) Cytotoxicity, mutagen and carcinogenic potential of heavy metals related to human environment. In: *Environment NATO- ASI Series*, Kluwer, Dordrecht.
- Hall, J. L. (2002) Cellular mechanisms for heavy metal detoxification and tolerance. *J. Exp. Bot.*53:1-11
- Harvey, P.A. (2004). Borehole Sustainability in Africa: An analysis of routine data. *30th WEDC International Conference, Vientiane, Lao PDR, 2004*, Loughborough University.
- Heckrath, G., Brookes, P.C., Poulton, P. R. and Goulding, K.W.T. (1995). Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk Experiment. *J. Environ. Qual.* 24: 904-910.

- Heckrath, G., Brookes, P.C., Poulton, P.R. and Goulding, K.W.T. (1995). Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk experiment. *J. Environ. Qual.* 24: 904–910
- Hem, J.D. (1985). Study and interpolation of the chemical characteristics of natural water. United States Geological Survey Water-Supply Paper 2254: 1–263.
- Hewitt, J., Hunter, J.V. and Lockwood, D. (1979). A multiorder approach to BOD kinetics, *Water Research*, 13: 325-329.
- Hingston, J.A., Collins, C.D., Murphy, R. J. and Lester, J. N., (2001). Leaching of chromated
- Hit, B., Bachu, S. and Underschultz, J. R. (1990) Regional subsurface hydrogeology, Peace River Arc area, Alberta and British Colombia; Canadian Society of Petroleum Geologist, v. 38A pp. 196-217.
- copper arsenate wood preservatives: a review, *Environmental Pollution*, 111: 53-66.
- Institute of Aquatic Biology (1996). Status Report No. 2 on Chemu Lagoon, Tema. Consultancy Report Submitted to EPA, Ghana. 10 pp.
- International Agency for Research on Cancer (1980). Some metals and metallic compounds. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, 23: 205-323.
- Jambeck, J. R., Townsend, T. G., Solo-Gabriele, H., (2003). “The Disposal of CCA-Treated Wood in Simulated Landfills: Potential Impacts,” prepared for the IRG 34th Annual Meeting, Brisbane, Australia.

- Jambeck, J., Townsend, T and Solo-Gabriele, H (2004). Leachate Quality from Simulated Landfills Containing CCA-Treated Wood: *Environmental Impacts of Preservative-Treated Wood Conference Feb 8-11, Orlando, FL.*
- Jang, Y and Townsend, T (2001) Occurance of Organic Pollutants in Recovered Soil Fines from Construction and Demolition Waste.. *Waste Management* 21 703-715 2001
- Jang, Y and Townsend, T (2003a) Effect of Waste Depth on Leachate Quality from Laboratory Construction and Demolition Debris Landfills. *Environmental Engineering Science* 20 (3) 183-196
- Jang, Y., and Townsend. T. (2003b) Leaching of Lead from Computer Printed Wire Boards and Cathode Ray Tubes by Municipal Solid Waste Landfill Leachate. *Environ. Sci. Technol.* 37, 4718- 4784.
- Jang, K. L., Livesley, W. J., & Vernon, P. A. (2002). The aetiology of personality function: The University of British Columbia Twin Project. *Twin Research*, 5(5), 342–346.
- Jensen K. H., Rosenbom, A.E., Therrien R. and Refsgaard J. C. (2009), Numerical analysis of water and solute transport in variably-saturated fractured clayey till, *J. Contam. Hydrol.*, 104, 137-152.
- Jensen P. H, J. Ensink, G. Jayasinghe, W. van der Hoek, S. Cairncross and A. Dalsgaard, "A Domestic Transmission Routes of Pathogens: The Problem of In-House Contamination of Drinking Water during Storage in Developing Countries," *Tropical Medicine and International Health*, Vol. 7, No. 7, 2002, pp. 604-609. [doi:10.1046/j.1365-3156.2002.00901.x](https://doi.org/10.1046/j.1365-3156.2002.00901.x)

- Jindal, R. and Kuaur, B. (2000) Effects of heavy metal toxicity on the productivity of a fresh water ecosystem. *Indian, J. Ecol.* 27: 27- 32.
- Kabata-Pendias, A. and Pendias, H. (1999) *biogeochemistry of Trace Elements* (Polish) PWN. Warszawa. Poland.
- Kabata-Pendias, A. and Pendias. H. (2001) *Trace Elements in Soils and Plants.* (3rd Edn.) CRC.Press.
- Karikari, A. Y., Asante, K. A. and Biney, C. A. (2006). Water Quality Characteristics at the Estuary of Korle Lagoon in Ghana. *West African Journal of Applied Ecology* 10: 73-85.
- Karikari, A.Y., Ansa-Asare, O.D. (2006). Physico-chemical and Microbial Water Quality Assessment of Densu River of Ghana. *West Africa Journal of Applied Ecology*, 10: 87-100.
- Keeney, D. R. (1982). Nitrogen management for maximum efficiency and minimum pollution. In F.J. Stevenson (ed.) *Nitrogen in Agricultural Soils.* Agron Monogr. 22. Amer. Soc. Agron., Keeney, D., (1986). Sources of nitrate to ground water: *CRC Critical Review Environmental Control*, 16: 257–304 Madison, Wisconsin pp. 605-649.
- Keeney, D.R. (1986a). Sources of nitrate to ground water. *CRC Critical Review of Environmental Control* 16:257-304.
- Kelsall, Y., Allinson, M., Allison, G. Turoczy, N., Stagnitti, F. Nishikawa, M., Morita, M. (1999) Leaching of Copper, Chromium and Arsenic in a Soil of

South West Victoria, Australia. *Toxicological and Environmental Chemistry* **70**, 375-384

Kelter, P. B., Grudman, J., Hage, D.S., and Carr, J. D. (1997). A Discussion of Water Pollution in the US and Mexico with High School Laboratory Activities for Analysis of Lead, Anthrazine and Nitrate. *Chem. Educ.* 74 (12): 1413–1418.

Kochian, L. V. (1995) Cellular mechanisms of aluminium toxicity and resistance in plants. *Annu Rev. Plant Physiol. Plant Mol. Biol.* 46: 237- 260.

Kempster, P. L., Van Vliet, H. R. and Kuhn, A. (1997). The Need for Guideline to Bridge the Gap between Ideal Drinking Water Quality and Quality which is Practicably Available and Acceptable. *Water SA* 23(2): 163–167.

Landner, L. and Lindestrom, L. (1999). Copper in society and in the environment. Vasteras, Swedish Environmental Research Group (MFG) (SCDA S-721 88).

Lahiry, A.K. (1997). An introduction to environmental aspects of groundwater arsenic and CCA treated wood poles in Bangladesh, Section 5 (Environmental Aspects), Doc. IRG/WP 97 – 50081, Int. Res. Group on Wood Preservation, Stockholm.

Lebow, S. (1996). “Leaching of wood preservative components and their mobility in the environment. Summary of pertinent literature”, General Technical Report, Forest Products Laboratory, USDA Forest Service, Madison, WI., FPL-GTR-93:36.

Lewis, J.W., Stephen, S.D.F., Bohumil, S. and Drasar, B.S. (1982) *The Risk of Groundwater Pollution by On-Site Sanitation in Developing Countries*. International Reference Centre for Wastes Disposal (IRCWD), Duebendorf.

Life Water Canada, Water Quality Testing Section 16, from <http://www.lifewater.ca/Section16.htm#N2>

Lund, U. and Fobian, A. (1991). Pollution of two soils by arsenic, chromium, and copper. *Geoderma* 49: 83-103.

MacCutcheon, S. C., Martin, J. L. and Barnwell Jr, T. O. (1983). Water Quality. In Handbook of Hydrology. McGraw-Hill Inc., New York.

Madison, R.J. and Brunett, J.O. (1985). Overview of the occurrence of nitrate in Groundwater of the United States in National water summary 1984-hydrologic events, selected water-quality trends, and Groundwater resources: U.S. Geological Survey Water-Supply Paper 2275,467 p.

Marcovecchio, J.E., Botte, S.E. and Freije, R.H. (2007). Heavy Metals, Major Metals, Trace Elements. In: Handbook of Water Analysis. L.M. Nollet, (Ed.). 2nd Edn. London: CRC Press; 275-311.

Mateu, J., Forteza, M., Colom-Altes, M., Cerda. V. (1996) Atmospheric background levels and transport of heavy metals in the Balearic Islands. *Water, Air and Soil Pollution* 86: 157-172.

McNeilly, T. (1994) metal toxicity. In: A. R. Yeo and Flowers, T. J. (Eds.). Soil Mineral Stresses: Approach to Crop Improvement. Springer- Verlag. New York, 145-174.

Merz,S. K. (1999), Review of the landfill disposal risks and the potential for recovery and recycling of preservative treated timber, prepared for the South Australian Environment Protection Authority, Adelaide, viewed 4 July 2008,

<www.epa.sa.gov.au/pdfs/timber.pdf>.

Migocka, M. and Klobus, G. (2007) The properties of Mn, Ni, and Pb transport operating at plasma membranes of cucumber roots. *Physiol. Plant.* 129: 578-587.

Mihelcic, J. R. 1999. Fundamentals of Environmental Engineering, 355 pp., John Wiley & Sons, New York.

Ministry of Health,(1999)

MMSD. (2000 to 2004) Stormwater Monitoring Program.

Mok, W. M. and Wai, C. M. (1994). Mobilisation of arsenic in contaminated river waters. In: Arsenic in the Environment. Part I: Cycling and Characterisation (Ed. J. O. Nriagu), p. 99-117. John Wiley and Sons, Inc., New York, U.S.A.

Moore, P.A., Daniel, T.C., Gilmour, J.T., Shreve, B.R., Edward, D.R., Wood, B.H., (1998). Decreasing metal runoff from poultry litter with aluminium sulfate. *J. Environ. Qual.*, 27:92-99.

Moore, P. A., Jr. and Rebby, K. R. (1994). Role of Eh and pH on phosphorus geochemistry in sediments of lake Okeechobee,Florida. *J. Environ. Qual.* 23:955- 964.-`

Mozaffari, M. and Sims.J. T. (1994). Phosphorus availability and sorption in an Atlantic coastal plain watershed dominated by animal-based agriculture. *Soil Sci.* 157:97-107.

Murray, K., Du Preez, M. and Van Ginkel, C. (2000). National Eutrophication Monitoring Programme. Implementation Manual Draft. Water Research Commission, Pretoria, South Africa.

- Nkansah, M.A., Boadi, N.O. and Badu, M. (2010). Assessment of the Quality of Water from Hand-Dug Wells in Ghana. *Environmental Health Insights* 4: 7-12.
- Nkansah, M.A., Ofosuah, J. and Boakye, S. (2011). Quality of Groundwater in the Kwahu West District of Ghana. *Environmental Research Journal*, 5: 31-37.
- Nolan, B.T. and Stoner, J.D. (2000). Nutrients in groundwaters of the conterminous United States, 1992–1995. *Environ Sci Technol*; 34: 1156–65.
- Nordic Council of Ministers (1999) Arsenic in Impregnated Wood. A Compilation of Data from Nordic Reviews. TemaNord 1999:535, Ekspressen Tryk & Kopicenter, Copenhagen.
- Nriagu, J.O. and Azcue J. M. 1990. Food contamination with arsenic in the environment. In: *Food Contamination from environmental sources* (Ed. J.O. Nriagu and M. S. Simmons) pp. 121-144. John Wiley & Sons, Inc. N. Y.
- Nriagu, J. O. and Pacyna J. M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* (London), 333, 134-139.
- Orcutt D, Nilsen, E. and Hale, M. (2000). The physiology of plants under stress: soil and biotic factors. Wiley, New York.
- Oteng-Amoako, A. (1989) In search of alternative antisapstain chemicals for use in Papua New Guinea. *International Research group on wood preservatives Document Number: 3472*. Stockholm, Sweden.

- Pelig-Ba, K.B., Biney, C.A. and Antwi, L.A. (1991). Trace metal concentration in borehole waters from the Upper regions and the Accra plains of Ghana. *Water, Air and Soil Pollution* 103: 71–89.
- Pelig-Ba, K.B. (1998). Trace elements in groundwater from some crystalline rocks in the Upper Regions of Ghana. *Water, Air Soil Pollut.* 103: 71-89.
- Petrovic, A.M.(1990a). The fate of nitrogenous fertilizers applied to turfgrass: *Environmental Quality*, 19: 1-14.
- Petrovic, A.M. (1990b). The fate of nitrogenous fertilizers applied to turfgrass. *Journal of Environmental Quality*. 19:1-14.
- Petrovic, A.M. (1989). Golf course management and nitrates in groundwater. *Golf Course Management*. 57(9):56-64.
- Petrovic, A.M. (1993). Leaching: current status of research. *International Turfgrass Research Journal*. 7:138-147.
- Pilon-Smits, E. (2005) Phytoremediation. *Annu, Rev. Plant Biol.* 56: 15-39. Pittman, J. K., Shigaki, T. and Hirschi, K. D. (2005) Evidence of differential pH regulation of the *Arabidopsis* vacuolar $\text{Ca}^{2+}/\text{H}^{+}$ antiporters CAX1 and CAX2. *FEBS Lett.* 579: 2648- 2656
- Pitt, R., Robertson, B., Barron, P., Ayyoubi, A. and Clark, S. (1999). Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT). U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, Ohio. 505 pgs.
- Prasad, M. N. V. (1997) Trace metals. In: M. N. V. Prasad (Ed.). *Plant Ecophysiology*. John Wiley & Sons. Inc. 207-249.

- Pye, V.I., R. Patrick, and J. Quarles. 1983. Groundwater contamination in the United States. University of Pennsylvania Press, Philadelphia, PA.
- Rahman, F. A., Allan, D. L., Rosen, C. J. and Sadowsky, M. J. (2004). Arsenic Availability from Chromated Copper Arsenate (CCA)-Treated Wood. *Journal of Environmental Quality*, 33:173-180.
- Rajkumar, N., Subramani, T. and Elango, L. (2010). Groundwater contamination due to municipal solid waste disposal – A GIS based study in erode city. *International Journal of Environmental Sciences*, 1: 39-55.
- Ramesh, R., Shivkumar, K., Eswarmoorathi, J., and Purvaja, G.R. (1995). Migration and Contamination of Major and Trace Elements in Groundwater of Madras City, India. *Environmental Geology*. 25: 125-136.
- Rasmussen, G., Andersen, S. (1999) Episodic Release of Arsenic, Copper and Chromium from Wood Preservation Site Monitored by Transplanted Aquatic Moss. *Water, Air, and Soil Pollution*, **109**, 41-52
- Rast, W. and Thornton, J. A. (1996). Trends in Eutrophication Research and Control. *Hydrol. Proc.* 10: 295- 313.
- Rausser, W. E. (1990) Phytochelatins. *Annu Rev. Biochem.* 59: 61- 86.
- Ravichandran, S. and Pundarikanthan, N.V. 1991. Studies of ground water quality of Madras Ind. J. of Env'l.Hlth., 33(4), 481-487.
- Ross, H. B. (1994) on the use of mosses (*Hylocomium splendens* and *Pleurozium schreberi*) for estimating atmospheric trace metal deposition. *Water Air Soil pollut.* 50: 63- 76.

- Salt, D. E., Smith, R. D. and Raskin, I. (1998) Phytoremediation. *Annu. Rev. Plant Physiol. Mol. Biol.* 49: 643- 668.
- Sangodoyin, A. Y. and Sanyalou, O. S. (1995). Land use pattern correlated with fresh water pollution in a developing environment. *Envir. Educ. Info.* 14(2): 163–170.
- Sharma, R. S., & Al-Busaidi, T. S. (2001). Groundwater pollution due to a tailings dam. *Engineering Geology*, 60, 235–244. doi:10.1016/S0013-7952(00)00104-6.
- Shiller, A.M., and Boyle, E.A. (1987). Variability of dissolved trace metals in the Mississippi River. *Geochimica et Cosmochimica Acta* 51(12): 3273-3277.
- Simard, R. R. D., Cluis, G., Gangbazo and Beauchemin, S. (1995). Phosphorus status of forest and agricultural soils from a watershed of high animal density. *J. Environ. Qual.* 24: 1010- 1017.
- Sims, J.T., Simard, R.R. and Joern, B.C. (1998). Phosphorus loss in agricultural drainage: Historical perspective and current research. *J. Environ. Qual.* 27:277-293.
- Sinclair, K.M.L. (1999). Review of the landfill disposal risks and the potential for recovery and recycling of preservative treated timber, prepared for the Environment Protection Agency, Adelaide SA, viewed on 8 September at www.epa.sa.gov.au/pdfs/timber.pdf.
- Singh, B., R. Ramasubban, R. Bhatia, J. Briscoe, C. Griffin, and G. Kim. 1993. Rural Water Supply in Kerala, India: How to Emerge from a Low-level Equilibrium Trap. *Water Resources Research*, Vol. 29, No. 7, pp 1931-1942.

- Smedley, P. L., Ednunds, W. M., West, J. M., Gardner, S. J. and Pelig-Ba, K. B. (1995). Vulnerability of Shallow Groundwater Quality due to Natural Geochemical Environment. Health problems related to Groundwater in the Obuasi and Bolgatanga Areas, Ghana. Report Prepared for ODA under the ODA/BGS Technology Development and Research Programme, Project 92/5.
- Smith, A.H., Lopipero, P.A., Bates, M.N. and Steinmaus, C.M. (2002). Arsenic epidemiology and drinking water standards. *Science*, 296: 2145-2146.
- Smith, R.A, R.B. Alexander, and M.G. Wolman 1987. Water-Quality Trends in the Nation's Rivers. *Science* 27, Vol. 235. no. 4796, 1607 – 1615.
- Snyder, J. D. and Merson, M.H. (1982). The magnitude of the global problem of acute diarrhoeal disease: a review of active surveillance data. *Bull World Health Organ.* 60(4): 605–613.
- Solo-Gabriele, H., Kalitu, V., Kormienko, M., Townsend, T. G. and Messick, B. (1999). Disposal of CCA-treated Wood. An Evaluation of Existing and Alternative Management Options. Final Draft, Florida Center for Solid and Hazardous Waste Management, Report 99-6. Gainesville, FL.
- Solo-Gabriele, H. M., Townsend, T. G. and Schert, T. (2003). Environmental Impact of CCA treated wood: A summary from seven years of study focusing on the US and Florida environments. The International Research Group for Wood Preservation, IRG/WP 03-50205.
- Solo-Gabriele, H., Townsend, T.G., Kormienko, M., Gary, K., Stook, K. and Tolaymat, T. (2000). Alternative Chemicals and Improved Disposal-End

- Management Practices for CCA-Treated Wood (Report #00-08). Florida Center for Solid and Hazardous Waste Management, Gainesville, FL.
- Stallord, R. F. and Edmond, J. M. (1983). Geochemistry of Amazon River: the influence of the geology and weathering environment on the dissolved load. *Journal of Geophysical Research*, 88: 9671–9688.
- Stamm C, Flübler H, Gächter R, Leuenberger J & Wunderli H (1998) Preferential transport of phosphorus in drained grassland soils. *J Environ Qual* 27: 515–522
- Steffens, J. C. (1990) The heavy metal binding peptides of plants. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 41: 533- 575.
- Stephan, I., Leithoff, H. and Peek, R. J. (1996). Microbial Conversion of wood treated with salt Preservatives. *Material and Organisms*, 30: 179-199.
- Stilwell, D.E. and Gorny, K.D., (1997). Contamination of soil with copper, chromium, and arsenic under decks built from pressure treated wood. *Bull. Environ. Contam. Toxicol.* 58: 22–29.
- Stumm, W. and Morgan, J. J. (1981). *Aquatic Chemistry*. Willey, New York. 780 pp.
- Townsend, T., Stook, K., Tolaymat, T., Song, J.K., Solo-Gabriele, H., Hosein, N., Khan, B. (2000). *New Lines of CCA-treated Wood Research: In-service and Disposal Issues* (Technical Report 00-XX). Florida Center for Hazardous Waste.
- Tsai, S.Y., Chou, H.Y., The, H.W., Chen, C.M. and Chen, C.J. (2003). The effects of chronic arsenic exposure from drinking water on neurobehavioral development in adolescence. *Neurotoxicology* 24:747–753.

- Tyagi, P., Buddhi, D., Choudhary, R, and Sawhney, R.L. 2000. Physico-Chemical Quality of Ground Water in Industrial Areas of India. A Review, *Poll, Res-19*(3):443-455.
- Umar, R., and Absar, A. (2003). Chemical characteristics of groundwater in parts of the Gambhir river basin, Bharatpur District, Rajasthan, India. *Environmental Geology*, 44: 535–544.
- Umar, R., Muqtada, M., Khan, A. and Absar, A. (2006). Groundwater hydrochemistry of a sugarcane cultivation belt in parts of Muzaffarnagar district, Uttar Pradesh, India. *Environmental Geology*, 49: 999–1008.
- UNESCO/WHO/UNEP (1996). Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring -Second Edition. Editor Chapman D.
- UNEP. 2008. Water Quality for Ecosystem and Human Health. Second Edition. From: http://www.gemswater.org/publications/pdfs/water_quality_human_health.pdf
- US EPA (2006) Ground Water and Drinking Water. "Consumer Factsheet on: Nitrates/Nitrites." <http://www.epa.gov/safewater/dwh/c-ioc/nitrates.html>.
- US EPA (2002). Notice of Receipt of Requests to Cancel Certain Chromated Copper Arsenate (CCA) Wood Preservative Products and Amend to Terminate Certain Uses of CCA Products. *Office of Pesticides Washington D.C.*
- U.S. EPA 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices, Report EPA-821-R-99-012, Aug.

- United States Environmental Protection Agency. 1976. Quality criteria for water. EPA-440/9-76-023. Office of Water Planning and Standards. USEPA., Washington, D.C.
- US EPA (1993). Wellhead Protection: A Guide for small communities, Office of Research and Development Office of Water, Washington DC (CEPA/ 625/ R-93/002).
- Vallee, B. L. (1957). Zinc and its biological significance. *Arch. ind. Hlth*, 16: 147.
- Vodela, J.K., Renden, J.A., Lenz, S.D., Henney, W.H.M. and Kemppainen, B.W. (1997). Drinking water contaminants. *Poult. Sci.*, 76: 1474-1492.
- Wang, L. and Huang, J. (1994). Chronic arsenism from drinking water in some areas of Xinjiang, China. In *Arsenic in the environment, Part II: Human Health and Ecosystem effects*. (J. O. Nriagu, ed.), pp. 1259–172. Wiley, New York.
- Warner, J.E. and Solomon, K.R. (1990). Acidity as a factor in the leaching of copper, chromium and arsenic from CCA-treated dimension lumber. *Environ. Toxicol. Chem.* 9: 1331–1337.
- Wangness, D.J., Frick, E.A., Buell, G.R., and DeVivo, J.C. (1994). Effect of restricted use of phosphate detergent and upgraded wastewater-treatment facilities on water quality in the Chattahoochee River near Atlanta, Georgia: U.S. Geological Survey Open-File Report 94-99, 4p.
- Wasserman, G.A., Liu, X., Parvez, F., Ahsan, H., Factor-Litvak, P. and van Geen, A. (2004). Water arsenic exposure and children's intellectual function in Araihaazar, Bangladesh. *Environ Health Perspect.* 112: 1329–1333.

- Water Research Institute (1999). Baseline Data and Monitoring of Pollution on Volta Lake and Kpong Headpond. WRI Technical Report Submitted to VRA, No. 556.55. Accra. 118 pp.
- Water Resources Commission (2003). Ghana Raw Water Criteria and Guidelines, Vol. 1. Domestic Water. CSIR-Water Research Institute, Accra, Ghana.
- Webb, B. W. and Walling, D. E. (1992). Water Quality. II. Chemical Characteristics. In *The Rivers Handbook*, volume I. (P. Calow and G. E. Petts, ed.), pp. 73–100. Blackwell Scientific Publications, Oxford, UK.
- Weis, P., Weis J.S. and Proctor T. (1993). “Copper, Chromium and Arsenic in Estuarine Sediments Adjacent to Wood Treated with Chromated-Copper Arsenate (CCA)”. *Estuarine, Coastal and Shelf Science* 36, 71-79.
- Weis, J. S. and Weis, P. (1966). Reduction in toxicity of chromated copper arsenate (CCA) - treated wood as assessed by community study. *Marine Environmental Research* 41:15-25.
- Weber, J., Jang, Y., Townsend, T. and Laux, S. (2002). Leachate from Land Disposed Residential Construction Waste. *Journal of Environmental Engineering*, 128(3): 237-245.
- WHO (1985). Guidelines for Drinking Water Quality. World Health Organisation, Geneva.
- WHO (1987). Report of Proceedings, International Drinking Water Supply and Sanitation Consultation, Interlaken, Switzerland.
- WHO (1988). Chromium. Environmental Health Criteria No.61. World Health Organization, Geneva.

WHO (1993). Guidelines for Drinking Water Quality. World Health Organisation. Geneva, Switzerland.

WHO (1996). Guidelines for Drinking Water Quality. World Health Organisation. Geneva, Switzerland.

WHO (2003). Chromium in drinking-water: background document for development of WHO guidelines for drinking-water quality. World Health Organization, Geneva. p 13.

WHO (2004). Copper in drinking-water: background document for development of WHO guidelines for drinking-water quality. World Health Organization, Geneva. p 12.

WHO (2006). Guidelines for Drinking Water Quality. First Addendum to 3rd Edition, vol. 1. Geneva. WHO press. 515pp.

WHO (2006). Guidelines for Drinking Water Quality, Vol. 1, first Addendum to the third edition, Recommendations. Geneva: WHO Publication.

Young, J.C. and Cowan, R.M., 2004, *Respirometry for environmental science and engineering*, Springdale, AR: SJ Publications.

Zagury, G. J., Dobran, S., Estrela, S. and Deschênes, L. (2008), *Inorganic arsenic speciation in soil and groundwater near in-service chromated copper arsenate-treated wood poles*. *Environmental Toxicology and Chemistry*, 27: 799–807. doi: 10.1897/07-305.1

Zilkey, M.M. 2001. Fate of nutrients under an irrigated manured field, southern Alberta. M.Sc. Thesis, University of Calgary, Dept. of Geology and Geophysics.

Zimmels, Y., Kirzhner, F. and Roitman, S. (2004) Use of naturally growing aquatic plants for waste water purification. *Water Environ. Res. Found.* 76: 220-230

Zuane, J. D. (1990). *Drinking Water Quality: Standards and Control*, Van Nostrand Reinhold, New York.

KNUST



APPENDICES

ANOVA for metal concentration in water from the sampling location

Completely Randomized AOV for As

Source	DF	SS	MS	F	P
LOCATION	3	2.407E-34	8.025E-35	M	M
Error	76	0.00000	0.00000		
Total	79	2.407E-34			

Grand Mean 1.00E-02 CV 0.00

WARNING: The total sum of squares is too small to continue. The dependent variable may be nearly constant.

Completely Randomized AOV for Cu

Source	DF	SS	MS	F	P
LOCATION	3	0.00699	0.00233	0.35	0.7868
Error	76	0.50075	0.00659		
Total	79	0.50774			

Grand Mean 0.0637 CV 127.35

Completely Randomized AOV for Cr

Source	DF	SS	MS	F	P
LOCATION	3	0.00000	0.00000	0.00	1.0000
Error	76	2.111E-34	2.778E-36		
Total	79	2.111E-34			

Grand Mean 0.0100 CV 0.00

Completely Randomized AOV for Zn

Source	DF	SS	MS	F	P
LOCATION	3	0.30598	0.10199	0.99	0.4024
Error	76	7.83310	0.10307		
Total	79	8.13908			

Grand Mean 0.2007 CV 159.94

ANOVA for metal concentration in water from the sampling points

Completely Randomized AOV for As

Source	DF	SS	MS	F	P
Sample	19	2.407E-34	1.267E-35	M	M
Error	60	0.00000	0.00000		
Total	79	2.407E-34			

Grand Mean 0.0100 CV 0.00

WARNING: The total sum of squares is too small to continue.
The dependent variable may be nearly constant.

Completely Randomized AOV for Cu

Source	DF	SS	MS	F	P
Sample	19	0.07244	0.00381	0.53	0.9397
Error	60	0.43529	0.00725		
Total	79	0.50774			

Grand Mean 0.0637 CV 133.64

Completely Randomized AOV for Cr

Source	DF	SS	MS	F	P
Sample	19	2.407E-34	1.267E-35	M	M
Error	60	0.00000	0.00000		
Total	79	2.407E-34			

Grand Mean 0.0100 CV 0.00

Completely Randomized AOV for Zn

Source	DF	SS	MS	F	P
Sample	19	2.10380	0.11073	1.10	0.3734
Error	60	6.03528	0.10059		
Total	79	8.13908			

Grand Mean 0.2007 CV 158.00

ANOVA for Physico-chemical property of water sampled from the locations

Completely Randomized AOV for TEMPERATURE

Source	DF	SS	MS	F	P
LOCATION	3	0.3964	0.13212	0.22	0.8810
Error	76	45.2675	0.59563		
Total	79	45.6639			

Grand Mean 28.009 CV 2.76

Completely Randomized AOV for pH

Source	DF	SS	MS	F	P
LOCATION	3	17.2205	5.74016	122.66	0.0000

Error	76	3.5567	0.04680
Total	79	20.7771	

Grand Mean 5.7386 CV 3.77

Completely Randomized AOV for TURBIDITY

Source	DF	SS	MS	F	P
LOCATION	3	0.6000	0.20000	1.00	0.3959
Error	76	15.1415	0.19923		
Total	79	15.7415			

Grand Mean 0.0575 CV 776.26

Completely Randomized AOV for CONDUCTIVITY

Source	DF	SS	MS	F	P
LOCATION	3	942875	314292	38.41	0.0000
Error	76	621802	8182		
Total	79	1564677			

Grand Mean 237.16 CV 38.14

Completely Randomized AOV for TDS

Source	DF	SS	MS	F	P
LOCATION	3	283637	94545.6	30.67	0.0000
Error	76	234319	3083.1		
Total	79	517956			

Grand Mean 130.95 CV 42.40

Completely Randomized AOV for TSS

Source	DF	SS	MS	F	P
LOCATION	3	136.250	45.4167	10.10	0.0000
Error	76	341.700	4.4961		
Total	79	477.950			

Grand Mean 2.9750 CV 71.27

Completely Randomized AOV for COLOUR

Source	DF	SS	MS	F	P
LOCATION	3	8.437	2.81250	1.03	0.3861
Error	76	208.376	2.74180		
Total	79	216.814			

Grand Mean 0.3200 CV 517.45

ANOVA for Physico-chemical property of water sampled from sampling points

Completely Randomized AOV for TEMPERATURE

Source	DF	SS	MS	F	P
Sample	19	4.6964	0.24718	0.36	0.9917
Error	60	40.9675	0.68279		
Total	79	45.6639			

Grand Mean 28.009 CV 2.95

Completely Randomized AOV for pH

Source	DF	SS	MS	F	P
Sample	19	19.7766	1.04087	62.42	0.0000
Error	60	1.0006	0.01668		
Total	79	20.7771			

Grand Mean 5.7386 CV 2.25

Completely Randomized AOV for TURBIDITY

Source	DF	SS	MS	F	P
Sample	19	3.8000	0.20000	1.00	0.4690
Error	60	11.9415	0.19903		
Total	79	15.7415			

Grand Mean 0.0575 CV 775.86

Completely Randomized AOV for CONDUCTIVITY

Source	DF	SS	MS	F	P
Sample	19	1564400	82336.8	17818.6	0.0000
Error	60	277	4.6		
Total	79	1564677			

Grand Mean 237.16 CV 0.91

Completely Randomized AOV for TDS

Source	DF	SS	MS	F	P
Sample	19	486564	25608.6	48.95	0.0000
Error	60	31392	523.2		
Total	79	517956			

Grand Mean 130.95 CV 17.47

Completely Randomized AOV for TSS

Source	DF	SS	MS	F	P
Sample	19	447.950	23.5763	47.15	0.0000
Error	60	30.000	0.5000		
Total	79	477.950			

Grand Mean 2.9750 CV 23.77

Completely Randomized AOV for COLOUR

Source	DF	SS	MS	F	P
Sample	19	48.437	2.54934	0.91	0.5750
Error	60	168.377	2.80628		
Total	79	216.814			

Grand Mean 0.3200 CV 523.50

ANOVA for Nutrient concentrations of water sampled from location

Completely Randomized AOV for NO₃

Source	DF	SS	MS	F	P
LOCATION	3	0.00028	9.251E-05	6.15	0.0008
Error	76	0.00114	1.503E-05		
Total	79	0.00142			

Grand Mean 5.09E-03 CV 76.22

Completely Randomized AOV for PO₃

Source	DF	SS	MS	F	P
LOCATION	3	1.10027	0.36676	3.66	0.0160
Error	76	7.61309	0.10017		
Total	79	8.71336			

Grand Mean 0.1168 CV 270.98

Completely Randomized AOV for BOD

Source	DF	SS	MS	F	P
LOCATION	3	0.00028	9.198E-05	0.38	0.7670
Error	76	0.01835	2.414E-04		
Total	79	0.01862			

Grand Mean 0.0519 CV 29.92

ANOVA for Nutrient concentrations of water sampled from sampling points

Completely Randomized AOV for NO₃

Source	DF	SS	MS	F	P
Sample	19	0.00050	2.630E-05	1.71	0.0590
Error	60	0.00092	1.535E-05		
Total	79	0.00142			

Grand Mean 5.09E-03 CV 77.00

Completely Randomized AOV for PO₄

Source	DF	SS	MS	F	P
Sample	19	1.51929	0.07996	0.67	0.8356
Error	60	7.19408	0.11990		
Total	79	8.71336			

Grand Mean 0.1168 CV 296.46

Completely Randomized AOV for BOD

Source	DF	SS	MS	F	P
Sample	19	0.00731	3.845E-04	2.04	0.0192
Error	60	0.01132	1.886E-04		
Total	79	0.01862			

Grand Mean 0.0519 CV 26.44