

**BOREHOLE/WELL WATER QUALITY ANALYSIS OF THE
PERIPHERAL MINING COMMUNITIES OF GOLD FIELDS GHANA
LIMITED, TARKWA GOLD MINE**

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COLLEGE OF ENGINEERING

BY

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**SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE
AWARD OF MASTER OF SCIENCE DEGREE [MSc Environmental Resources
Management]**

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DECLARATION

I declare that this thesis is my own work. It is being submitted for the Master of Science (MSc) degree at the Kwame Nkrumah University of Science and Technology, Kumasi. It has not been submitted for any degree or examination in any other university.




(Candidate's Signature)

12/11/2008

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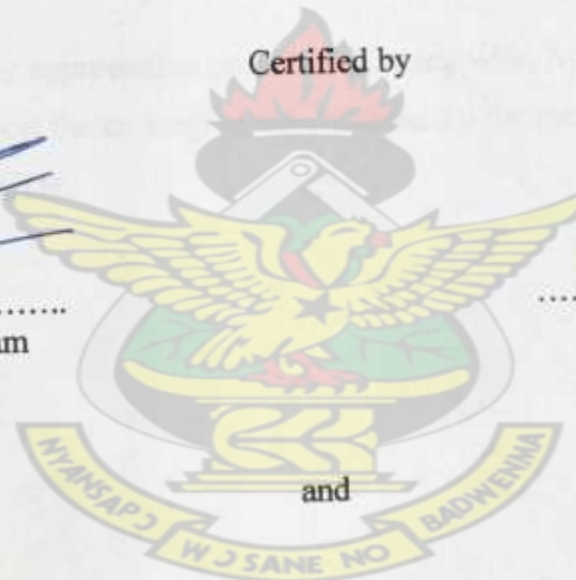
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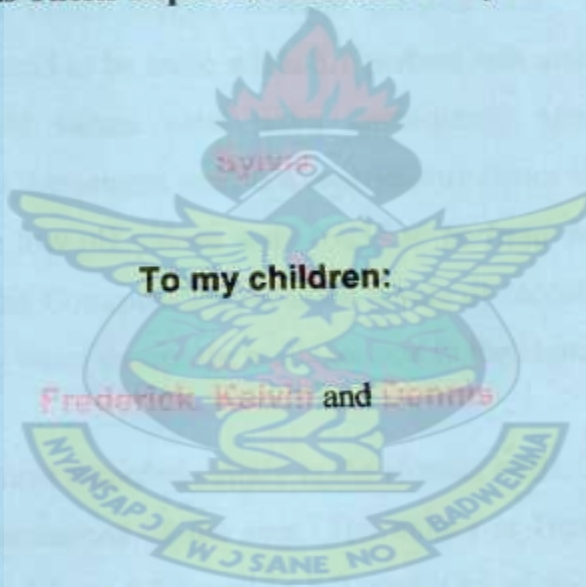


ABSTRACT

DEDICATION

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This Thesis Report is dedicated to my wife



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ABSTRACT

Some parts of the minerals industry and the community have viewed water as an inexpensive commodity rather than an asset with significant value. It is important to recognize the role water plays in the environment and in the economic development of communities.

This research assessed the quality of community borehole and well water provided by Gold Fields Ghana Limited, as part of its industry approach to water management. The research also assessed the impact of Gold Fields operations and other activities on the quality of the borehole and well water in its peripheral communities. Data was collected and analyzed on sixty four boreholes and wells over a period of three years.

The study revealed that pH values ranged between 4.7 and 11.3. Out of the 359 samples analyzed, 3.6 percent was found to be basic while 8.1 percent was acidic. It was also found out that, samples with high pH values were taken immediately after concrete works were undertaken and the impact of the cement used is a contributory factor since cement increases the pH of water. Samples with low pH values were found to be from wells with unhygienic and unsanitary conditions. All the Communities recorded levels of faecal coliforms exceeding the WHO standards for drinking water except the wells located in the Huniso Community.

High values of Manganese were recorded mainly in the Huniso wells. These trends could be due to the geology and rock formations of the area. The values at Huniso exceeding the WHO guideline of 0.33 mg/l ranged from 0.37 mg/l to 5.0 mg/l. Out of the 12 wells at huniso, three had consistent elevated values of manganese. Well HNSO13 increased from 2.54 mg/l in 2003 to 5.0 mg/l in 2005, while HNSO16 increased from 1.0mg/l in 2003 to 1.48 mg/l in 2005.

Conductivity Values were very low, confirming the low metal dissolution of the Tarkwaian rock.

The community wells should be sited properly and must be kept in good hygienic condition to prevent contamination.

It was observed that water from some of the boreholes is not potable and hence not good for drinking even though it could be treated. This was due to contaminants such as high and low pH

values, high TDS values, high faecal coliforms which do not meet the EPA and WHO guidelines for drinking water.

Cyanide values were at the detection limit or absent in all the samples taken.

Mercury, lead, iron and arsenic concentrations in samples analyzed from wells around the TSF were very low. It is therefore evident that the operations of Gold Fields Ghana Limited, Tarkwa Gold Mine have not polluted the borehole and well water in its peripheral communities. All the possible contaminants from the company have been observed to be absent from the samples or in negligible amounts. Some of the contaminants observed in the boreholes/wells might be coming from other sources and must be critically investigated if these facilities will continue to serve as sources of drinking water for these communities.

The study clearly underscores the need to deepen wells, relocate those which are near access roads and cottage industries, raise the basements of low lying ones and to keep a sanitary and hygienic environment around the wells.



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CHAPTER ONE

INTRODUCTION

The use of ground water as a source of potable water from aquifers is a global issue. The Tarkwa Community, as a whole, is no exception to the use of ground water as a resource. This vital resource is threatened in many areas by over exploitation and pollution from human activities.

In developing countries, particularly rural areas, water quality concerns have mostly been on bacteriological parameters with little emphasis on chemical characteristics. This could be due to the fact that bacteriological pollution on most occasions produces immediate health effect on the people. However, new hazards are now being detected in domestic water supplies of countries due to chemical contamination i.e. effect of elements, heavy metal toxicity, nitrates, organic compounds or pesticides. Hence chemical characteristics of ground water must also be assessed in the overall determination of water quality for rural water supply; as it is widely believed that ground water is not easily polluted because of the assumption that the soil is capable of filtering solids and binding chemicals as it percolates through it (Cunningham and Saigo, 1999).

The history of Gold Fields Ghana Limited (GFGL), Tarkwa Mine is characterized by some remarkable achievements following its acquisition of the right to operate the then underground mine at Tarkwa from the government (State Gold Mining Corporation of Ghana) on 1st July 1993. At that time, the remaining life-span was estimated at most to be three years; however through its long expertise in the industry and commitment to the project, the company was able to run the underground mine for a total of six years. Having reviewed the large, low grade deposit adjacent to the existing operations in 1996, GFGL was able to add about 20 years of life to a mine on the verge of complete closure by developing a heap leach surface mining operation. The open-pit heap leach operations commenced in 1998.

The company expanded its operations in Ghana by acquiring a portion of the Teberebie Goldfields Limited in 2000 and completely taking over Aboso Goldfields Damang Mine in January 2002.

GFGL has constructed several community boreholes in settlements around the Northwestern section of its concession to provide potable water for the inhabitants of these communities due to its anticipated impact on surface waters draining the area. These boreholes are monitored every quarter of a year and samples sent to an external laboratory for analysis. The issue of chemical pollution from mining activities cannot be ruled out as it has been established that trace elements cause malfunctioning of vital organs in the human body (Luke-Tay, 1999).

Despite the provision of the borehole water for the people in these communities, the management of the company still received several complaints from the communities using these facilities with regard to the quality of water from the boreholes. There is therefore the need for thorough studies with respect to this resource to come out with recommendations to mitigate any source of pollution.

This research was therefore carried out to investigate the possibility of mining chemicals that could seep through into these boreholes as contaminants.

The objectives of this research are to:

- Assess the quality (physical, chemical and bacteriological) of the community boreholes/wells water
- Assess the impact of mining activities on the ground water which is a source of water supply for the communities
- Suggest and recommend improvements in the quality of borehole/well water within the periphery of Gold Fields Ghana Limited (GFGL) mining area.

The research focused on sixty four (64) boreholes in the communities sited around the North section of Gold Fields Ghana Limited concession. The main data used for the project comprised of certified results of these borehole water samples taken and analyzed quarterly in the company's environmental laboratory or by an outside laboratory (SGS). Sample collection and analyses span over a period of three years, 2003 to 2005. The 2003 data was used as the primary data. The work also included on site determination of certain important parameters such as temperature, colour, conductivity, pH etc.

A physical inspection of the site and sanitary conditions of the sampled boreholes was also conducted periodically.

The methods used include quarterly sampling of these sixty four community boreholes by employing standard sampling protocols. On site determination of temperature, colour, conductivity, pH etc. was carried out before the samples were sent to SGS for further analyses to determine other parameters likely to be present in the borehole as pollutants. Provision was made for quality control and quality assurance. Care was also taken to prevent contamination.

Certified results of these samples from SGS were then analyzed. Other related data from the environmental department were also used.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Ground Water Occurrences

Ground water, being one of the sources of potable water, is a very important natural resource existing as a result of the movement of water in its different forms.

2.1.1 The Water Cycle

Water is a unique substance that can exist in all three states of matter; namely solid, in the form of ice and snow; the liquid and the gaseous, in the form of vapour.

Globally, there is a movement of water in its various forms and the hydrological cycle clearly explains this phenomenon. According to Anon, (1981), the energy from the sun's rays evaporates water from the sea, open water bodies on the land i.e. rivers, lakes, streams etc. and from the leaves of vegetation. The water vapour thus formed rises and collects into clouds, which are carried by the wind to the point where meteorological conditions cause them to precipitate as rain or snow. During rainfall periods, part of the water percolates into the ground, part is used by vegetation and part sinks below root level through porous soil until it reaches bedrock or other impermeable layer while the rest runs off into surface water systems. Then under force of gravity, it gradually finds its way downhill until it either emerges as springs forming rivers, streams or retains below ground to the sea to be re-evaporated in due course. The rivers and streams then flow into the sea from where it is re-evaporated in due course to continue the cycle.

2.1.2 Ground water

According to Cunningham and Saigo, (1996), Precipitation that does not evaporate back into the air or run off over the surface percolates through the soil into pores and hollows of permeable rocks into aquifers. Ground water is held mainly in aquifers. This process allows for filtration of the water which may render it safe for drinking.

The stage of the hydrological cycle where the water first sinks into the ground and its re-emergence in springs, rivers or the sea itself, is what is known as 'groundwater' and the saturated soil layer containing it is called 'aquifer'. The word aquifer comes from the Latin

words, aqua (water) and ferre (to carry). The aquifer literally carries groundwater. Aquifers may be of several types. When the lower part of a porous soil reaching the surface is saturated, it is known as 'open' aquifer. The upper surface of the water it contains is then called the 'water table'.

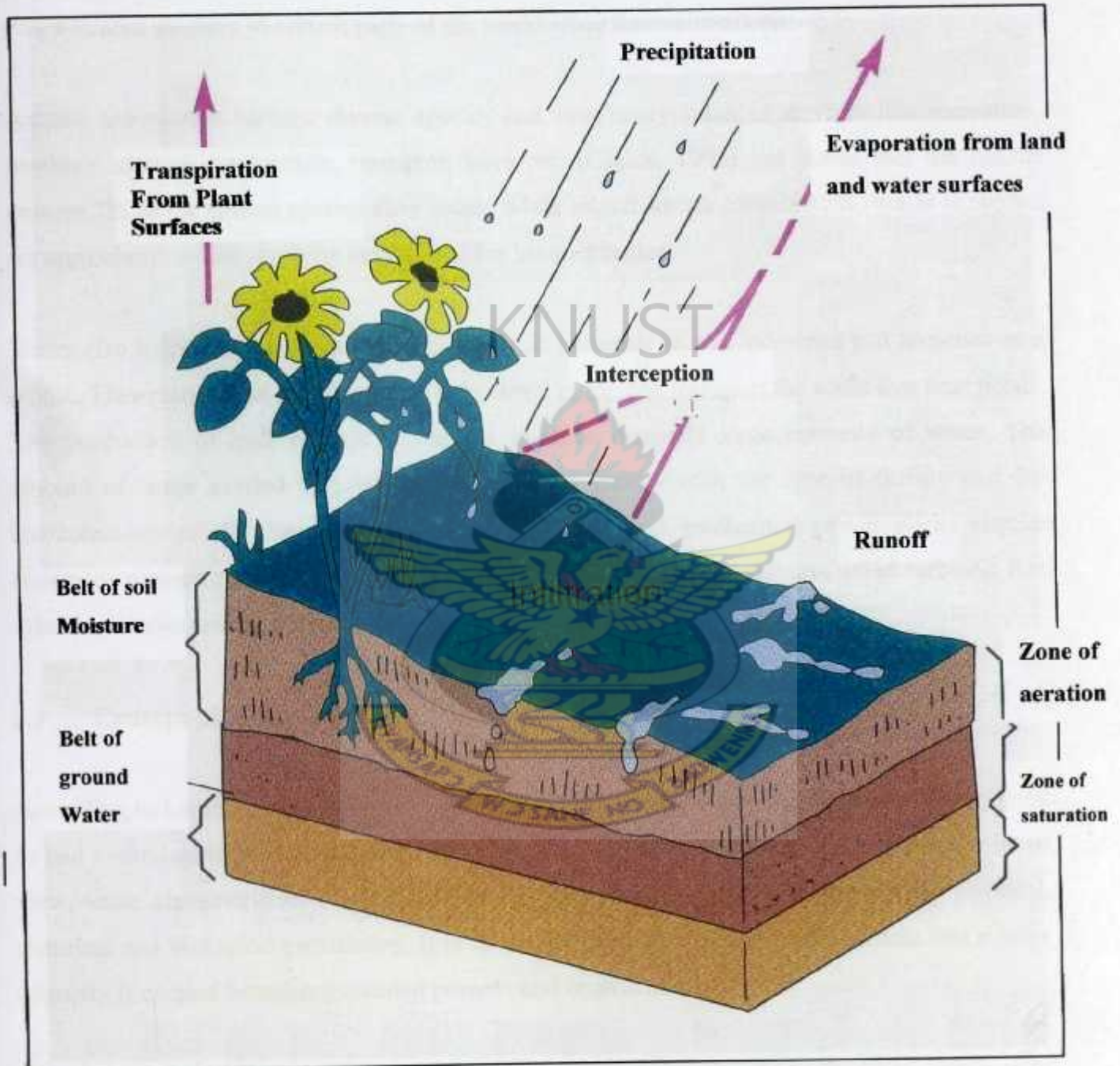


Figure 2.1: Ground Water Formation (After Cunningham & Saigo, 1995)

2.2 The Uses of Water

Water is among the most essential resources that nature provides to sustain life for plants, animals and humans. Humans and animals need water to drink and to remove wastes, particularly in large cities. Lack of clean water has resulted in a number of water borne and water-related diseases in certain parts of the world since time in memorial.

Aquatic ecosystems harbour diverse species and over many valuable services like recreation, aesthetic scenery for tourism, transport ways etc. (Gleick, 1993) has stated that the oceans contain 7% of the animal species alive today, while inland waters contain 12%. Water is needed for agriculture, which provides man's food for his sustenance.

Water also helps man to produce the energy that he needs to run industries and societies as a whole. This energy is in turn needed to help clean, pump and transport the water that man needs. The production of hydroelectric power for instance demands large amounts of water. The amount of water needed to produce energy varies greatly with the type of facility and the characteristics of the fuel cycle. Fossil fuel, nuclear and geothermal power plants require enormous amount of water for cooling. Solar photovoltaic power systems, wind turbines, and other renewable energy sources often require minimal amounts of water.

2.3 Concept of Water Quality

According to Lamb, (1985) quality water refers to the characteristics or attributes of water, good or bad that relate to its acceptability for certain purposes or uses. From a technological point of view, those characteristics or attributes usually are defined in terms of appropriate physical, chemical and biological parameters. It is in the interpretation of water quality data that a wide disparity is created between interested persons and organizations.

Quality can be judged accurately only by comparing concentrations of various constituents in water with those that would be optimum for the intended use. Consequently, Schulz and Okun (1984) proposed that a safe and potable drinking water should conform to the following water quality characteristics:

- Free from pathogenic organisms;
- Low in concentrations of compounds that are acutely toxic or that have serious long-term effects, such as lead;

- Clear and colourless;
- Not saline (salty);
- Free from compounds that cause an offensive taste or odour; and
- Non corrosive, nor should it cause encrustation of piping or staining of clothes.

According to Holden, (1970) water can be rightly designated as pure and wholesome if it is free from visible suspended matter, colour, odour and taste from all objectionable bacteria indicative of the presence of disease-producing organisms, and contains no dissolved mineral matter which in quantity or quality would render it dangerous to health. It should not contain dissolved substances injurious to health. International bodies like European Union (EU), World Health Organization (WHO) and the International Reference Centre for Community Water Supply and Sanitation have also come out with quality guidelines for water for different purposes.

Many standards have been proposed for the quality of drinking water for rural areas, and these vary from one country to another. Much stricter standards have been laid down for urban water supplies where one central source may serve millions of people, where the standards must be strictly adhered to. It is however possible for developing countries to develop their own water quality standards taking into consideration their cultural, environmental, geographical, health and political conditions and designated uses.

2.4 Factors Influencing Ground Water Quality

Ground water quality is influenced by several factors which may include both natural and manmade activities.

2.4.1 Geology and Mineralogy

The quality of a ground water is affected by factors including the source rock, the composition of the soil, or overlaying superficial deposits, chemical reactions between ions in the water and minerals in associated rocks, the trace minerals in the rock, the rate of movement of groundwater and human activity within the catchment basin. Certain chemical qualities can be related to the major rock types. Groundwater passing through igneous rocks for example may dissolve only very small quantities of mineral matter because of the relative insolubility of the rock composition. Percolating rainwater containing dissolved carbon dioxide (CO_2) from the atmosphere dissolves the silicate minerals of the igneous rocks to produce leachate such as bicarbonates. These tend to yield soft waters with high pH and relatively high silica content in

case of alkali rich rocks; whereas alkali-earth and Ferromagnesian igneous rocks yield hard waters with low pH and relatively low silica content.

Generally, the waters from igneous rocks tend to have low total dissolved solid contents. This is the case with hard, compact, metamorphic rocks such as quartzite and slates, because they do not easily dissolve. The silicate minerals in metamorphic rocks tend to weather in a similar manner like those of igneous rocks (Holden, 1970). Todd, (1980) noted that sedimentary rocks (mineral sources: feldspar, gypsum and types of CaCO_3) because of their high solubility, combined with the great abundance in the earth's crust, furnish a major portion of the soluble constituents to groundwater. Sodium and calcium are commonly added cations; bicarbonate and sulphate are corresponding anions, chloride occurs to only a limited extent under normal conditions. Occasionally, nitrate is an important natural constituent; high concentrations may indicate sources of past or present pollution.

According to Holden, (1970), silica is not usually an important constituent of waters from sandstone. Shales and mudstones of marine origin are likely to contain sodium saturated clay minerals. Waters in argillaceous rocks tend also to have high sulphate and sometimes chloride contents.

2.4.2 Human Activities

Human activities acting as sources of contaminants in ground water are virtually limitless. Sanitary sewers are intended to be watertight; however, in reality leakage of sewage into the ground is a common occurrence, especially from old sewers. Leakages may result from poor workmanship, defective sewer pipe, and breakage by tree roots, ruptures from heavy loads or soil slippage, fractures from seismic activity, loss of foundation support, shearing due to differential settlement of man holes and infiltration causing sewage to flow into abandoned sewer laterals. Sewer leakage can introduce high concentrations of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate, organic chemicals, and possibly bacteria into groundwater.

The land disposal of solid wastes could create an important source of groundwater contamination. Most landfills are simply refuse dumps; only a fraction can be described as sanitary landfills. Leachates from such landfills can contaminate groundwater if water moves through the fill materials. Possible sources of water include precipitation, surface water infiltration, percolating water from adjacent land, and ground water in contact with the fill.

Underground storage and transmission of a wide variety of fuels and chemicals are common practices for industrial and commercial installations. These tanks and pipelines are sometimes subject to structural failures so that subsequent leakages become a source of surface and groundwater pollution.

2.4.3 Mining Activities

Contamination of ground water by mining activities depends on the type of mineral being mined and the beneficiation process applied. Both surface and underground mines invariably extend below the water table so that dewatering to expand mining is common. Water so pumped may be highly mineralized and is frequently referred to as acid mine drainage. Normal characteristics include low pH and high levels of iron, aluminum and sulphate.

Pollution of groundwater can also result from leaching of old mine tailings and settling ponds; and mobilization of Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, and Mercury can occur.

2.4.4 Agriculture

Approximately one-half to two-thirds of the water applied for irrigation of crops is consumed by evapotranspiration; the remainder, termed irrigation return flow, drains to surface channels or joins the underlying ground water. Irrigation increases the salinity of irrigation flow from 3 to 10 times that of the applied water (Todd, 1980). Principal cations include calcium, magnesium, and sodium; major anions include bicarbonate, sulphate, chloride and nitrates.

Where animals are confined within a limited area, for milk production, large amounts of wastes are deposited on the ground. Storm runoffs in contact with the manure carry highly concentrated contaminants to surface and subsurface waters. Animal wastes may transport salts, organic loads, and bacteria into the soil. Nitrate nitrogen is the most important persistent contaminant that may reach the water table.

When fertilizers are applied to agricultural land, a portion could leach through the soil and to the water table. Primary fertilizers are compounds of nitrogen, phosphorus and potassium. Phosphorus and potassium fertilizers are readily adsorbed on the soil particles and seldom constitute a contaminant problem. But nitrogen in solution is only partially used by plants or adsorbed on soil particles and it is the primary contaminant. Fertilizers are extensively used and will undoubtedly increase in the future.

Pesticides can be significant in agricultural areas as a source of groundwater contamination. The presence of the material even in minute concentrations can have serious consequences in relation to the potability of the water. The impact of pesticides on groundwater quality depends on the properties of the pesticide residue, rainfall or irrigation rates, and soil characteristics. Organic compounds of chlorinated hydrocarbons and aromatic hydrocarbons form the myriad of compounds that could pose as pollutants.

2.5 Water Quality and Health

Even though water plays an essential role in supporting human life, it also has, if contaminated, great potential for transmitting a wide variety of diseases and illnesses. A WHO survey highlighted the following:

Each day some 30,000 people die from water-related diseases. In developing countries 80% of all illnesses are water-related. A quarter of children born in developing countries will have died before the age of 5, the great majority from water-related diseases. At any one time there are likely to be 400 million people suffering from gastroenteritis, 200 million with schistosomiasis (Tibbutt, 1985).

All these diseases can be water-related, although other environmental factors may also be important. There are several contaminants, which may be naturally occurring or manmade having known effects on the health of consumers. It is imperative, therefore that the relationship between water quality and health be fully understood and appreciated. There are two major health concerns in relation to water quality; microbial related diseases and chemical related illnesses.

2.5.1 Microbial Related Diseases

The incidence of microbial related diseases may be due to viruses, bacteria, protozoa or worms. The major concern here is related waterborne diseases. With this type of diseases, infection occurs when the pathogenic organisms gain access to water which is then consumed by a person who does not have immunity to the disease.

Cholera, typhoid, bacillary dysentery, etc. follow this classical faecal-oral transmission route and outbreaks are characterized by simultaneous illness amongst a number of people using the same source of water. Though these diseases are waterborne they can also be spread by any

other route which permits direct ingestion of faecal matter from a person suffering from the disease. Common bacteria that can cause water borne diseases and their primary sources are presented in Table 2.1.

Table 2.1: Sources and causes of Pathogenic Diseases

BACTERIA	ASSOCIATED DISEASE	PRIMARY SOURCE
Salmonella typhi	Typhoid fever	human faeces
Salmonella Paratyphi	Paratyphoid fever	human faeces
Shigella	Bacillary dysentery	human faeces
Vibrio Cholerae	Cholera	human faeces
Enteropathogenic E. coli	Gastroenteritis	human faeces
Yersinia enterocolitica	Gastroenteritis	human/animal faeces
Campylobacter jejuni	Gastroenteritis	human/animal faeces

For enteric viruses the group Enteroviruses; Poliovirus, Coxsackie virus A and B, cause poliomyelitis and aseptic meningitis respectively and have their primary source as human faeces.

Majority of infectious diseases in developing countries are water-related diseases which include those which are carried by water or where water provides the vital link in their transmission. They also include diseases that can be prevented or reduced by the hygienic handling and use of water. Diseases of this nature occur as a result of the unhygienic disposal of human and household waste combined with poor hygienic practices. Water can be safe at a source as far as microbial contamination is concerned but it may become contaminated during collection, carrying, handling and use. Therefore, in discussing the microbial water quality in relation to boreholes, the provision of safe water is not enough to guarantee an improvement in the health of the community, but must in addition include effective sanitation and emphasis on good hygiene practices through complementary hygiene promotion activities.

2.5.2 Chemical Related Illnesses

There are many chemical substances whose presence in water could be harmful or fatal to human life. An acute effect could be produced by the accidental discharge of sufficient toxic matter into a water source to produce more or less immediate symptoms in consumers. This seldom occurs and if it does, contaminants in most cases produce obvious type of chemical

contamination. A more insidious type occurs when it produces a long-term hazard due to exposure to minute concentrations, perhaps over many years.

Health effects resulting from exposure to chemical contaminants may be classified reversible, non-reversible or irreversible. Reversible effects are those that disappear quite soon after exposure ends. Non-reversible effects are those which do not disappear totally or partially, and which may progress at a lower rate after exposure is terminated. According to Gower, (1980), Irreversible effects continue to progress after cessation of exposure.

Nitrates themselves in water are not poisonous but, when reduced to toxic nitrates in the stomach, two serious conditions can result. The first affects only infants because of their stomach pH, which is particularly favourable for microbial reduction of nitrates to nitrite. The resultant condition is known as "blue baby syndrome" (methaemoglobinaemia). This predominantly affects bottle-fed infants babies and Jagerstad, (1977) noted some 2,000 cases had been reported in the literature from 1945. There is no single dose/response relationship between nitrate level and infant methaemoglobinaemia and where careful epidemiological investigations have been conducted, other factors which influence infant morbidity rates have been found by Magee, (1982).

Hardness in water is important because most studies indicate an inverse correlation between the hardness of drinking water and the incidence of cardiovascular disease (heart disease, hypertension and stroke). Some of the studies indicate similar inverse correlation between the hardness of water and the risk from several non-cardio-vascular causes of death (Amavis, 1976). Fluoride, above 1.5 mg/l; yellow stains on the teeth may appear and at much higher levels bore fluorosis may occur. But a small about 1 mg/l in water may be needed to inhibit tooth decay (Tebbutt, 1985).

A number of the heavy metals in water are of great clinical concern due to the cumulating effect on human health. Lead, a cumulative poison causes kidney infection (nephritis). It may produce kidney tubular damage or a chronic interstitial nephropathy (Waldron, 1980). Lead is strongly suspected of producing subtle effect (i.e. effects due to low level or long term exposures insufficient to produce overt symptoms) such as impaired neurologic and motor development and renal damage in children (Train, 1979). Mercury poisoning causes weakening of muscles i.e. complaint of legs feeling weak followed by repeated fall, persistent pains in limbs, persistent headaches, disturbances of sight, difficulty with speech and history of rash. In severe cases, it

may cause complete blindness and paralysis which can result in coma and death (Al-Mufti *et al*, 1976). Mercury poisoning from organic derivatives is the most poisonous. For example Alkyl compounds are the derivatives of mercury most toxic to man producing illness, irreversible neurological damage or death from the ingestion of amounts in milligrams (Train, 1979). Generally mercury poisoning is known for the "Minamata" disease.

Chronic arsenic poisoning, according to Waldron (1980), occurs over a period of many weeks or months and, because of the similarity to many progressive disorders, may be difficult to diagnose unless suspected. A poisoned individual may have progressive symptoms and signs of loss of appetite, fainting, nausea and vomiting, dry throat, shooting pains, diarrhoea, nervous weakness, tingling of the hands and feet, jaundice and erythema of the skin (Reddened skin due to localized inflammatory process of the skin). Increased exposure results in dry, falling hair, brittle, loose nails, skin rashes, darkening of skin and hyperkeratosis (Excess lay down of keratin in the skin, which leads to hardening of the skin) on the palms and soles. Early observations of manganese poisoning demonstrated the occurrence of hyperkinesias (reduced mobility of the muscles), a kinesis (absence of movement of mobility), rigidity and tremor, and a mask-like face. These findings have been confirmed by a number of researchers (Waldron, 1980). Manganese poisoning has been reported in the general population by Kawamura *et al*, (1940) in individuals ingesting manganese in drinking water from a well near which manganese containing batteries had been buried.

Cadmium occurs in nature chiefly as a sulphide salt, frequently in association with zinc and lead ores. Accumulation of cadmium in soils in the vicinity of mines and smelters may result in high local concentrations in nearby waters. Seepage of cadmium from electroplating plants has resulted in groundwater concentrations of 0.01 to 3.2 mg/l (Train, 1979). The incubation period for chronic cadmium intoxicification varies between 5 and 10 years and some cases up to 30 years. During the first phase of poisoning, a yellowish discoloration of the teeth (cadmium ring) is formed, the sense of smell is lost and the mouth becomes dry. Subsequently, the red blood cells are reduced which results in impairment of bone marrow (Asiam, 1997). Once cadmium is absorbed, it is stored largely in the kidneys and liver and excreted at an extremely slow rate. Chronic kidney disease (renal tubular dysfunction) will begin to occur in an individual when the cadmium accumulated in the kidney reaches critical concentration level which varies from person to person (Train, 1979). It can therefore be seen that chemical contaminants in water could cause a real health problem. Furthermore, composition and concentration sometimes could be difficult to establish.

2.6 Sources of Water Supply

There are various sources and means by which water can be extracted for use by man for different purposes. Some of these sources are: Rivers and Lakes, Rainwater, Springs, Tube Wells and Hand-Dug Wells. The quality of the water from these sources depends very much on the nature and/or activities taking place at the source at the time of extraction.

Rivers and streams are often polluted, especially those passing through urban and industrialized areas and water from such sources would have to be treated before being used for drinking and other purposes.

Water from rainfall is most likely to be polluted by bird droppings. Hand-dug wells and tube wells can be polluted by contaminants in runoffs.

Water from all these sources will be good for consumption and other uses if it is from the right sources which are kept clean and monitored regularly.

That apart, certain laid down standards relating to the maintenance of clean water must be adhered to if water extracted from these sources is to be useful to man without any undesirable health problems.

2.7 Water Purification

For palatability, water obtained from natural sources should be free from unpleasant tastes, odours, must have a clear appearance and must be free from disease-spreading germs. The degree of treatment required depends on the quality of raw water and the enforcement of standards of quality. Purification processes could include sedimentation, filtration and disinfections.

Sedimentation is the process where discrete suspended particles in the water are allowed to settle down under the free force of gravity. It involves plain-sedimentation and the use of chemical coagulants to aid sedimentation.

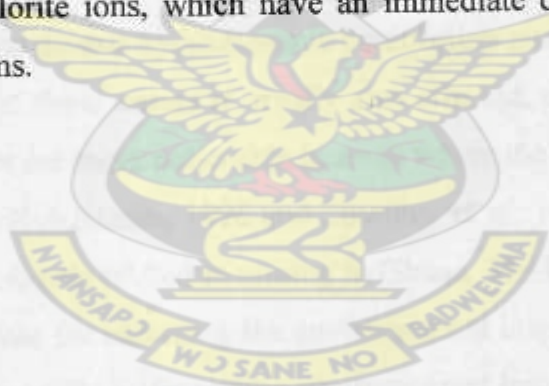
Santosh, (1996) and Birdie and & Birdie, (1996) listed the commonly used coagulants as follows:

Aluminum Sulphate ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$) commonly called alum, Sodium Aluminate ($\text{Na}_2\text{Al}_2\text{O}_4$), Ferric Chloride (FeCl_3) and Ferric Sulphate ($\text{Fe}_2(\text{SO}_4)_3$). Lime is also added as a flocculation aid.

Coagulation is by far the most widely used process to remove the substances producing turbidity in water (American Water Works Association, 1971). This was confirmed by Birdie and Birdie, (1996).

Filtration is the passage of fluid through a porous medium such as beds of sand or other granular materials to remove matter held in suspension (American Water Works Ass., 1971). Filters are used for the removal of bacteria, colour, taste, odours and producing clear and sparkling water.

The process of killing disease producing bacteria and making it safe to the user is called disinfection (Santosh, 1996; Birdie & Birdie, 1996). This generally follows filtration since filters are unable to remove all the disease causing bacteria. Chlorine has been found to be the best disinfectant widely used throughout the world. When chlorine is added to water, it forms hypochlorous acid or hypochlorite ions, which have an immediate disastrous effect on most forms of microscopic organisms.



CHAPTER THREE

STUDY AREA

3.1 Brief History

Gold mining has been associated with the (then) Gold Coast (the former name of Ghana) for several centuries. Between 1490 and 1600, the Gold Coast produced about 36% of the world's gold and before 1900 there were about 400 companies operating mainly in the southern part of the country (Junner, 1935; Kesse, 1985). The first unpublished private report on the gold fields around the Tarkwa area was by Collings, (1909), and several small and large holdings have existed until the beginning of the Second World War. Since the late 1980s, three large-scale open-pit gold mines, namely, Teberebie Goldfields Limited (TGL), Ghana Australian Goldfields (GAG) in Iduapriem and Goldfields Ghana Limited (GGL) have been operating in the Tarkwa area.

Mining causes distortions to the natural hydrodynamic equilibrium attained by both surface and groundwaters. The chemistry of these waters is usually also affected, especially with regards to surface waters and these effects are more noticeable in areas where the mine is located upstream or near communities. (Dzighodi-Adzimah, 1996 and Smedley *et al*, 1996) among others, have highlighted water pollution problems related to mining in Ghana. The Environmental Protection Agency (EPA) has a firm regime for enforcing the environmental laws of the country. There is also a greater awareness by the public in discussing environmental issues. One of the reasons for the increased awareness and participation of the public in the Tarkwa district is that surface mining has gained currency and has actually become the main mode of mining gold in the country. Consequently, the visual scars of mining are readily observed. There have been instances when these issues hit national headlines. For example, the partial failure of a tailings dam belonging to TGL gave rise to the release of cyanide-rich water in June 1997 into the Awunabeng stream. Another serious spill of cyanide-rich processing effluents breached a GGL tailings dam in October 2001, introducing cyanide into the River Essuman which provides drinking water to the villages of Abekoase and Huniso. Such mishaps have further deepened suspicion of the public concerning the operations of mineral mining, which they perceive as impacting negatively on the environment. Both GGL and GAG have constructed hand-pump wells for communities perceived to be in danger of drinking contaminated stream water.

However, due to the much-publicized environmental concerns in the media, some people are apprehensive of even drinking groundwater from the hand-pump wells provided.

GFGL began surface mining in 1998 and expanded its operations in Ghana by acquiring a portion of the Teberebie Goldfields Limited in 2000 and completely taking over Aboso Goldfields Damang mine in January 2002. Heap leaching, carbon-in-leach, electrowinning and zinc cementation are the main processing methods. Detoxification of low grade excess cyanide solutions is also practised. Discharge of the detoxified solution to the environment is done after all the polluting parameters are checked and are within the legal limits.

3.2 Location of Study Area and Geographical Characteristics

3.2.1 The Wassa West District

The Wassa West district occupies the mid-southern part of the western region of Ghana with Tarkwa as its administration capital. The population is about 236000 and is mainly composed of the indigenous Wassa tribe but all tribal entities in Ghana are well represented. Subsistence farming is the predominant occupation of the people although rubber, oil palm and cocoa are also produced. Mining is the main industrial activity in the area (Avotri *et al*, 2002). The area lies within the main gold belt of Ghana that stretches from Axim in the southwest to Konongo in the northeast (Kortatsi, 2004).

Gold Fields Ghana Limited is located in the Wassa West district of the western Region of Ghana, 6 km by road, and south of the town of Tarkwa. Access to the region is via the main road that links Tarkwa to the main shipping port of Takoradi to the south, and to the capital Accra, 240 km to the east. Currently, all supplies into the mine are transported by road and there is an airstrip for light aircraft, which allows easier access to the mine for key personnel as well as faster and more secure transportation of gold bullion. Fig 3.1 shows the location of the Tarkwa Mine.

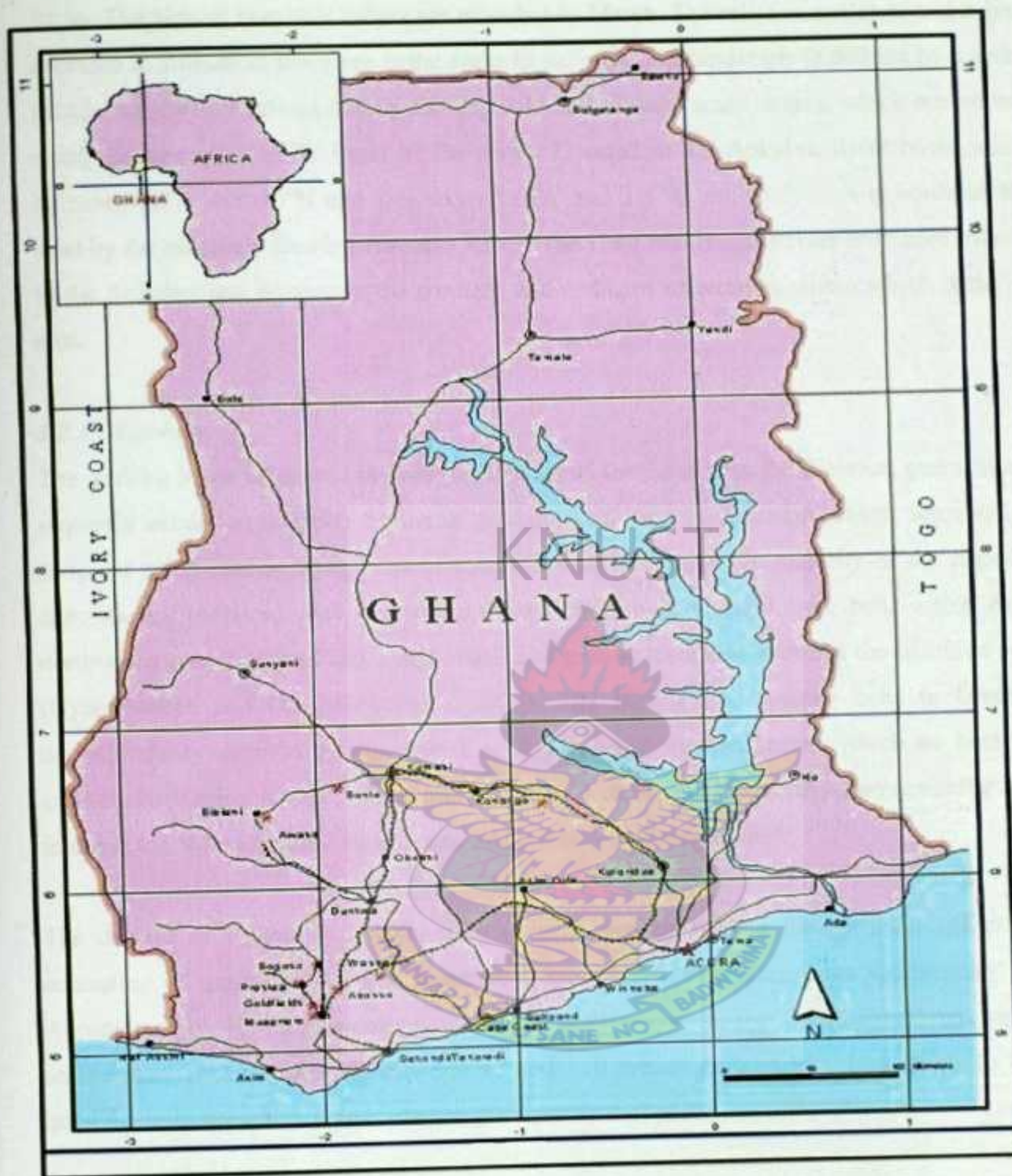


Figure 3.1 Map of Ghana Showing Location of Tarkwa

3.2.2 Topography and Climatic Conditions

A tropical and humid climate pertains in the Tarkwa area, which is located in the transition zone between the Rain Forest and Moist Semi-deciduous Forest in Ghana (Dickson and Benneh, 1980). A double maxima rainfall regime is experienced with average annual rainfall of over 1,750 mm. The major wet season is from April to July and September to November is the minor wet season. Daily temperatures are between 28–33 °C and relative humidity varies from 83 to

91 %. The highest humidity values are recorded in March. The relief is moderate and a general decrease in altitude to the south is the norm in the area. The landscape is defined by a series of parallel ridges and valleys due to pitching fold and dip-and-scarp slopes, which are orientated along the general NE-SW trend of the rocks. Located in the Ankobra River basin which is latitudes 4.8°N and 6.5°N and longitudes 1.6°W and 2.3°W, the study area is bordered to the west by the southerly flowing Ankobra River. The Huni and Bonsa Rivers are major tributaries to the Ankobra and demarcate the northern and southern extremities within which is the study area.

3.2.3 Geology

The Tarkwa Mine is located in Western Region of Ghana where, the Birimian greenstone belt sequence occurs as irregular basins of predominantly metasedimentary strata, separated by a series of north-east trending belts of metavolcanics on which the majority of the major gold deposits are clustered and a north-northwest striking belt, the Lawra belt, which extends northwards into Burkina Faso. Large masses of granite have also intruded the Birimian system (Gyau-Boakye and Dapaah-Siakwan, 2000). The Birimian greenstone belts in Ghana are unconformably overlain by Proterozoic aged Tarkwaian metasediments, which are host to the gold mineralisation at the Tarkwa mine. The style of the gold mineralisation is similar to that found in the Witwatersrand Basin, concentrated in conglomerate reefs.

The deposit at Tarkwa is composed of a succession of stacked tabular palaeoplacer units, consisting of quartz pebble conglomerates, developed within Tarkwaian sedimentary rocks. Approximately 10 such separate economic units occur in the concession area within a sedimentary package ranging between 40 and 110 meters in thickness. Low grade to barren quartzite units are interlayered between the separate reef units.

Granitoids of the Dixcove granitoids systems have also intruded the tarkwaian system in many places (Kortatsi, 2004). The rocks of the tarkwaian system consist of the Kawere group, the blanket series,

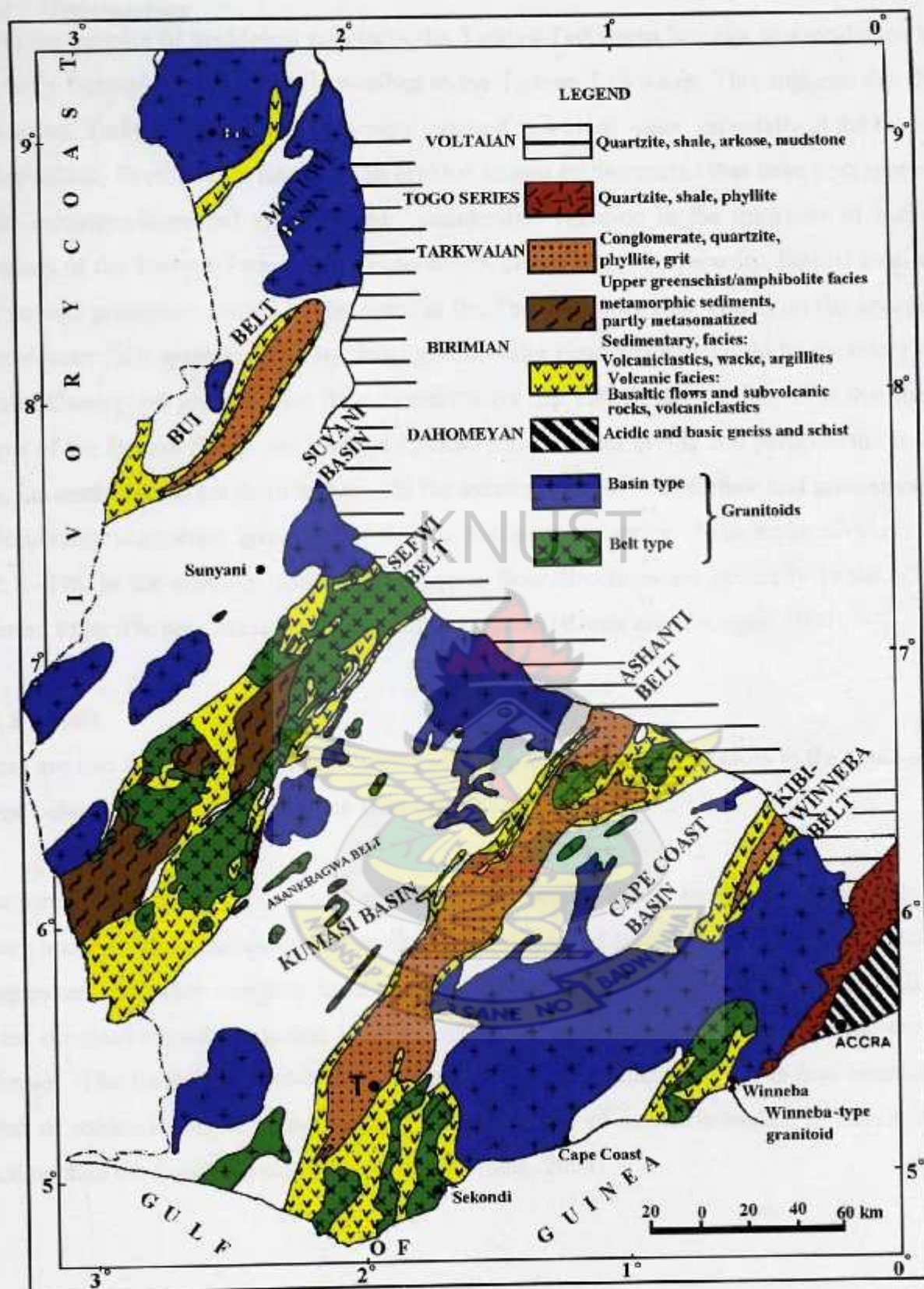


Figure 3.2 Geological Map of Ghana

the Tarkwa phyllite and the Huni Sandstone. Most of the rocks that resemble sandstone at the surface are weathered equivalents of parent quartzites (Kuma and Younger, 2001).

3.2.4 Hydrogeology

Using the concept of geological provinces the Tarkwa-Tarkwaian belongs to a sandstone basin. A wholly fluviatile environment is ascribed to the Tarkwa-Tarkwaian. This suggests that during deposition, Tarkwa- Tarkwaian rocks were exposed to a lot of water, especially at the beginning of deposition. Even though deposited in braided stream environments that have undergone low-grade metamorphism and are fractured, considerable variation in the thickness of individual members of the Tarkwa-Tarkwaian is expected. Aquifers with dual porosity, limited areal extent and storage properties should be the norm in the Tarkwa-Tarkwaian. Based on the grouping of groundwater flow systems made by, local groundwater flow systems should be prevalent in this terrain. Conceptual groundwater flow directions for the Tarkwa-Tarkwaian show that the twin ridges of the Banket Series and Tarkwa Phyllite form a water divide and partition the area into two, i.e. northern and southern sectors. On the assumption that both surface and groundwater are hydraulically connected, groundwater flow in the southern sector of the water divide is due S and S-SW. In the northern sector, groundwater flow directions are generally to the NW, but inferred to be SW near the nose of the Huniso syncline (Kuma and Younger, 2000).

3.2.5 Soils

There are two types of soils in the Tarkwa –Prestea area, the forest oxysols in the south and the forest ochrosols-oxysols in the north (Kortatsi, 2004).

The forest oxysols are porous, well drained and generally loamy brown to orange. Due to the heavy and plentiful rainfalls in the south, a high degree of leaching and reduction of calcium, magnesium and other nutrients have occurred in the soil. This has made the soil acidic. The forest ochrosol-oxysol integrated is an intermediate between the forest oxysols and the forest ochrosol. The forest ochrosol-oxysol integrated is highly coloured as it is less leached, as a result of reduced rainfall in the north. It contains more of its nutrients and is therefore more alkaline than the forest oxysols in the south (Kortatsi, 2004).

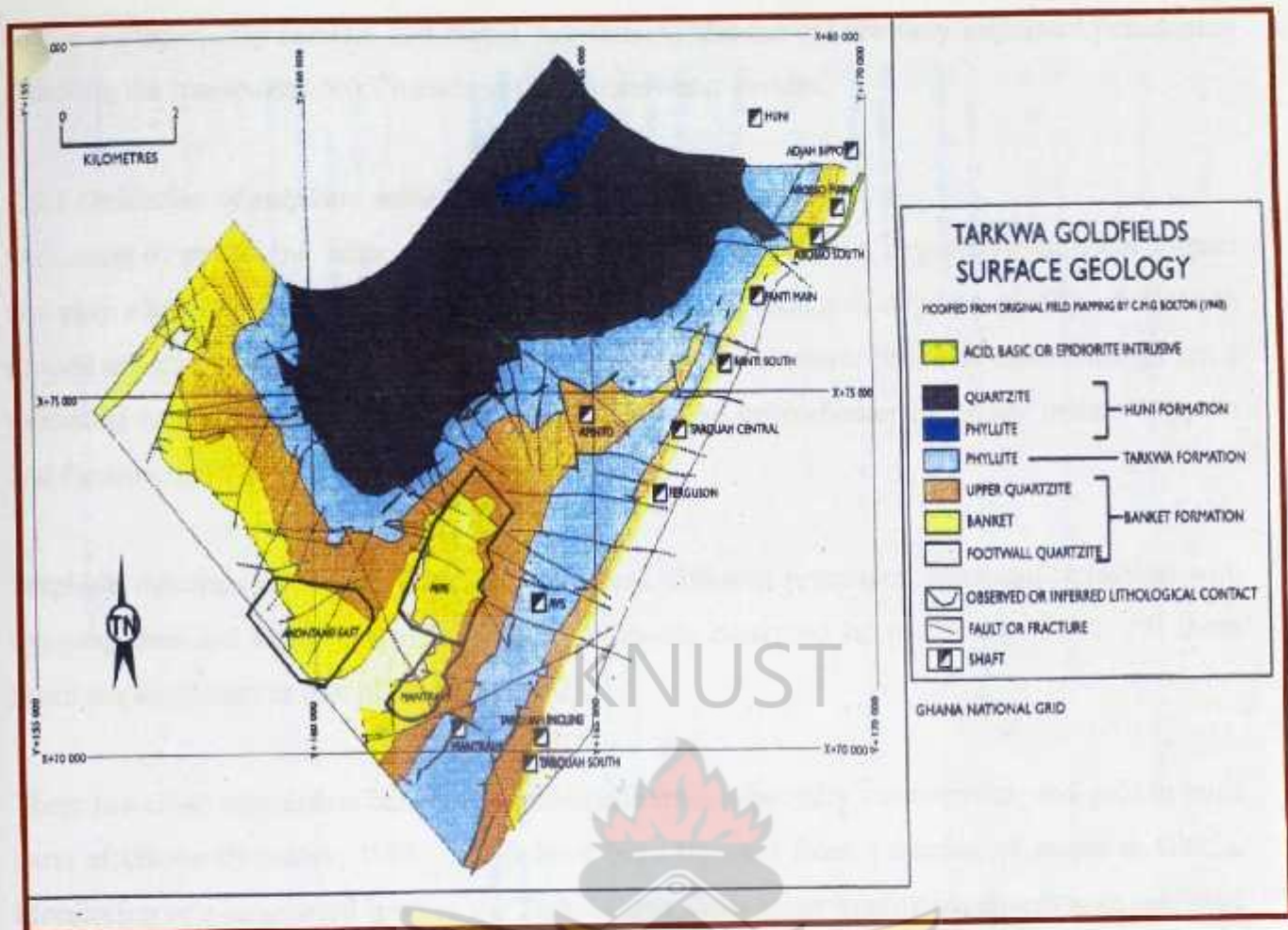


Figure 3.3: Surface Geology of Study Area (After SRK-EIS, 1996)

The soil in the Tarkwa area consists of mostly silty-sands with minor patches of laterite, mainly on hilly areas (Kuma and Younger, 2001).

3.3 Environmental geochemistry

The groundwater composition varies widely and is a combined result of the composition of the water entering the groundwater reservoir and the reactions with minerals present in the rock that may modify the water composition. Some minerals dissolve quickly and significantly change the water composition, like carbonates, others dissolve slowly and have less effect on the water composition, like silicates. The retention time is also important in determining the water chemistry. Long residence times allow reactions to take place and these waters are likely to have higher concentrations of ions than water with short residence time (Appelo & Postma, 1999). Usually in unaffected environments the concentration of most metals is very low and is mostly determined by the mineralogy and the weathering. There are a few examples of local metal pollution through natural weathering but in most cases metals become an environmental and health issue because of anthropogenic activity. Mainly mining and smelting plants release metals from the bedrock (Walker & Sibly, 2001). Soil concentration of adsorbing surfaces

(oxide surfaces, clay mineral and humic substances) and the pH are very important parameters affecting the transportation of metals in the groundwater system.

3.3.1 Oxidation of sulphide minerals and Acid mine Drainage

Oxidation of pyrite and other sulphide minerals by oxygen have a large environmental impact and play a key role in Acid Mine Drainage (AMD). It is a source of sulphate, acidity, and iron in groundwater and is a source of heavy metals in the environment. Sulphide mine tailings are a notorious source to contamination of both streams and groundwater by heavy metals (Appelo and Postma, 1999).

Sulphide minerals can be oxidized through three different processes: chemical oxidation with oxygen, chemical oxidation with Fe^{3+} and oxidation catalyzed by micro organisms. All these reactions accelerate at low pH (SEPA, 2002).

There is a close connection between sulphide minerals, especially arsenopyrite, and gold in most parts of Ghana (Smedley, 1996). AMD have been reported from a number of mines in Ghana. Monitoring of a large spoil heap in the Tarkwa area show water quality consistent with sulphate, silica, aluminium, iron and manganese and shows little variation during the year (Kuma, 2003).

The problems associated with AMD can therefore be expected in gold mining areas in Ghana. The pH levels of the groundwater in the Tarkwa Prestea indicate AMD. Acid rain and acid geothermal water cannot fully explain these low values (Kortatsi, (2004).

3.3.2 Factors affecting the mobility of heavy metals in the environment

Besides the metals man have created through nuclear reactions the rest have been on earth since the planet was formed (Walker and Sibly, 2001). The metals exist naturally in the bedrock and are released through weathering. In water, metals exist in different forms, both dissolved and suspended, depending on a number of different parameters. The solubility, transportation and toxicity differ between different metal species.

The transportation of metals with groundwater is normally affected by sorption to solid aquifer material (Appelo and Postma, 1999). The most important chemical retention mechanisms are sorption processes and precipitation.

Other chemical processes of importance are redox reactions and complexation. An increased aqueous complexation often makes an element more soluble, but the form is often less toxic. The redox status decides the speciation of some redox-sensitive elements. Different redox species have different retention capacity and the redox status is important for transport.

These mechanisms and the mobility of metals are affected by a number of different parameters e.g. the oxidation state of the metal ion, pH and Eh (Appelo and Postma, 1999). Determining the mobility of heavy metals is a very complex matter.

3.3.3 Major metallic contaminants related to mining

Several of the metals are essential to the human body. The metals are mainly utilized in enzymes to make them function properly. But we only need the metals in small quantities (WHO, 1996). Some of them we need as trace elements and some are non-essential for us. Calcium, sodium and magnesium are essential metals and cobalt, molybdenum, selenium, chromium, nickel, vanadium and silicon are added as trace metals. Mercury and cadmium are examples of non-essential metals (Walker and Sibly, 2001).

The term heavy metal is used for metals with a density more than 5 g/cm^3 (Walder and Sibly, 2001). Heavy metals important in environmental and health issues are for example Arsenic, Lead, Cadmium, Copper, Chromium, Mercury, Zinc, Cobalt, Nickel, Tin and Vanadium (SEPA, 2003). Those are not normally a part of the human body and are more poisonous to us than other metals (WHO, 1996).

Many metals can be stored in living tissue and remain there for a long time (SEPA, 2003). If a metal acts as a pollutant or becomes harmful to our health depends on both the properties of the metal and the environment it is acting in. Both humans and plants exhibit a big variation concerning both the need of essential metals and the sensitivity to non-essentials metals and to high levels of essential metals and trace metals. Some metals are harmful mostly to plants, for example zinc, nickel and chromium, and some mostly to animals, for example cadmium and molybdenum. Previous work in the Tarkwa area has mainly been conducted by Kuma and Kortatsi. Some of their results are presented in the section below.

3.3.3.1 Aluminium

Aluminium salts are widely used in water treatment as flocculants. An associated link between the Alzheimer disease and aluminium in drinking water has lately been suspected. The

associated link is not confirmed and more studies need to be conducted. The epidemiological and physiological evidence does not at present support a health-based guideline value for aluminium. However aluminium concentration levels of 0.2 mg/l have been suggested as a good compromise between practical use and caution (WHO, 1996). Previous studies show maximum levels in groundwater to be 2.51 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.22 mg/l (Kuma, 2004).

3.3.3.2 Arsenic

The results of available studies indicate that arsenic may be an essential element for several animal species, but there is no evidence that it is essential for humans. The level of arsenic in natural waters generally varies between 1 and 2 µg/l. Concentrations may be elevated, however, in areas containing natural sources, values as high as 12 mg/l have been reported. Inorganic arsenic compounds are classified as carcinogenic to humans. Lethal doses in humans range from 1.5 mg/kg to 500 mg/kg of body weight depending on the compound.

Early clinical symptoms of acute intoxication include abdominal pain, vomiting, diarrhea, muscular pain, and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping, and the appearance of a popular erythematous rash. Within a month, symptoms may include burning parasthesias of the extremities, palmoplantar hyperkeratosis, Mee's lines on fingernails, and progressive deterioration in motor and sensory responses. Signs of chronic arsenicalism, including dermal lesions, peripheral neuropathy, skin cancer, and peripheral vascular disease, have been observed in populations ingesting arsenic-contaminated drinking-water.

In view of reducing the concentration of arsenic in drinking-water, a provisional guideline value of 0.01 mg/l is recommended. The guideline value has been derived on the basis of estimated lifetime cancer risk (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.046 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.137 mg/l (Kuma, 2004).

3.3.3.3 Cadmium

Cadmium is chemically similar to zinc and occurs naturally with zinc and lead in sulphide ores. Cadmium concentrations in unpolluted natural waters are usually below 1 µg. Median concentrations of dissolved cadmium measured at 110 stations around the world were less than 1 µg/l. The maximum value recorded being 100 µg/l in the Rio Rimao in Peru. Food is the main

source of cadmium intake. Crops grown in polluted soil or irrigated with polluted water may contain increased concentrations, as may meat from animals grazing on contaminated pastures. The estimated lethal oral dose for humans is 350-3500 mg of cadmium; a dose of 3 mg of cadmium has no effects on adults. A guideline value for cadmium is calculated to 1.003 mg/l drinking-water (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.003 mg/l (Kortatsi, 2004) and maximum levels in surface water to be <0.05 mg/l (Kuma, 2004).

3.3.3.4 Chromium

Chromium is widely distributed in the earth's crust. In water, chromium(III) is a positive ion that forms hydroxides and complexes, and is adsorbed at relatively high pH values. The ratio of chromium(III) to chromium(VI) varies widely in surface of water. In general, chromium(VI) are more soluble than those of chromium(III), making chromium(VI) relatively mobile. The daily chromium requirement for Adult is estimated to be 0.5-2 µg of absorbable chromium(III). That equals to approximately 2- 8 µg of chromium(III) per day since only about 25% can be absorbed. The average concentration of chromium in rainwater is approximately 0.2-1 µg/l. Natural chromium concentration of groundwater is generally low (<1 µg/l). The natural total chromium content of surface water is approximately 0.5-2 µg/l and the dissolved chromium content 0.02-0.3 µg/l.

The health effects are mostly determined by the oxidation state. Therefore two different guidelines for chromium(III) and chromium(VI) should be derived. However, current analytical methods and the variable speciation of chromium in water favour a guideline value for total chromium. As a practical measure, the guideline is set to 0.05 mg/l, which is considered to be unlikely to give rise to significant risk to health (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.066 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.49 mg/l (Kuma, 2004).

3.3.3.5 Iron

Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day. In drinking-water supplies, iron(II) salts are unstable and are precipitated as insoluble iron(III)hydroxide, which settles out as a rust-coloured silt. Anaerobic groundwater may contain iron(II) at concentrations of up to several milligrams per liter without discolouration may develop in piped systems at iron levels above 0.05-0.1 mg/l, whereas levels

of 0.3-3 mg/l are usually found acceptable. As a precaution against storage of excessive iron in the body a provisional maximum tolerable daily intake was calculated to about 2 mg/l drinking water. That level does not present a hazard to health. The taste and appearance of drinking water will usually be affected below this level, although iron concentrations of 1-3 mg/l can be acceptable for people drinking anaerobic well-water.

No health-based guideline value for iron is proposed (WHO, 1996). Previous studies show maximum levels in groundwater to be 18.3 mg/l and maximum levels in surface water to be 4.01 mg/l (Kuma, 2004).

3.3.3.6 Lead

Lead is the most common of the heavy elements, accounting for 13 mg/kg of the earth's crust. More than 80 % of the daily intake of lead is derived from the ingestion of food, dirt, and dust. That means that an average of 5 µg/l lead intake from water forms a relatively small proportion of the total daily intake for children and adults, but a significant one for bottle-fed infants. Lead is a possible human carcinogen (evidence inadequate in humans, sufficient in animals) and it is also a cumulative poison so that any increase in the body burden of lead should be avoided. A provisional tolerable daily intake is set to 3.5 µg of lead per kg of body weight of infants are considered to be the most sensitive subgroup of the population, this guideline value will also be protective for other age groups (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.026 mg/l (Kortatsi, 2004) and maximum levels in surface water to be <0.05 mg/l (Kuma, 2004).

3.3.3.7 Manganese

Manganese concentrations above 0.1 mg/l impart an undesirable taste to drinking water. Even at about 0.02 mg/l, manganese will form coatings on piping that may later tear off as a black precipitate. When manganese(II) compounds in solution undergo oxidation, manganese is precipitated. Humans can consume as much as 20 mg/day without apparent ill effects. Manganese is believed to have a neurotoxic effect; a provisional health-based guideline value of 0.5 mg/l is proposed to protect public health (WHO, 1996). Previous studies show maximum levels in groundwater to be 1.3 mg/l and maximum levels in surface water to be 2.43 mg/l (Kuma, 2004).

3.3.3.8 Mercury

Almost all mercury in uncontaminated drinking water is thought to be in the form of Hg^{2+} . It is only the carbon-mercury bonds in organic mercury compounds that are chemically stable. The solubility of mercury compounds in water varies. Mercury (II) chloride is readily soluble; mercury (I) chloride is much less soluble. Mercury sulphide has a very low solubility and chemical mercury vapour is insoluble. Some anaerobic bacteria are capable of mercury methylation. Methyl mercury can then easily enter the food chain as a consequence of rapid diffusion and light binding to proteins. Environmental levels of methyl mercury depend on the balance between bacterial methylation and demethylation. Naturally occurring levels of mercury in groundwater and surface water are less than $0.5\mu\text{g/l}$. The WHO guideline value for total mercury is 0.001 mg/l . Previous studies show maximum levels in groundwater to be 0.037 mg/l (Kortatsi, 2004) and maximum levels in surface water to be 0.093 mg/l (Kuma, 2004).

3.3.3.9 Nickel

In aqueous solution, nickel occurs mostly as the green hexa-aquanickel(II) ion, $\text{Ni}(\text{H}_2\text{O})_6^{2+}$. The nickel ion content of groundwater may increase as a result of the oxidation of natural nickel containing ferrosulphide deposits. Oxidation can occur if the groundwater table is lowered or if nitrate has leached from the soil. Nickel concentrations in drinking water around the world are normally below $20\mu\text{g/l}$, although levels up to several hundred micrograms per liter in groundwater and drinking water have been reported. Leaching from nickel-chromium plated taps and fittings is also a factor. The nickel intake from food exceeds that of drinking water, even if a health-based guideline value for drinking water is calculated to 0.02 mg/l . That should provide sufficient protection even for nickel sensitive individuals (WHO, 1996). Previous studies show maximum levels in groundwater to be 0.076 mg/l (Kortatsi, 2004).

3.3.3.10 Nitrate and Nitrite

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. The nitrate ion (NO_3^-) is the stable form and it can be reduced by microbial action to a nitrite ion (NO_2^-) which is a relatively unstable oxidation state for the ion. It is the nitrite ion that constitutes the toxicity to humans. It is involved in the oxidation of normal haemoglobin to methaemoglobin, which is unable to transport oxygen to the tissues. Therefore the health guideline for nitrate-nitrogen is set to 10 mg/l . this value should not be expressed in terms of nitrate-nitrogen but as nitrate itself which is the chemical entity of health concern, and the guideline value for nitrate alone is therefore 50 mg/l (WHO, 1996). Previous studies show maximum levels in groundwater to be

(NO₃) 27.0 mg/l (Kortatsi, 2004) and maximum levels in surface water to be (NO₃) 60 mg/l (Kuma, 2004).

3.3.3.11 Sulphate

The presence of sulphate in drinking water results in a noticeable change of taste. The lowest taste threshold concentration for sulphate is approximately 250 mg/l. The physiological effects resulting from the intake of large quantities of sulphate are catharsis, dehydration, and gastrointestinal irritation. Water, containing magnesium sulphate at levels above 600 mg/l, acts as a purgative in humans. Sulphate may also contribute to the corrosion of distribution systems. Drinking water should not have sulphate levels exceeding 500 mg/l (WHO, 1996) Previous studies show maximum levels in groundwater to be 21.0 mg/l and maximum levels in surface water to be 490 mg/l (Kuma, 2004).

3.4 Environmental Impact Statement on Groundwater around Gold Fields Ghana Limited, Tarkwa Gold Mine (METAGO ENVIRONMENTAL ENGINEERS, 2007)

According to METAGO, (1997), there is no available information to indicate the quality of groundwater at the Tarkwa Gold Mine prior to the commencement of mining activities. Groundwater is extracted by GFGL Tarkwa Gold Mine to provide potable water for domestic purposes. In addition, local communities use groundwater from boreholes and hand dug wells. A number of boreholes and wells have been installed by GFGL at settlements on the Tarkwa lease in close proximity to the mine site.

3.4.1 Groundwater Levels

It is reported that there are two distinct, but hydraulically connected aquifers at the Tarkwa Gold Mine. Groundwater levels vary depending on the topography of the site. Rest levels vary from 5m below ground level where the topography is relatively flat at the site to up to 30m below ground level beneath the peaks. Swamp and lakes exist where the groundwater seeps out at the low points of the site. Groundwater either provides base flow to streams or rises as a spring.

Localized and manmade variations in groundwater levels and flows will result from the tailings storage facility (TSF) as a result of the water deposited with the tailings. The groundwater levels in the vicinity of the TSF will rise and flows may be locally reversed or diverted due to the head of pressure exerted by the facility.

3.4.2 Regional Flow Directions and Conceptual Groundwater Model

The regional flow directions are believed to follow the topography in the area. GFGL believe that the groundwater flow is generally from the east in a westerly/north westerly direction.

3.4.3 Background Water Quality

Boreholes that are considered by Metago, (1997), to be representative of background groundwater quality have been used to investigate the potential impact that mining infrastructure may be exerting on groundwater.

Groundwater monitoring borehole NBH02 was selected by Metago to represent background water quality as it was sufficiently far enough from the mining infrastructure as well as local communities (hence unlikely to be impacted from non-mining related activities). It is also located to the north of the North Heap Leach Pad and TSF, where the groundwater flow is believed to be in a west to north- west direction.

Samples of groundwater were analysed by SGS Laboratories in Accra for the same determinants as surface water samples. GFGL initially included analysis for TSS, but stopped in 2003 as TSS concentration rapidly declined in groundwater and high concentrations are likely as a result of contamination introduced from sampling.

The interpretation of data from monitoring of NBH02 focused on trends that may be observed for pH, TDS and CN^- .

The pH remains relatively constant with an average value of pH 6.6 with the exception of a peak in March 2005 to pH 8.2. The pH exceeded the minimum WHO Standard of pH 6.5 for 10 samples (minimum pH 5.8).

NBH02 – TDS

The average concentration of TDS in groundwater collected at NBH02 was 101 mg/l, with a maximum concentration of 152 mg/l, both well below the WHO Standard of 1000 mg/l.

NBH02 – CN^-

The free and total CN^- concentrations recorded for the groundwater collected from NBH02 were either at the limit of detection of 0.01 mg/l or below.

3.4.4 Groundwater Quality in the Vicinity of Existing Mining Infrastructure

Groundwater monitoring data in the vicinity of existing mine infrastructure at the Tarkwa Gold Mine was interpreted by Metago to determine if mining activities were impacting on the aquifers. GFGL have installed groundwater monitoring boreholes at the North Heap Leach Pad, South Facilities and TSF in order to monitor groundwater quality.

North Heap Leach Pads

The designation of groundwater monitoring boreholes at the North Heap Leach Pad is shown in Table 3.1 together with the original designation and the approximate locality (note NBH02 was used as the background comparison).

Table 3.1: Borehole Designation and Locality

CURRENT BOREHOLE DESIGNATION	OLD BOREHOLE DESIGNATION	LOCALITY
NBH01	P5	North west of heap leach pad (down gradient)
NBH02	P7	North east of heap leach pad (down gradient)
NBH03	Constructed 2006	North east corner of Phase 4 leach pad
NBH04	Constructed 2006	West of 'Chop House'
NBH05	P6	North of heap leach pad (down gradient)
NBH06	P4	West of containment pond
NBH07	P3	West of heap leach solution ponds
NBH08	P2	North west of TSF between heap leach and TSF (down gradient of TSF)
NBH09	Constructed 2006	West of excess solution pond
NBH10	P11	South of Pad 4 (North Heap Leach Pad)

Source: Metago PLC EIS Report-2006

To identify trends in the data, the interpretation of the results of monitoring pH, TDS, conductivity, Ca^{2+} , Alkalinity and sulphate were selected, based on the possible composition of process water (pH and TDS), the effect of borehole construction materials (Ca^{2+} and alkalinity) and the use of conservative species as tracers (TDS and SO_4^{2-}). Monitoring data was generally available from 2002.

General Groundwater Monitoring Trends.

It is unlikely that groundwater will be impacted by the heap leach pads, solution ponds and solution trenches as these facilities are all covered in an impermeable liner that will prevent liquid discharges occurring. In addition, each facility is fitted with leak detection systems to detect the presence of process solution lying between the two liners. There were no general trends observed in the individual boreholes to indicate impact from mining activity (e.g. increasing concentration of contaminants).

Data has been collected over a number of years which should allow identification of trends. However there are gaps in the data that reduce the reliability of any trends identified, and the lack of aquifer characterization make it impossible to determine contaminant transport and fate in the environment.

Other general trends identified were as follows:

- The pH exceeded the lower and upper WHO Standard occasionally at all monitoring points. Average pH values ranged from pH 5.6 at NBH08 to pH 7.8 at NBH05.
- The average TDS concentration was below the WHO Standard occasionally at all monitoring points.
- There is also close correlation between Ca^{2+} and alkalinity, where the alkalinity increases in close proportion to the Ca^{2+} (average proportionality factor is 4.24).
- All boreholes exhibited high concentrations of manganese (average concentration 1.2 mg/l, three times the WHO Standard of 0.4 mg/l) and maximum concentration 12 mg/l, (thirty times the standard) and Fe (average concentration 12mg/l and maximum concentration 109 mg/l).
- Free and total CN concentrations were either recorded at the limit of detection or below in boreholes NBH01, NBH03, NBH04, NBH05 and NBH08. Total CN concentrations above the limit of detection (but within WHO Standards) were recorded over a 5 year period as follows:
 - NBH06 – two samples (0.03 mg/l and 0.05 mg/l);
 - NBH07 – two samples (0.02 mg/l and 0.03 mg/l); and
 - NBH10 – one sample (0.02 mg/l).
- The pH was similar for all samples, with a peak occurring for all samples between December 2004 and March 2005.
- Low sulphate concentrations were observed in all samples (due to low sulphur concentrations in the host materials).

- The trace metals were generally found to be below the limit of detection or well within standard values. Fe and Mn were elements that were present at elevated concentrations, which are considered to be due to the geology of the area.

Comparison of TSF Water Quality

Sampling of the water in the TSF monitoring boreholes has been carried out since construction and quarterly analytical data is available from October 2004 to June 2006. Whilst this period of time was considered insufficient for the heap leach pads, the TSF is an unlined facility that will leach water as soon as deposition commences.

Spatial and temporal trends in the data provided were investigated to see how the borehole water composition varied over the time period of sampling. The identification of trends focused on the macro chemical parameters (pH, TDS, Ca, Na, Cl and SO₄) as the concentration of trace metals was close to or below the detection limit.

Seepage water quality data is compared against key process chemical elements indicative of CIL process water, specifically, Na, CN, conductivity and chloride (inert reference) to identify TSF seepage impacts in groundwater. It is recommended that sampling of these process water streams is carried out in future to the same analytical suite as current surface water samples. This will provide the initial composition of the water that can impact on surface and groundwater. The groundwater monitoring point NBH02 was selected by Metago to represent background groundwater quality.

Variation in Data across the TSF Sampling Boreholes

The results of analysis for the shallow and deep boreholes were reviewed to see if there were any similarities or trends between them. The following trends were observed.

- The average concentration of TDS was lower in all shallow borehole samples compared to the deep borehole samples as shown in Table 30 below;
- The average concentration of TDS generally increased from TSF1 to TSF4, peaking for the shallow aquifer in TSF3S and the deep aquifer in TSF2D; and
- Samples collected from TSF1S most closely resembled composition of water collected at NBH02, considered representative of the background water quality.

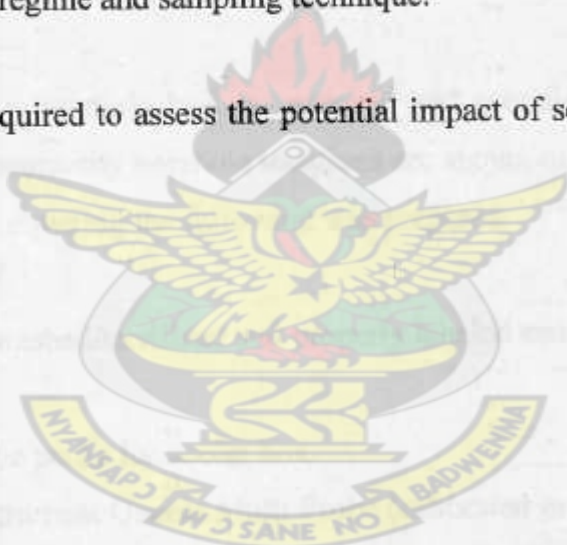
3.4.5 Variation between Borehole pairs

The variation between shallow and deep samples from the same borehole pairs did not show any conclusive trends. What is clear from the results is that the deeper groundwater samples show greater variability in data. The shallower groundwater samples correspond more closely with the water quality found in borehole NBH02.

Whilst there appears to be an increasing trend in TDS concentration in the boreholes from visual interpretation of the data points are all within 1 standard deviation suggesting variability rather than a trend.

The apparent decline in TDS is due to variability and is not a general trend for the boreholes. Further investigation will be required to determine the reason for the variability which may be a combination of factors such as meteorological conditions, soil and geological composition, variations in the groundwater regime and sampling technique.

Further monitoring will be required to assess the potential impact of seepage from the TSF on the groundwater.



CHAPTER FOUR

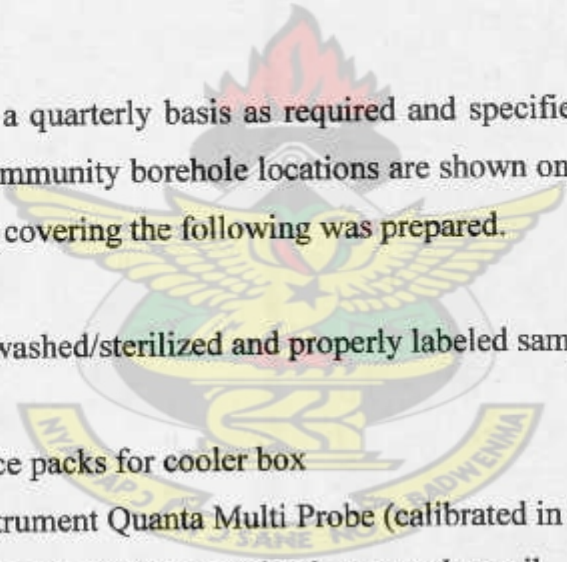
FIELDWORK AND LABORATORY INVESTIGATIONS

4.1 Fieldwork

Fieldwork was carried out by sampling sixty four community boreholes located in seven communities around the Northern section of the Gold Fields Ghana Limited Concession. The period for the sampling regime was from the year 2004 to 2005 and this formed the secondary data source for the research work whiles existing data for 2003 from the Environmental Department, formed the basis of the primary data used.

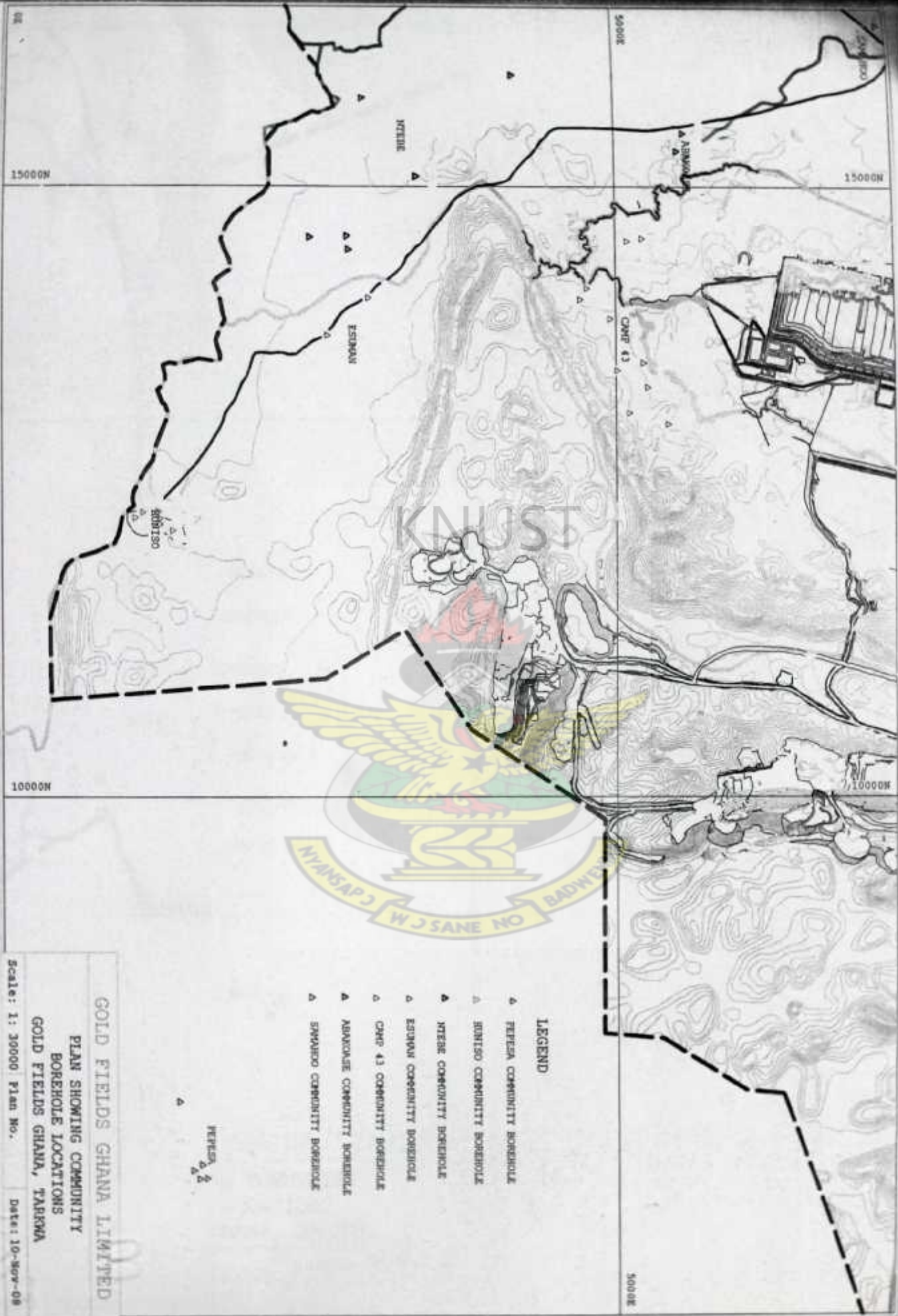
4.2 Sampling Regime

Sampling was carried out on a quarterly basis as required and specified by the Water Quality monitoring Procedure. The community borehole locations are shown on Figure 4.1. Prior to any sampling exercise, a checklist covering the following was prepared.

- 
- i. Adequate quantity of washed/sterilized and properly labeled sample bottles
 - ii. Cooler box
 - iii. Adequate number of ice packs for cooler box
 - iv. On-site measuring instrument Quanta Multi Probe (calibrated in the laboratory)
 - v. Sampling data recording sheet, field note book, pen and pencil
 - vi. Appropriate PPE in place (Hand gloves, gum boots, goggles, hard hat etc.)
 - vii. Wash bottle filled with distilled water
 - viii. Tissue paper
 - ix. Cleaning agents (methylated spirit)

4.2.1 Sample Bottle Preparation

The sample bottles used were all prepared in order to avoid contamination and several factors were taken into consideration:



LEGEND

- ▲ FERESA COMMUNITY BOREHOLE
- ▲ KUNISO COMMUNITY BOREHOLE
- ▲ NIEBE COMMUNITY BOREHOLE
- ▲ ESUNAN COMMUNITY BOREHOLE
- ▲ CAMP 43 COMMUNITY BOREHOLE
- ▲ ABANAKA COMMUNITY BOREHOLE
- ▲ SWANED COMMUNITY BOREHOLE

FERESA
▲ ▲

GOLD FIELDS GHANA LIMITED

PLAN SHOWING COMMUNITY
BOREHOLE LOCATIONS
GOLD FIELDS GHANA, TARKWA

Scale: 1: 30000 Plan No. Date: 10-NOV-08

All sample bottles were washed and sterilized before use. Washing/sterilization was done by the contract laboratory (SGS Laboratory).

One liter sample bottles were used. Sample bottles were clearly labeled with the descriptive code of every sample to be taken before leaving the office. Labels were created with permanent marker on white plastic bottles.

4.2.2 Sampling Procedure

During the sampling regime, the appropriately labeled sterilized bottle is kept air tight just before the sample was taken at the appropriate sample point. The following steps were undertaken to ensure representative and uncontaminated samples:

The borehole is pumped for water to flow for about 2 minutes to flush the pipeline followed by rinsing of the sample bottles thoroughly with the tap water for about 1 minute (3 times or more). The sample bottles were then filled directly, with water from the tap, leaving enough room to expel air before capping. The bottle is lightly squeezed to expel air before capping it (with gloves on). Gloves were changed after each sampling event to avoid contamination from fingers.

The samples are then placed in the cool box immediately to maintain a storing temperature of 4°C and then transported to the Environmental Department laboratory in the cool box to be stored in a refrigerator (set at 4°C) for storage until they are to be taken to the contract laboratory and submitted for analysis.

4.3 On Site Water Quality Measurements (Physical Parameters)

The Quanta Multi Probe instrument was used in the field to measure the pH, conductivity, Total Dissolved solids (TDS), temperature and dissolved oxygen of samples. The Quanta Multi Probe instrument was calibrated with standard solutions in the office before the monitoring exercise was undertaken. At the field sampling site, the equipment probes are removed from their housing case. A bucket is thoroughly rinsed and filled with sample from the borehole and the probe of the equipment immersed to read.

In order to avoid contamination, the probes were carefully rinsed from the wash bottle by squeezing distilled water out against the probes.

4.4 Sample Preservation, Storage & Analysis

The samples were preserved in accordance with monitoring procedures of GFGL, and are represented as follows:

Samples for total analysis of metals were preserved through acidification with 4 ml of concentrated nitric acid (70 %). Samples were then kept at a temperature of about 4°C until submission. For “dissolved” concentrations of metals no chemical preservation was required apart from samples to be kept at 4°C. Nitrate, Nitrite, Ammonia, Phosphorus, Oil & Grease – Sample preservation was accomplished through addition of 4 ml of analytical grade Sulphuric Acid to the sample volume of 1 liter and kept at a temperature of 4°C until submission. In the case of physical parameters and microbiological parameters (Coliforms, plate count), no chemical sample preservation was required. Samples were kept at a temperature of about 4°C and were submitted to the external laboratory within 24 hours after collection. All analyses were done by an external laboratory (SGS) except the physical parameters which were measured at sampling time to cross check returns from the laboratory.

4.5 Quality Control Samples

Quality control samples (duplicates and blanks) were taken monthly for Quality Analysis. For every monthly sampling event, two duplicate samples, one from South ADR Plant area and another from the North ADR Plant area were taken from monitoring bores or downstream surface water monitoring points and analyzed for all of the same parameters as the primary or original sample. Duplicate samples were taken at the same time as primary samples. Two blank samples of de-ionized water were prepared and submitted monthly to the external laboratory. One blank sample was analyzed for physical parameters, while the second for free and total cyanide. Labeling of the duplicate and blank samples was decoded.

4.6 Determination of Water Quality

Common analyses in the field of water quality are usually based on relative analytical principles. Quantitative analysis could be carried out by gravimetric, volumetric or colorimetric methods. Various types of electrode and automated techniques may determine certain constituents. Microbiological analysis is also employed for the determination of micro-

organisms in the water. These are the methods used to determine the various parameters in the samples sent to the external laboratory (SGS).

4.6.1 Gravimetric Analysis

This form of analysis depends upon weighing solids obtained from the sample by evaporation, filtration or precipitation. Because of the small weights involved, a balance accurate to 0.000/g is required together with a drying oven to remove all moisture from the sample. Its main uses are:

- **Total and Volatile Solids** - A known volume of sample in a pre-weighed dish is evaporated to dryness on a water bath, dried at 108 °C for potable water and weighed. The increase in weight is due to the total solids. The loss in weight on firing at 500 °C presents the volatile solids.
- **Suspended Solids (SS)** - A known volume of sample is filtered under vacuum through a pre-weighed glass fiber paper with a pore size of 0.45 µm (Micro meter). Total SS is given by the increase in weight after drying at 103 °C and volatile SS are those lost on firing at 500 °C.
- **Sulphate** - For concentrations above 10 mg/l it is possible to determine the sulphate by precipitating it as barium sulphate after addition of barium chloride. The precipitate is filtered, dried and weighed.

4.6.2 Volumetric Analysis

This technique depends on measurement of volumes of a liquid reagent of known strength. The requirements for volumetric analysis are:

- A pipette to transfer a known volume of the sample to a conical flask.
- A standard solution of the appropriate reagent. It is often convenient to make the strength of the standard solution such that 1ml of the solution is chemically equivalent to 1mg of the substance under analysis.
- An indicator to show when the end point of the reaction has been reached. Various types of indicators include electrometric, acid-base, precipitation, adsorption and oxidation-reduction.
- A graduated burette for accurate measurement of the volume of standard solution necessary to reach the end point.

4.6.3 Colorimetric Analysis

Colorimetric analyses are often particularly appropriate when dealing with low concentration and therefore are used for many determinations in water quality control which can quickly and easily be carried out by this form of analysis.

To be of quantitative use, a colorimetric method must be based on the formation of a completely soluble product with a stable colour. The coloured solution must conform to

- Beer's law (light absorption increases exponentially with the concentration of the absorbing solution), and
- Lambert's law (light absorption increases exponentially with the length of the light path).

These laws apply to all homogeneous solutions and can be combined as

$$OD = \log \frac{I_0}{I} = abc$$

Where:

OD	=	Optical density
I_0	=	Intensity of light entering sample,
I	=	Intensity of light leaving sample,
a	=	Constant characteristics of particular solution
b	=	Length of light path in solution
c	=	Concentration of absorbing substance in solution

(Tibutt, 1985).

The colour produced can be measured by a variety of methods.

4.6.4 Electrode Techniques

The pH is a measure of the amount of hydrogen ion in solution and can be measured by the potential produced by a glass electrode. The output from the pH electrode is fed to an amplifier and then to a meter or digital display. Some of which are extremely useful in water quality analysis.

An increasing number of specification electrodes for determinations such as NH_4^+ , NO_3^- , Ca^{2+} , Na^+ , Cl^- , Br^- , F^- , etc., are now available. These electrodes permit rapid measurements down to

low concentrations but they are relatively costly and in some cases their stability is not particularly high.

4.6.5 Microbiological Analysis

For larger micro-organisms like algae, estimation of number and actual identification of species can be achieved by using a special microscopic slide containing a depression of a known volume. Numbers are obtained by counting the appropriate micro-organisms in the chamber aided by a grid etched into the slide.

In estimating the number of living bacteria (viable cell count) in a water sample, a plate count using nutrient agar medium is used. About 1ml of the water, diluted if necessary, is mixed with liquefied agar at 40 °C in a petridish. The plate is then incubated under appropriate conditions (72 hr at 22 °C for natural bacteria, 24 ± 2 hr at 37 ± 0.5 °C for bacteria originating from animals or man). At the end of the incubation period, the individual bacteria will have produced colonies visible to the naked human eye and the number of colonies is assumed to be a function of the viable cells in the original sample.

To examine water sample for the presence of a specific pathogen, a more sensitive test is used which employs an indicator organism, an example is *E. coli*. Detection of coliforms can be achieved using a lactose medium inoculated with serial dilutions of the sample. The appearance of an acid and gas after $24 \text{ hr} \pm 2 \text{ hr}$ at 37 ± 0.5 °C is taken as a positive indication of the presence of coliforms bacteria, results being expressed with the aid of statistical tables as most probable number (MPN)/100ml. As a confirmatory test for *Escherichia coli*, positive tubes are subcultured in a fresh medium for 24hr at 44°C under which conditions only *E.coli* will grow to give acid and gas.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Acidity (pH)

The results of pH are presented in Table 5.1. It can be seen that the pH of samples was between 4.5 and 11.3. Out of the total samples of 359 studied over a three year period, 13 samples which represent 3.6% have pH above the EPA and WHO permissible limits (6 and 9 respectively) for potable drinking water. A few of the samples, representing 8.1% of the total samples have pH less than 6.0, being acidic. Therefore some of the boreholes in the host communities are not potable. For example, a sample around Abekoase, (ABK20) in particular, was found to be slightly acidic. The lowest values occurred in the month of March 2004 and September 2005 which are characterized by very dry periods (absence of rainfall within the last eight days of rainfall. Refer to Appendix 1 for rainfall data of the area).

The Camp 43 area also recorded anomalies in the samples with the most significant ones at C27 and C32 with values of 11.0 during the month of October 2003. C30 and C31 in the same area recorded values of 5.9 and 9.9 respectively.

The Huniso Community wells were found to have pH ranging from 4.7 to 11.3. HNSO16, HNSO12 and HNSO11, recorded values of 4.7, 4.9 and 5.8 respectively. These wells are located at the center of the Community and the sampling period was in the rainy season with a monthly rainfall value of 280.4mm. Well HNSO-Clinic had a value of 11.0; the high pH may be due to the effect of cement because the samples were taken just after its construction.

The Ntebe wells also showed slight acidic values in the range of 5.5 to 5.8, which by the WHO and EPA Standards (6-9) is not healthy for drinking. All the low values were samples taken in June 2003 and in December 2003. December 2003 was very dry whiles June was marked by high rainfall levels.

The Pepesa area recorded few high pH values (11.1) but it could be observed that those values were recorded at the early stages of the well construction; the high pH could be due to the cement used for the construction. In the Samahu area, only well SMHU exhibited low pH values

from 2003 to 2004 but the values were normalized in the year 2005. It could be noticed that a bund was constructed around the well to prevent runoffs from seeping into the well. Since cement increases the pH of water in the wells, it will not be advisable to use the well water soon after its construction. Some time should be given for the cement to cure properly.

5.2 Total Dissolved Solids (TDS)

Total Dissolved Solids were between 0.3 mg/l and 2125 mg/l. Well SMHU24 located at Samanhu had values between 1062 mg/l and 2125 mg/l, well above the EPA and WHO guidelines of 1000 mg/l for potable drinking water. Figure 5.1 gives the variation of TDS between 2003 and 2005 for SMHU24.

In contrast, there are general low TDS values for the other wells; hence there is the need for detailed investigation on well SMHU24.

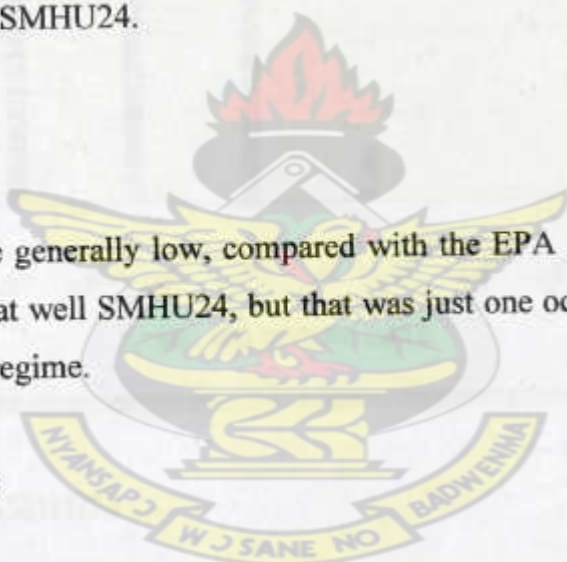
5.3 Conductivity (EC)

The conductivity values were generally low, compared with the EPA standard of 1500 $\mu\text{S}/\text{cm}$. The only deviation occurred at well SMHU24, but that was just one occurrence of 2290 $\mu\text{S}/\text{cm}$ in December 2004 sampling regime.

5.4 Chemical Parameters

Nitrate levels monitored at Huniso were extremely high. In general, the values range from a low value of 0.23 mg/l to a high value of 455.6 mg/l, as against the WHO guidelines of 10 mg/l and EPA guideline of 50 mg/l. Out of the 312 samples analyzed, 98 exceeded the WHO guideline limit for drinking water (representing 31.8 % of the total samples), while 25 exceeded the EPA standards (representing 8.1 % of the total samples).

Cyanide concentrations were at the detection limit or very negligible.



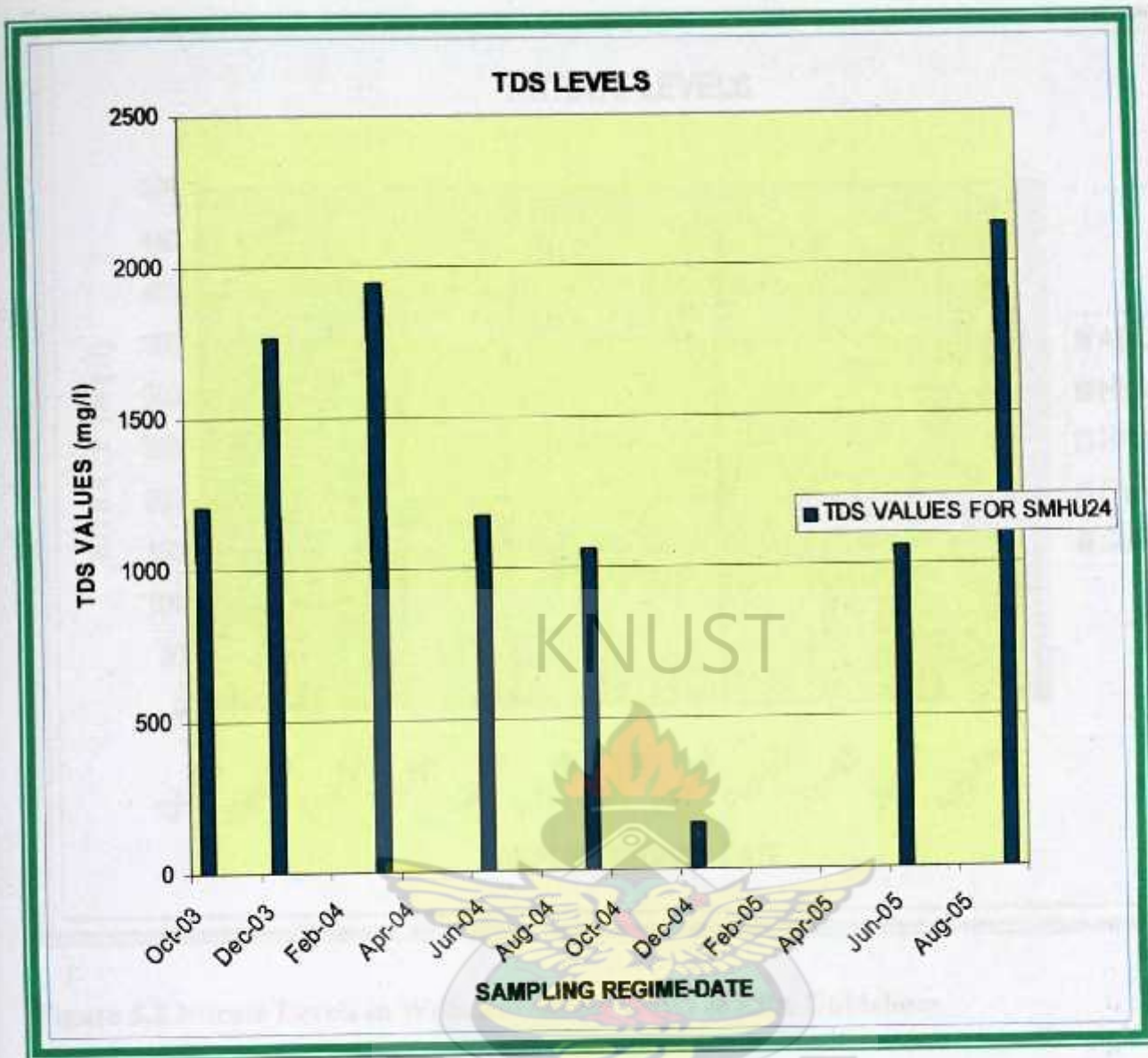


Figure 5.1 TDS Values for SMHU24

The Communities with nitrate anomalies are Abekoase (well ABK20), Huniso (wells HNSO 12, 14, 15, 16), Samanhu (wells SMHU 24 and 25) and Pepesa (PSA 5, 6, 7, 8, and 9). Figure 5.2 gives levels of nitrate in the Community wells. A detailed investigation is required in this area to ascertain the main source of nitrate levels.

Nitrite values were negligible with 97 % below the detection limit. Sulphate values detected ranged from an insignificant value of 0.1 mg/l to a high value of 206.9 mg/l as compared to the EPA standard of 200 mg/l for drinking water.

NITRATE LEVELS

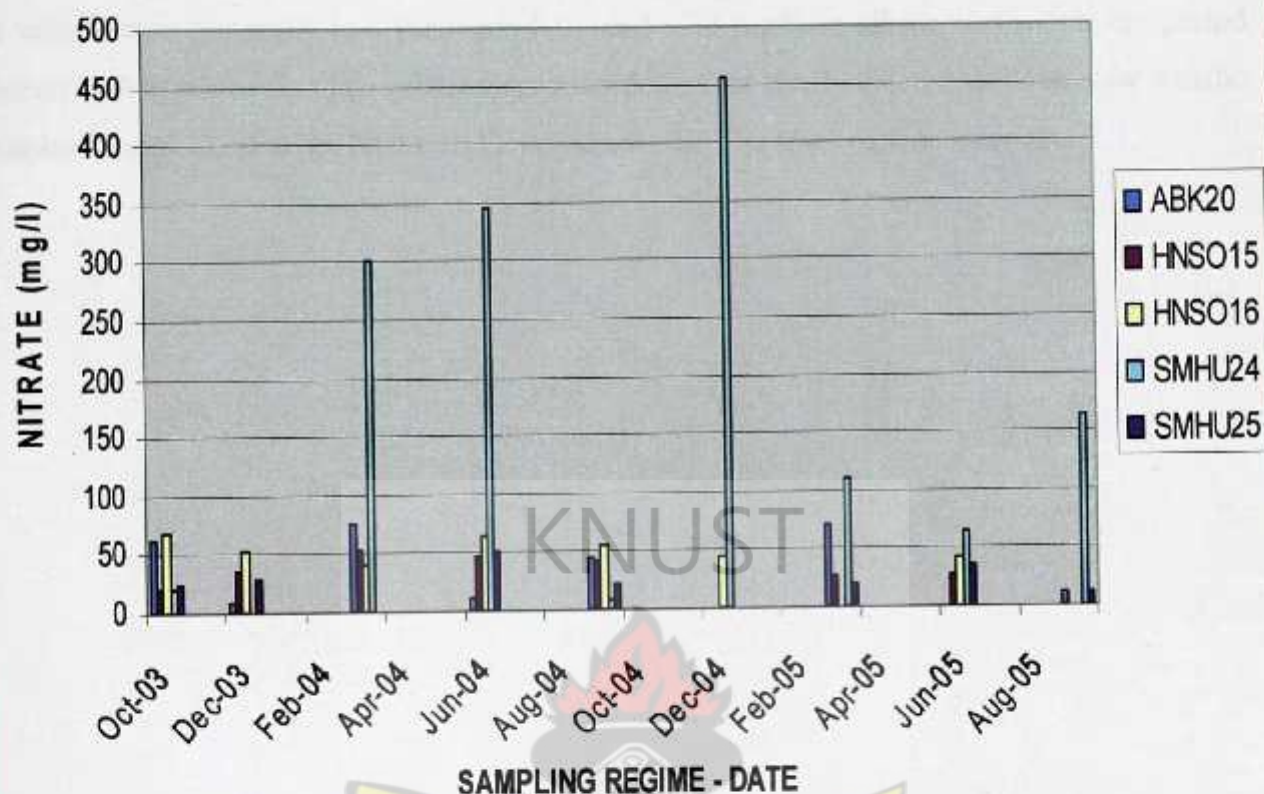


Figure 5.2 Nitrate Levels in Wells Exceeding WHO & EPA Guidelines

It is noted that, only two samples exceeded this limit and all the high values were from a single well, SMHU24, which is located at Samanhu. Sulphate contamination is therefore not an issue here. The values were between 123.8 mg/l and 236.7 mg/l.

Chlorides, which when in excess in drinking water basically affect the taste was also observed to be low from the results of the analysis.

5.5 Metals Analysis

High values of Manganese were recorded mainly in the Huniso wells. The values at Huniso exceeding the WHO guideline of 0.33 mg/l ranged from 0.37 to 3.58 mg/l. A few anomalies were recorded in the Samanhu area (SHMU24 and SHMU22) as well as at Ntebe (NTB4). Early studies carried out on the underlain rocks indicate high value of manganese. These levels may be attributed to weathered phyllites in the area which were identified from debris dug.

However, the levels of manganese at Huniso should be further investigated to find the exact source of the anomalous.

Iron values were generally low (between 0.01 and 17.4 mg/l) in all the wells over the period. However, a few relatively high values were recorded in the newly created wells at New Atuabo, Samanhu, Camp 43, Huniso, Ntebe and Essuman wells. The level of zinc was low.

KNUST



TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 to 2005

DATE	REF	DESCRIPTION	pH	TDS	Conductivity 1825(us/cm)	DO	TH	Alkalinity	Ca++	Mg++	Na+	K+	Cl-	NO ₃ -N	NO ₂ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
			6.5 - 8.0	1000			500						250	50	-	2	200	10	0.1	5	10
EPA EFFLUENT DISCHARGE GUIDELINES MINING																					
23-Oct-03	E4478	ABK20	6.2	435	70.5	6.2	184.8	107	59	9.1	37	47	57	69.7	0.04	<0.01	20.6	0.05	0.16	<0.01	0.13
21-Dec-03	E4576	ABK20	7.5	178	29.4	1.4	147.8	145	57.7	0.9	5.2	6.2	0.5	0.9	<0.01	<0.01	0.25	0.08	<0.01	<0.01	0.57
16-Mar-04	E4730	ABK20	5.2	65	8.2	7.5	12.8	3	3.3	1.1	9.4	0.3	7.4	11.1	<0.01	<0.01	<0.1	2.73	0.08	0.01	0.1
15-Jun-04	E4912	ABK20	6.9	367	300.0	4.3			42	7.6	34	39	32.2	75.1	0.05	0.01	28.5	0.17	0.12	<0.01	0.14
20-Sep-04	E5085	ABK20	8.8	395.0	0.5	4.0			43.3	7.7	39	45	44.6	45.3	0.07	0.01	36.8	0.23	0.14	<0.01	0.1
16-Mar-05	E5417	ABK20	8.6	100	122.0	0.9	27.7	16.4	8.8	1.4	14	0.9	21.8	7.76	<0.01	<0.01	2.4	0.13	0.09	<0.01	0.1
14-Jun-05	E5612	ABK20	8.0	433.0	64.6		113.2	52	31	8.7	34	49	41.4	61	<0.01	<0.01	35.1	0.21	0.09	0.01	<0.01
18-Sep-05	E5830	ABK20	5.8	105	11.7		22.2	9.2	69	1.2	12.2	0.8	13.7	11.8	0.01	0.01	0.1	0.14	0.08	0.01	0.1
29-Dec-05	E6036	ABK20	6.9	42	7	7.8	25.4	26.5	9.5	0.4	3.4	0.7	5.9	0.21	<0.01	<0.01	3.3	0.37	<0.01	<0.01	0.13
28-Oct-03	E4476	ABK21	6.7	151	28.2	4.5	121.8	133.2	47.3	0.8	6.4	11	0.5	1.5	<0.01	<0.01	<0.1	0.02	<0.01	<0.01	0.03
21-Dec-03	E4576	ABK21	6.6	247	36.3	1.1	110.6	88	38.7	3.4	24	13	27	42.4	0.12	<0.01	2.8	0.06	0.16	<0.01	0.08
16-Mar-04	E4730	ABK21	7.3	92	13.2	8.5	60.3	66	20.7	2.1	4.9	1.2	3	0.84	0.01	<0.01	<0.1	0.32	0.07	<0.01	0.05
15-Jun-04	E4912	ABK21	7.4	149	100.0	8.3			35	1.2	4.8	3.4	0.5	0.57	<0.01	<0.01	3.2	0.09	0.06	<0.01	0.04
20-Sep-04	E5085	ABK21	6.8	88.0	0.2	3.8			26.8	0.8	4.2	1.6	0.5	0.4	<0.01	<0.01	0.5	0.21	0.08	<0.01	<0.01
16-Mar-05	E5417	ABK21	8.7	24	63.0	1.0	34.8	46.8	10.8	1.9	5.9	1.4	7.7	0.3	<0.01	0.07	<0.1	0.05	0.05	<0.01	0.05
14-Jun-05	E5612	ABK21	6.1	103.0	15.9		64	65.3	24.3	0.8	4.9	1.7	5.4	0.86	<0.01	<0.01	<0.1	0.08	0.02	<0.01	<0.01
18-Sep-05	E5830	ABK21	6.3	58	6.8		18.5	28.2	4.1	2	7	0.8	2	0.04	0.01	0.01	0.1	0.38	0.02	0.01	0.12
29-Dec-05	E6036	ABK21	6.9	251	35.8	7.9	69	32.7	20.2	4.5	28	28	32.9	58.4	0.04	<0.01	10	0.44	0.14	<0.01	0.02
15-Jun-04	E4912	ABK21B	7.2	307	300.0	5.2			59	1.2	6.7	2.7	83.4	9.29	<0.01	0.01	6.1	5.24	0.04	0.66	2.01
20-Sep-04	E5085	ABK21B	7.1	128.0	0.2	3.8			42.8	0.7	5.4	2.5	0.5	0.65	<0.01	<0.01	2.8	0.87	0.08	<0.01	<0.01
15-Dec-04	E5417	ABK21B	7.8	100	126	2.7	59.4	70.9	22.3	0.9	8.7	4.7	5.5	2.11	0.02	0.04	11.1	4.91	0.09	0.82	16.3
18-Mar-05	E5612	ABK21B	8.5	100	163.0	0.9	40.9	39.5	15.4	0.6	3.5	0.9	6.7	0.25	<0.01	<0.01	3.2	0.54	<0.01	<0.01	<0.01
14-Jun-05	E5830	ABK21B	6.0	78.0	10.6																
29-Dec-05	E6036	ABK21B	6.8	52	8.5	7.3	34.9	34.1	12.5	0.9	4.1	0.5	3.4	0.95	<0.01	0.01	<0.1	0.38	<0.01	<0.01	0.03
28-Oct-03	E4476	C27	10.7	854	152.0	3.2	205.5	371	82.3	<0.01	18	20	3.4	1.88	0.03	<0.01	0.7	0.02	<0.01	<0.01	<0.01
21-Dec-03	E4576	C27	11.0	937	158.0	3.0	269.4	376	103.7	0.1	16	28	4.9	0.02	<0.01	<0.01	1.3	0.02	<0.01	<0.01	<0.01
18-Mar-04	E4730	C27	7.8	121	20.2	6.0	73.2	103	28	0.6	5.3	6.2	1.5	0.04	0.03	<0.01	0.9	0.7	0.04	4	0.19
15-Jun-04	E4912	C27	7.8	195	140.0	5.7			59	0.6	5.2	5.1	2.4	0.06	0.03	0.02	3.5	0.44	0.03	<0.01	0.03
20-Sep-04	E5085	C27	7.5	164.0	0.3	2.8			50.3	0.7	6.7	4.4	2.3	0.13	0.01	<0.01	1.3	1.12	0.03	<0.01	<0.01
15-Dec-04	E5417	C27	8.1	200	313	3.1	150.5	156.9	58.3	0.6	4.4	2.8	3.5	0.46	0.04	0.01	2.4	0.28	<0.01	<0.01	<0.01
16-Mar-05	E5612	C27	8.5	200	350.0	5.9	150.2	157.6	58	0.7	5.1	2.2	0.5	0.41	<0.01	<0.01	3.4	0.56	<0.01	<0.01	<0.01
14-Jun-05	E5830	C27	7.4	199.0	33.4		120.7	152.2	47	0.8	4.2	2	2	0.41	0.01	0.01	1.8	0.46	0.01	0.01	0.02
29-Dec-05	E6036	C27	7.3	185	31.1		104.5	133.8	40.7	0.7	4.1	1	2.6	0.22	<0.01	0.02	1.2	0.79	0.02	<0.01	0.03
28-Oct-03	E4476	C28	7.9	150	27.5	3.1	74	77	28	1	3.4	2.7	0.5	3.53	0.02	<0.01	4.9	0.8	0.01	<0.01	0.06
21-Dec-03	E4576	C28	6.3	136	17.9	6.0			28.6	1.1	3.4	1	0.5	2.54	<0.01	<0.01	1.9	0.22	<0.01	<0.01	0.3
16-Mar-04	E4730	C28	6.8	90	17.3	2.3	75.9	81	10.1	0.8	7.5	0.8	3	0.76	0.01	<0.01	2.5	0.22	0.06	<0.01	0.07
15-Jun-04	E4912	C28	7.0	78	9.8	6.8	28.5	37	18.9	0.9	3	1.5	0.5	0.08	0.01	0.01	7.3	0.9	0.03	<0.01	0.08
20-Sep-04	E5085	C28	6.9	76	50.0	7.5			43.3	0.7	3.1	1.3	0.5	0.04	<0.01	<0.01	4.3	0.32	0.01	<0.01	0.44
15-Dec-04	E5417	C28	6.9	91.0	0.0	2.7															
16-Mar-05	E5612	C28	7.5	100	145	4.2	74.4	82.3	28.3	0.9	3.6	1.6	0.5	0.02	<0.01	<0.01	3.9	0.11	0.09	<0.01	0.04
14-Jun-05	E5830	C28	8.6	0	2.0	5.0	44.4	98.2	16.3	0.9	2.7	0.9	4.4	<0.01	<0.01	0.06	6.2	0.32	0.01	0.01	<0.01
18-Sep-05	E6036	C28	6.6	104.0	22.8		62.8	69.7	24	0.7	3.7	1.4	0.5	0.01	0.01	0.01	3	0.02	0.01	0.01	0.09
29-Dec-05	E6036	C28	6.8	97	15.4		65.5	65.6	24.9	0.8	2.5	0.8	4.4	0.73	<0.01	0.03	4.3	0.38	<0.01	<0.01	0.07
			7.4	90	14	7.7															

Table 5.1: Physical Parameters

TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 to 2005

DATE	REP	DESCRIPTION	pH	TDS	Conductivity 1800(us/cm)	DO	TH	Alkalinity	Ca++	Mg++	Na+	K+	Cl-	NO ₃ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
25-Oct-03	E476	C29	8.9	152	26.8	3.4	83.7	123	30.4	1.9	16.0	10	1	4.65	<0.01	<0.1	0.09	<0.01	<0.01	<0.01
25-Oct-03	E476	C29	7.1	165	31.7	2.7	109.4	150	38.7	3.1	9.3	2.5	2	0.21	<0.01	<0.1	0.43	0.08	<0.01	<0.01
21-Dec-03	E476	C29	7.2	159	20.6	5.0	83.6	104	26.7	4.1	9.1	1.6	6.9	0.68	<0.01	<0.1	0.2	0.02	<0.01	0.17
16-Mar-04	E4812	C29	7.5	170	120.0	7.5			38	2	8.6	3.8	2.9	0.85	0.01	6.4	1.2	0.07	<0.01	0.09
15-Jun-04	E4812	C29	7.1	140.0	0	2.64			50.3	2.1	8.6	14.6	2	<0.01	<0.01	3	1.79	0.12	<0.01	<0.01
20-Sep-04	E4812	C29	8.3	200	244	3.3			32.3	3.7	9.3	1.2	2	<0.01	<0.01	1	0.45	0.1	<0.01	0.09
16-Dec-04	E4812	C29	9.6	200	230.0	4.6			12	1.7	8.8	1.4	4.9	<0.01	<0.01	0.9	0.8	<0.01	<0.01	<0.01
16-Mar-05	E4812	C29	8.1	96.0	10.5		37	43	24.1	4.3	9.9	1.1	2	0.09	0.01	0.1	0.11	0.01	0.01	0.17
14-Jun-05	E4812	C29	6.9	161	20.6		77.9	94.9	24.1	3.2	8.8	1	2.5	0.57	0.01	2	0.58	0.02	<0.01	0.07
16-Sep-05	E4812	C29	7.4	169	25.2	7.2	92.3	119.9	31.7	3.2	8.8	1	2.5	0.57	0.01	<0.1	0.08	0.05	<0.01	0.13
25-Dec-05	E4812	C30	6.9	144	19.9	4.0	61.7	94	21.9	1.7	19.0	1.1	2.5	1.14	<0.01	<0.1	0.12	<0.01	<0.01	0.19
28-Oct-03	E4812	C30	6.5	137	18.5	6.1	61.1	82	19.2	3.2	17	0.9	3.4	0.01	0.06	<0.1	0.12	<0.01	<0.01	<0.01
21-Dec-03	E4812	C30	7.0	156	18.7	6.0	61.1	89	19.7	2.9	17	1.1	8.4	0.08	0.01	<0.1	0.31	0.06	<0.01	0.14
16-Mar-04	E4812	C30	6.9	143	100.0	5.2	29.6	85	20.3	2.8	15	0.9	2.9	<0.01	0.04	3.2	0.27	0.1	<0.01	<0.01
15-Jun-04	E4812	C30	6.6	134.0	0	2.7			23.3	2.8	19.0	1.0	2.0	<0.01	0.12	1.9	0.26	0.11	<0.01	<0.01
20-Sep-04	E4812	C30	7	100	170	3.3			24.7	2.8	15	1.1	2.5	<0.01	0.09	0.5	0.48	0.13	<0.01	0.09
16-Dec-04	E4812	C30	8.6	100	204.0	5.0	73.2	90.9	19.8	2.8	15.0	0.9	1.0	<0.01	0.11	<0.1	0.17	0.05	<0.01	<0.01
16-Mar-05	E4812	C30	6.2	120.0	17.8		61	75	19.8	2.8	15.0	0.9	1.0	<0.01	0.11	<0.1	0.17	0.05	<0.01	<0.01
14-Jun-05	E4812	C30	8.7	152	18.4		60.4	80.9	18.9	18.9	3.2	13.4	1.1	4.4	0.01	0.18	0.28	0.04	0.01	0.05
16-Sep-05	E4812	C30	7.2	161	18.1	7.4	85.4	82.5	29.1	3.1	15	0.9	3.4	0.58	0.01	0.17	0.1	<0.01	<0.01	0.05
29-Dec-05	E4812	C31	7.0	168	22.1	3.4	39.4	66	14.3	0.9	15.0	26	3	51.2	7.14	<0.01	1.7	0.25	<0.01	0.02
28-Oct-03	E4812	C31	9.8	154	27.6	6.1	29.6	85	11.2	0.4	13	15	4.4	1.08	0.81	0.01	0.06	0.01	<0.01	0.01
21-Dec-03	E4812	C31	7.8	171	150.0	6.1			41	0.3	6.7	8.3	0.5	<0.01	0.03	4.8	0.08	0.05	<0.01	0.02
15-Jun-04	E4812	C31	7.3	161.0	0.289	2.88			52.3	0.4	5.8	5.4	0.5	2.03	0.02	<0.01	2.6	0.23	<0.01	0.18
20-Sep-04	E4812	C31	8.1	200	670	3.7			47	0.7	3.5	2.3	0.5	<0.01	<0.01	<0.1	0.01	0.07	<0.01	0.02
16-Dec-04	E4812	C31	8.8	200	277.0	5.2	120.2	138	49	0.6	4.5	3.1	0.5	2.02	<0.01	0.3	0.05	0.03	<0.01	<0.01
16-Mar-05	E4812	C31	7.1	169.0	29.8		124.8	136.8	49	0.6	4.5	3.1	0.5	2.02	<0.01	0.3	0.05	0.03	<0.01	<0.01
14-Jun-05	E4812	C31	7.5	166	28.3		110.3	137.4	43	0.7	4.1	2.4	0.5	1.63	0.01	1.4	0.14	0.01	0.01	0.06
18-Sep-05	E4812	C31	7.8	164	29	7.4	106.6	138.7	41.7	0.6	6.1	3.1	2.9	2.63	0.01	4.7	0.24	<0.01	<0.01	0.05
29-Dec-05	E4812	C32	8.1	148	19.0	4.1	52.7	76	18.8	1.4	13.0	17	0.5	44.3	3.91	<0.01	2.2	0.42	<0.01	0.02
28-Oct-03	E4812	C32	11	935	174.2		414.9	412	166	0.1	15	11	2	0.12	0.01	<0.01	7.3	0.13	<0.01	<0.01
21-Dec-03	E4812	C32	7.7	100	15.9	6.3	57.1	73	49.3	4.9	8.7	2.5	3.4	0.03	0.02	<0.01	2.5	0.51	<0.01	0.07
16-Mar-04	E4812	C32	7.5	167.0	0.271	2.81			49.3	4.9	8.7	2.5	3.4	0.03	0.02	<0.01	2.5	0.51	<0.01	0.07
20-Sep-04	E4812	C32	7.8	167	120.0	5.7			36	2	8.3	3.2	2.4	0.01	<0.01	0.03	3.6	1.31	<0.01	0.25
16-Jun-04	E4812	C32	8.7	200	360.0	5.3	142.9	155.2	48	5.6	7.9	1.5	13.9	0.83	0.01	4.7	1.76	0.32	<0.01	0.13
16-Mar-05	E4812	C32	7.4	211.0	31.2		131.7	147	42.5	5.2	8.9	1.6	0.5	0.86	<0.01	0.4	1.88	0.32	<0.01	<0.01
14-Jun-05	E4812	C32	7.5	188	31.2		136.3	137.8	46	5.2	8.3	1.1	6.4	0.24	0.01	5.3	0.7	0.26	0.01	0.1
18-Sep-05	E4812	C32	7.7	231	36.3	7.6	134.8	182	48.7	3.2	7.8	2.2	0.5	0.5	<0.01	0.05	2.9	0.38	<0.01	0.08
29-Dec-05	E4812	C33	6.6	141	24.2	4.3	103.8	113	37.3	2.6	6.9	4.1	0.5	1.72	0.06	<0.01	2.3	0.73	<0.01	0.07
28-Oct-03	E4812	C33	7.2	180.5	31.0		107.3	148	40	1.8	6.8	2.4	0.5	0.14	0.03	<0.01	1.9	2.33	<0.01	0.14
21-Dec-03	E4812	C33	7.4	160	100.0	6.3			37	2.6	6.6	1.2	0.5	0.01	0.04	10.9	4.78	0.07	<0.01	0.25
16-Mar-04	E4812	C33	8.8	136.0	0.197	2.68			36.3	2.6	6.1	1.3	0.5	0.07	0.05	<0.01	15.3	5.9	<0.01	0.6
20-Sep-04	E4812	C33	7.9	100	222	3.5			30	2.5	5.8	1.1	10.4	0.65	0.01	5	1.65	<0.01	<0.01	0.21
16-Dec-04	E4812	C33	8.4	100	214.0	5.2	85.2	92.5	30	2.5	5.8	1.1	10.4	0.65	0.01	5	1.65	<0.01	<0.01	0.21

Table 5.1: Physical Parameters - Continuation

TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 to 2006

DATE	REF	DESCRIPTION	pH	TD8	Conductivity	DO	TH	Alkalinity	Ca++	Mg++	Na+	K+	Cl-	NO ₃ -N	NO ₂ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
COMMUNITY WELLS WATER QUALITY																					
8.0 - 9.0																					
1000																					
1000(µm/cm)																					
500																					
29-Dec-05	E6036	HSNO12	6.8	423	81.8	8.2	43.5	76	11.3	3.7	80	29	106.3	33.7	0.01	0.010	18.2	0.62	0.98	<0.01	0.14
29-Dec-05	E6036	HSNO13	6.9	468	81.7	7.6	232.7	76.7	81.3	7.2	77	44	91.9	19.4	0.080	<0.01	128.8	0.25	3.58	<0.01	0.07
29-Dec-05	E6036	HSNO14	7.4	478	57.2	7.3	193.2	177.8	63.7	8.3	33	12	76.1	20.6	<0.01	0.01	14.1	0.38	1.07	<0.01	0.02
29-Dec-05	E6036	HSNO15	6.0	277	35.8	8.8	44.7	6	11.8	3.7	19	45.2	44.4	<0.01	<0.01	9.4	0.02	1.24	<0.01	0.18	
28-Oct-03	E4476	HSNO16	4.7	246	33.6	1.3	39.4	1.0	9.2	4.0	36	18	45.2	41.3	<0.01	<0.01	10.1	0.12	1	<0.01	0.01
21-Dec-03	E4678	HSNO16	7.6	356	300.0	5.6			50	3.1	42	21	49.7	64.9	<0.01	0.01	26.3	0.04	0.11	<0.01	0.02
15-Jun-04	E4812	HSNO16	6.6	226.0	0.3	3.8			7.8	4.1	39.0	18.0	53.9	40.2	<0.01	<0.01	11.1	0.09	1.06	<0.01	<0.01
20-Sep-04	E6088	HSNO16	7.2	200	316	10.4	62	1	16.4	5.1	41	19	56.6	54.3	<0.01	0.15	14.4	0.04	1.5	0.02	0.05
15-Dec-04	E6417	HSNO16	8.6	200	378.0	0.9	44.6	1.3	10.1	4.7	42.0	16.0	53.8	52.1	<0.01	<0.01	18	<0.01	1.48	0.01	<0.01
14-Jun-05	E6812	HSNO16	4.5	259.0	37.0		81.8	0.1	24	5.3	41	16	57	43.6	0.01	0.01	17.8	0.32	1.39	0.01	0.15
18-Sep-05	E6036	HSNO16	4.9	297	43.9	9.4	61.1	1.2	16.7	4.7	47	19	85.3	69	<0.01	<0.01	13.70	0.42	1.29	<0.01	0.04
29-Dec-05	E6036	HSNO16	6.9	349	54.8	7.4	142.5	69.4	29.7	16.6	43	13	59.4	49	0.01	<0.01	26.1	0.33	<0.01	<0.01	0.11
29-Dec-05	E6036	HSNO17	7.1	97	15.6	8.7	64.8	67.6	23	1.6	47	27	5.4	1.39	<0.01	<0.01	0.1	0.93	0.02	<0.01	0.05
29-Dec-05	E6036	HTQ	6.5	37	5.7	7.5	22.3	23.4	8.1	0.5	4.3	0.5	5.9	0.03	<0.01	<0.01	0.3	1.04	<0.01	<0.01	0.08
29-Dec-05	E6036	NTB01	6.4	41	5.9	7.4	19.1	17	6.5	0.7	5.6	0.4	9.3	0.08	<0.01	<0.01	2.9	0.69	0.02	<0.01	0.24
29-Dec-05	E6036	NTB02																			
29-Dec-05	E6036	NTB03	6.6	44	7.6	7.5	30.6	29.6	11.1	0.7	4	0.5	4.9	1.56	0.01	<0.01	<0.1	0.36	0.01	<0.01	0.07
29-Dec-05	E6036	NTB04	7.4	115	19.7	7.2	80.7	89.9	29.7	1.6	5.6	0.5	1.3	0.21	<0.01	<0.01	2.5	0.45	<0.01	<0.01	0.1
29-Dec-05	E6036	NTB05	7.6	168	29.7	9.2	107	139.3	41.2	1	3.3	1.7	0.5	9.25	<0.01	<0.01	1	0.42	0.08	<0.01	0.04
29-Dec-05	E6036	NTB05B	6.7	192	30.0	19.2	147	146	57.3	1.1	7.6	6.7	0.6	2.81	0.3	<0.01	1.7	0.28	<0.01	<0.01	0.05
28-Oct-03	E4478	NTB1	6.4	115	18.7	2.4	89	85	28.3	0.8	6.9	2	5.90	0.37	0.01	<0.01	0.3	0.06	<0.01	<0.01	<0.01
21-Dec-03	E4678	NTB1	7.5	188	25.4	7.5	96.5	133	35	2.2	19	3.1	3	0.26	0.01	<0.01	2.8	0.36	0.02	<0.01	0.21
16-Mar-04	E4730	NTB1	7.5	136	120.0	6.8			32	1	14	6.6	1.9	2.93	0.02	0.01	4.8	0.75	0.02	<0.01	0.05
15-Jun-04	E4812	NTB1	7.7	176.0	0.3	3.2			49.3	1.1	8.9	4.2	0.5	0.03	0.02	<0.01	2.0	0.42	0.03	<0.01	<0.01
20-Sep-04	E6088	NTB1	8.5	200	243	2.9															
16-Dec-04	E6417	NTB1	8.9	200	268.0	1.0	132	142.1	44.3	5.2	16	2.6	2	0.03	0.01	0.04	0.1	0.03	0.08	<0.01	<0.01
16-Mar-05	E6812	NTB1	7.2	208.0	34.6		158.1	160.7	00	2	9.7	4	0.5	1.59	<0.01	<0.01	<0.1	0.84	0.02	<0.01	<0.01
14-Jun-05	E6830	NTB1	7.4	212	33.4		130.2	156.3	48	2.5	12.6	3.8	2	1.47	0.01	0.01	5.7	0.2	0.01	0.01	0.02
18-Sep-05	E6830	NTB1	7.3	153	100.0	7.5			27.6	1.1	1.6	4.5	10.2	0.83	0.01	0.01	6.3	1.32	0.11	<0.01	0.23
16-Jun-04	E4812	NTB18B																			
20-Sep-04	E6088	NTB18B																			
16-Dec-04	E6417	NTB18B	8	100	223	3.6															
16-Mar-05	E6830	NTB18B	8.7	100	130.0	0.9	43.9	65.7	16.6	0.6	11	0.9	2.0	0.01	<0.01	0.04	4	0.31	0.14	<0.01	0.3
18-Sep-05	E4478	NTB2	6.8	138	16.8		58.8	74.4	23.3	0.4	10.5	0.7	0.5	0.25	0.01	0.01	0.1	0.14	0.01	0.01	0.25
28-Oct-03	E4678	NTB2	6.8	123.0	22.1		78.2	97	30.6	0.5	7.9	6.7	0.5	1.96	<0.01	<0.01	<0.1	0.02	<0.01	<0.01	0.02
21-Dec-03	E4678	NTB2	7.3	147.5	24.0	2.2	90.8	116	34.7	1	7.6	3.5	0.90	0.25	0.21	<0.01	0.3	0.17	0.02	<0.01	<0.01
16-Mar-04	E4730	NTB2	7.5	138	20.7	7.0	88.6	104	33	1.5	7.6	2.2	3.4	4.01	0.01	<0.01	3.8	0.44	0.01	<0.01	<0.01
15-Jun-04	E4812	NTB2	7.6	120	20.0	8.6			31.5	1.4	9.6	3.5	2.2	16.4	0.01	0.01	2.9	0.06	0.04	<0.01	0.01
20-Sep-04	E6088	NTB2	7.7	117.0	0.2	3.0			43.3	1.3	7.8	2.0	0.5	4.75	0.37	<0.01	2.1	0.01	0.04	<0.01	<0.01
15-Dec-04	E6417	NTB2	8.2	100	224	4															
16-Mar-05	E6812	NTB2	8.5	200	260.0	5.1	132.2	99.2	49.2	1.9	6.7	1.4	3.6	0.17	0.01	0.01	10.8	0.14	<0.01	<0.01	<0.01
14-Jun-05	E6830	NTB2	6.4	103.0	17.8		67.5	76.3	25.2	1.1	6.1	0.6	0.5	0.15	<0.01	<0.01	<0.1	0.17	<0.01	<0.01	<0.01
18-Sep-05	E6830	NTB2	7.2	155	22		91.9	100.9	34	1.7	8.7	1	0.5	0.41	0.01	0.01	11.4	0.22	0.03	0.01	0.03
28-Oct-03	E4478	NTB3	5.6	79	13.0		42.1	42	15.2	1	7.3	1.7	2.5	3.6	<0.01	<0.01	0.9	0.3	0.05	0.02	0.11

Table 5.1: Physical Parameters - Continuation

TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 TO 2005

DATE	REF	DESCRIPTION	pH	TDS	Conductivity 1600(us/cm)	DO	TH	Alkalinity	Ca++	Mg++	Na+	K+	Cl-	NO ₃ -N	NO ₂ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
			6.0-9.0	1000			800						240	10		1	200	10	0.1	0.01	10
EPA EFFLUENT DISCHARGES																					
21-Dec-03	E4576	NTB3	6.0	82	12.6	2.0	51.3	50	18.9	1	5.1	0.8	3.4	1.56	<0.01	0.89	0.1	0.09	0.7	<0.01	<0.01
16-Mar-04	E4730	NTB3	7.1	44	7.3	6.6	24.7	29	8.4	0.9	4	0.5	3	0.97	0.01	<0.01	0.2	0.29	0.06	<0.01	0.08
16-Jun-04	E4912	NTB3	7.0	200	130.0	5.8			56	1	9.2	1.9	0.5	0.86	0.01	0.01	10.5	1.71	0.07	<0.01	0.1
20-Sep-04	E5085	NTB3	6.7	77.0	0.1	2.8			15.6	0.7	6.3	1.0	0.5	0.26	0.01	<0.01	3.2	0.70	0.10	<0.01	<0.01
16-Dec-04		NTB3	7.3	100	117	3.3															
16-Mar-05	E5417	NTB3	8.2	100	100.0	5.1	35.1	36.5	12.9	0.7	5	0.6	7.4	0.22	<0.01	0.01	3.8	0.41	0.05	<0.01	0.02
14-Jun-06	E5612	NTB3	6.7	49.0	9.6		37	33.9	13.5	0.8	5.2	0.7	0.5	0.86	<0.01	<0.01	2.6	0.62	0.02	0.02	<0.01
18-Sep-06	E5830	NTB3	6.4	72	9.5		34	37.2	12.3	0.8	4.2	0.6	5.4	1.38	0.01	0.01	0.1	0.11	0.01	0.01	0.07
28-Oct-03	E4476	NTB4	6.7	116	20.2		49.2	36	13.6	3.7	7.5	14	7.4	0.04	0.04	<0.01	5.9	0.07	0.02	0.02	0.07
21-Dec-03	E4675	NTB4	6.0	72	11.0	2.3	30.4	35	9.7	1.5	7.4	5.2	6.9	0.02	<0.01	<0.01	1.7	0.49	0.06	<0.01	<0.01
16-Mar-04	E4730	NTB4	6.5	52	6.9	4.8	20	21	6.7	1.4	5.9	3.1	5.9	1.32	0.13	0.12	2.8	2.06	0.04	<0.01	0.07
16-Jun-04	E4912	NTB4	6.6	271	120.0	6.5			26.5	7.7	21	18	16.6	45.8	0.23	0.03	32.3	1.65	0.2	<0.01	0.43
20-Sep-04	E5085	NTB4	6.4	82.0	0.1	2.3			8.3	1.1	7.9	6.1	3.4	1.07	0.07	0.02	9.9	1.29	0.05	<0.01	0.73
16-Dec-04		NTB4	7.5	100	99	4															
16-Mar-05	E5417	NTB4	7.9	100	880.0	6.0	21.8	29	7.1	1	7	3.4	5	0.04	0.03	0.11	15.3	1.24	0.03	<0.01	0.57
14-Jun-06	E5612	NTB4	6.8	139.0	20.1		51.5	35.1	14.2	3.9	11	14	1.5	11.6	0.01	<0.01	24.8	0.65	<0.01	<0.01	<0.01
18-Sep-06	E5830	NTB4	6.3	69	8		20.8	26.8	8.2	1.3	6.7	3	0.5	0.31	0.01	0.01	9.5	1.27	0.03	0.01	0.37
16-Mar-04	E4730	NTB5	6.9	78	11.1	7.0	39.5	56.5	13	1.7	8.1	1	3.4	0.02	0.01	<0.01	2	0.29	0.14	<0.01	1.5
28-Oct-03	E4476	NTB5	6.2	105	18.9		72.8	74	26.7	1.5	6.2	2.5	1	1.4	0.06	<0.01	0.2	0.05	0.15	<0.01	0.13
21-Dec-03	E4576	NTB5	6.0	58	10.1	2.2	34.2	36	12.2	0.8	6.4	0.6	3	<0.01	<0.01	<0.01	0.9	0.34	0.04	<0.01	0.8
16-Jun-04	E4912	NTB5	6.7	88	194.0	5.5			19.9	1.5	7.2	2.4	0.6	0.29	0.02	0.02	8.4	1.15	0.07	0.01	0.47
20-Sep-04	E5085	NTB5	6.4	71.0	0.1	2.2			15.2	0.7	6.0	0.8	2.5	0.26	0.01	<0.01	4.2	0.45	0.05	<0.01	0.62
16-Dec-04		NTB5																			
16-Mar-05	E5417	NTB5																			
14-Jun-06	E5612	NTB5	6.9	125	18.6		74.2	80.3	26.4	2	7.8	1.2	0.5	0.26	0.01	0.01	5.5	0.18	0.02	0.01	0.21
28-Oct-03	E4476	NTB6(b)	6.6	36	4.7	2.4	16.7	15	4.2	1.5	4.5	0.2	6.4	0.03	0.02	<0.01	0.5	0.3	0.01	<0.01	<0.01
21-Dec-03	E4576	NTB6(b)	6.6	130	48.0	6.8			7.8	0.9	6.1	1.1	1.5	0.13	0.03	0.05	11.2	3.66	0.03	<0.01	0.07
16-Jun-04	E4912	NTB6(b)	6.2	43.0	0.1	2.2			6.2	0.5	4.8	0.6	0.5	0.10	0.01	<0.01	3.2	0.52	0.02	<0.01	0.23
20-Sep-04	E5085	NTB6(b)	7.6	40	49	3.6															
16-Dec-04		NTB6(b)	7.3	0	62.0	5.4	14.1	20.6	4.5	0.7	7.5	0.5	9.4	0.03	0.01	0.1	6.4	0.91	0.02	<0.01	0.01
16-Mar-05	E5417	NTB6(b)	6.8	39.0	6.0		19.7	20.9	8.8	0.6	5	0.6	0.5	0.13	<0.01	<0.01	2.2	0.8	0.03	<0.01	<0.01
14-Jun-06	E5612	NTB6(b)	6.2	54	8.4		15.7	23.6	4.8	0.9	7.3	0.7	0.5	0.28	0.01	0.01	7.6	0.99	0.01	0.01	0.04
18-Sep-06	E5830	NTB6(b)	7.5	238	39.5	8	114	161.8	42.2	2.1	24	11	9.6	13.3	0.01	<0.01	14.60	0.43	0.02	<0.01	0.1
28-Oct-03	E4476	PSA06	6.6	154	24.1	7.8	55.7	45.5	18.1	2.8	16	28	18.7	22.3	0.02	<0.01	<0.1	0.63	0.12	<0.01	0.04
29-Dec-06	E6036	PSA06	5.9	351	50.5	8.3	81.1	9.5	24.4	4.9	66	8.4	87	55.9	0.08	0.01	<0.1	0.33	<0.01	<0.01	0.06
29-Dec-06	E6036	PSA07	5.9	250	35.7	8.1	76.5	69.3	23.7	4.2	57	22	48.1	22.7	0.08	0.01	<0.1	0.3	0.02	<0.01	0.05
29-Dec-06	E6036	PSA08	6.9	185	27.9	7.4	80.3	75.9	26.7	3.3	23	4.4	21.1	18.2	0.01	<0.01	<0.1	0.01	0.01	<0.01	0.01
29-Dec-06	E6036	PSA09	7.2	163	21.1	4.5	41.3	86	15.9	0.4	17	17	0.5	45.6	3.79	<0.01	<0.1	0.01	<0.01	<0.01	<0.01
28-Oct-03	E4476	PSA10	7.2	153.0	24.7		62.5	110	23.7	0.8	15	13	1.5	1.23	0.01	<0.01	1	0.05	<0.01	<0.01	0.04
21-Dec-03	E4576	PSA10	7.3	196.0	200.0	8.2	88.1	112	32	2	7.1	1.8	2	0.56	<0.01	<0.01	6.6	2.63	0.02	<0.01	0.1
16-Mar-04	E4730	PSA10	7.8	196.0	200.0	8.2			51.0	1.0	6.0	4.4	1.5	2.24	0.01	<0.01	4.7	0.14	0.01	<0.01	0.1
15-Jun-04	E4912	PSA10	7.3	176.0	0.3	3.0			58.3	0.8	7.2	2.6	2.5	0.98	<0.01	<0.01	1.8	0.29	0.02	<0.01	<0.01
20-Sep-04	E5085	PSA10	7.3	176.0	0.3	3.0															

Table 5.1: Physical Parameters - Continuation

TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 to 2006

DATE	REF	DESCRIPTION	pH	TDSS	Conductivity (µS/cm)	DO	TH	Alkalinity	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	Fe	Cl ⁻	NO ₃ -N	NO ₂ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
8.0 - 8.5	1000	1500 (µmhos)					800						250			5	200	15	5.1	5	10
15-Dec-04	E5417	PSA10	8.4	200	263	6.8	133.9	132.2	51.3	1.4	7.2	1.1	0.5	0.16	<0.01	<0.01	5.6	0.07	0.02	<0.01	0.04
16-Mar-05	E5417	PSA10	8.1	260.0	270.0	0.5	139.4	150.9	54	1.1	7	2	0.5	0.38	<0.01	<0.01	3.4	0.08	0.01	<0.01	<0.01
14-Jun-06	E5417	PSA10	7.3	170.0	32.0		60.3	72.4	21.5	1.6	7.7	0.4	0.5	0.01	0.01	0.01	2.4	0.21	0.03	0.01	0.45
18-Sep-06	E5417	PSA10	6.9	112	2.4		79	59.4	28.2	3.9	40	13	40.8	20.5	<0.01	<0.01	10.2	0.99	<0.01	<0.01	0.11
29-Oct-06	E5417	PSA10	8.8	194	32.5		16.2	138	8	0.3	28	50	6.4	31.8	1.04	<0.01	5	0.24	0.01	<0.01	<0.01
28-Oct-03	E4476	PSA19	9.0	224	33.5	3.7	29.9	92	11	0.6	19	28	0.5	0.21	<0.01	<0.01	2.9	0.13	0.02	<0.01	<0.01
21-Dec-03	E4476	PSA19	7.3	153	21.4																
16-Mar-04	E4730	PSA19																			
15-Jun-04	E4912	PSA19																			
20-Sep-04	E5086	PSA19																			
16-Mar-04	E5417	PSA19	7.8	200	239	4.6	67.3	70.7	25.3	1	4.8	1.7	7.9	1.29	<0.01	<0.01	3.3	0.1	<0.01	<0.01	0.11
16-Mar-04	E5417	PSA19	8.3	100	146.0	0.5	69.4	103.7	34	1.1	4.6	2.9	3.9	0.03	<0.01	<0.01	4.3	0.05	<0.01	<0.01	<0.01
14-Jun-06	E5412	PSA19	6.7	114	22.4		43.4	46.2	18.4	0.6	2.1	0.5	0.5	0.25	0.01	0.01	0.1	0.02	0.01	0.01	0.31
18-Sep-06	E5412	PSA19	6.7	77	10.2		97	125.3	36.7	1.3	3.7	1.8	0.5	0.39	0.01	<0.01	2.0	0.49	<0.01	<0.01	0.18
29-Oct-06	E5036	PSA19	7.7	142	25.8	8.8	131.3	143.2	46	4	19	24	15.3	13	<0.01	0.08	12.6	1.1	<0.01	<0.01	<0.01
14-Jun-06	E5412	PSA40	7.3	265	41.8		512.3	504.7	205	0.1	30	29	3.9	0.22	0.19	<0.01	8	<0.01	0.01	0.02	<0.01
14-Jun-06	E5412	PSA41	11.8	626	266		552.6	657.7	220	0.8	7.3	7.5	17.3	1.49	1.32	<0.01	7.5	<0.01	0.02	0.03	<0.01
14-Jun-06	E5412	PSA42	11.8	669	307		547.9	98	61.3	4.8	48	2.4	54.8	80.8	3.03	<0.01	<0.1	<0.01	<0.01	0.04	0.04
14-Jun-06	E5412	PSA42	8.5	348	54.9	5.5	101.9	82	33.7	4.3	44	1.5	49.2	25.4	<0.01	<0.01	<0.1	0.09	0.08	<0.01	0.04
28-Oct-03	E4476	PSA6	6.6	294	44.7		6.7	106.8	105	36	4.1	38	1.5	44.1	30.9	0.01	0.5	0.39	0.03	<0.01	0.07
21-Dec-03	E4476	PSA6	7.3	302	40.9	6.7	106.8	105	90	3.6	40	1.5	42.4	35.7	0.01	<0.01	1.9	0.06	0.11	<0.01	0.08
16-Mar-04	E4730	PSA6	7.0	265	101.0	5.6	62	47.3	45.3	4.3	49.0	4.0	55.4	33.3	<0.01	<0.01	0.8	0.14	0.22	<0.01	0.17
18-Jun-04	E4912	PSA6	6.9	284.0	0.4	3.6															
20-Sep-04	E5086	PSA6	7.4	200	278	9.9	62	47.3	19.7	3.1	25	1.1	31.8	19.4	0.01	0.01	<0.1	0.04	0.02	<0.01	0.14
16-Dec-04	E5417	PSA6	8.9	0	0.0	0.6	123	88.2	42	4.4	46.0	7.0	53.8	25.3	<0.01	<0.01	4.5	0.18	0.07	0.01	<0.01
14-Jun-06	E5412	PSA6	6.6	333.0	48.8		53.2	38.4	15.2	3.7	25	1.7	31.4	35.5	0.01	0.01	0.1	0.38	0.04	0.01	0.06
18-Sep-06	E5412	PSA6	6.7	220	26.3		105.6	76	41.3	0.6	80	39	99.3	294.2	16.3	<0.01	1.8	0.02	<0.01	<0.01	<0.01
28-Oct-03	E4476	PSA7	10.9	526	94.8	3.8	105.6	76	47.7	8.2	85	4.9	113.1	95.8	1.06	<0.01	0.1	0.1	0.21	<0.01	0.33
21-Dec-03	E4476	PSA7	6.3	569	83.6		152.9	56													
16-Mar-04	E4730	PSA7	6.6	540	36.3	6.5	61	8	61	8	83	11	113.6	131.5	0.05	<0.01	2	0.34	0.15	<0.01	0.29
18-Jun-04	E4912	PSA7	6.2	432.0	0.6	3.5	37.3	36.5	37.3	8.6	70.0	16.0	102.5	0.68	0.03	<0.01	0.8	0.17	0.14	<0.01	0.06
20-Sep-04	E5086	PSA7	7	300	504	5.3	111.3	36.5	37.3	4.4	55	4.8	79.4	61.4	0.01	0.01	1.4	0.12	0.14	<0.01	0.04
16-Dec-04	E5417	PSA7	9.3	200	179.0	0.5	91.8	18.9	27.4	5.6	59.0	12.0	90.2	67.8	0.01	<0.01	<0.1	0.18	0.13	0.01	<0.01
18-Mar-06	E5412	PSA7	6.8	425.0	55.3		108.4	10.5	36	4.5	39	4.6	73.6	44.6	0.02	0.01	0.1	0.41	0.12	0.01	0.1
14-Jun-06	E5412	PSA7	6.4	343	45.1		496	938	188.3	0.2	20	53	6.4	35.3	0.19	<0.01	3.9	0.04	0.01	<0.01	0.02
18-Sep-06	E5412	PSA8	11.3	907	390.0	4.2	347.2	394	138.7	0.2	15	15	11.3	12.7	3.81	<0.01	4.3	0.05	0.01	0.01	<0.01
28-Oct-03	E4476	PSA8	11.1	890	172.2																
21-Dec-03	E4476	PSA8																			
16-Mar-04	E4730	PSA8	7.6	175	30.0	7.1	39	2	39	2	15	4.1	13.2	13.5	1.54	<0.01	2.9	0.1	0.06	<0.01	0.05
18-Jun-04	E4912	PSA8	6.8	171.0	0.3	2.7	39.3	19	39.3	1.9	17.0	4.3	15.7	12.3	<0.01	<0.01	1.2	0.16	0.11	<0.01	0.83
20-Sep-04	E5086	PSA8	7.4	100	155	7															
16-Dec-04	E5417	PSA8	9.3	100	0.0	0.5	72.7	67.9	26	1.9	12	2.1	13.4	9.44	<0.01	0.01	<0.1	0.05	0.13	0.01	0.08
14-Jun-06	E5412	PSA8	7.8	258	42		117.7	114.8	43	2.5	27	11	28	14.6	0.01	0.01	8.2	0.72	0.01	0.01	0.03
18-Sep-06	E5412	PSA8	6.4	281	45.5	3.1	127.9	93	43.3	4.8	28	13	44.3	22.7	0.08	<0.01	7.6	0.01	0.33	<0.01	0.02
28-Oct-03	E4476	PSA8	7.0	144	51.1	7.1	53.8	61	15.6	3.6	16	0.7	4.9	7.46	0.01	<0.01	<0.1	6.8	0.06	0.02	0.03
16-Mar-04	E4730	PSA9	7.0	216	21.6	6.1	30	5.8	30	5.8	27	12	29.2	24.3	0.16	0.04	11.7	0.98	0.06	<0.01	0.02
18-Jun-04	E4912	PSA9	6.7	196.0	0.3	2.7	47.3	3.6	47.3	3.6	26.0	14.0	27.5	12.9	0.02	0.04	9.1	1.18	0.04	<0.01	0.15
20-Sep-04	E5086	PSA9																			

Table 5.1: Physical Parameters Continuation

TARKWA GOLD MINE

COMMUNITY WELLS WATER QUALITY MONITORING RESULTS - 2003 to 2005

DATE	REF	DESCRIPTION	pH	TDS	Conductivity 1000(µm)	DO	TH	Alkalinity	Ca++	Mg++	Na+	K+	Cl-	NO ₃ -N	NO ₂ -N	PO ₄	Sulphate	Iron	Mn	Cu	Zn
15-Dec-04	E4575	PSA9	7.5	200	234	5.8	86.6	76	28.1	4	23	6.3	25.6	6.31	0.07	<0.01	0.6	0.19	0.02	<0.01	0.03
21-Dec-04	E4575	PSA9	8.8	181	29.8	0.6	55.3	66.6	17.2	3	17	0.8	7.4	3.84	0.01	0.01	1.7	0.06	0.03	<0.01	0.11
16-Mar-06	E6417	PSA9	9.1	100	170.0	0.6	98	76.6	32	4.4	31.0	15.0	30.1	11.5	<0.01	<0.01	23.2	0.37	0.03	<0.01	<0.01
14-Jun-06	E6417	PSA9	6.3	215.0	37.4		47.4	59.1	13.2	3.5	14.3	2.1	8.8	3.77	0.01	0.01	0.1	0.07	0.01	0.01	0.06
18-Sep-06	E6830	PSA9	6.9	148	17.2	5.4	81.4	83.8	26.3	2.8	5	1.6	1.5	2.66	<0.01	<0.01	<0.1	0.01	0.09	0.01	0.06
28-Oct-03	E4476	SMHU22	6.9	101	18.9	1.3	77.5	84	26.4	2.8	5	1	5.9	0.84	<0.01	<0.01	<0.1	0.06	0.05	<0.01	<0.01
21-Dec-03	E4575	SMHU22	6.7	108	18.4	4.9	71.4	78	21.5	4.3	5.6	1.1	3.9	0.11	0.01	<0.01	<0.1	0.05	0.07	<0.01	0.04
16-Mar-04	E4730	SMHU22	6.6	96	17.7	5.1	128.0	5.1	27.1	2.8	5.4	1.6	0.5	1.35	<0.01	<0.01	3.1	0.05	0.07	<0.01	0.02
15-Jun-04	E4912	SMHU22	6.8	0.3	0.1	4.6			20.0	2.5	4.7	0.8	0.5	1.23	<0.01	<0.01	<0.1	0.03	0.05	<0.01	0.01
20-Sep-04	E6085	SMHU22	7.0	81.0	0.1		62.3	65.8	19.5	3.3	4.9	0.8	0.5	0.8	<0.01	<0.01	<0.1	0.12	0.4	<0.01	0.02
16-Mar-06	E6417	SMHU22	6.8	200	270.0	3.4	58.2	55.3	19.2	2.5	4.5	0.8	3	1.18	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01
14-Jun-06	E6417	SMHU22	6.1	81.0	14.7				16.9	3.2	4.7	0.7	2.9	1.02	0.01	0.01	0.1	0.11	0.01	0.01	0.01
16-Dec-04	E6830	SMHU-22	7.8	100	128	4.1	55.4	58.6	16.9	1.3	7.4	0.5	3.9	4.37	0.01	<0.01	1.4	0.05	0.02	<0.01	0.04
18-Sep-06	E4476	SMHU-22	6.6	97	13.8	3.9	16.6	11	4.6	1.2	8	0.3	3.4	0.16	<0.01	<0.01	1.2	0.43	0.04	<0.01	<0.01
28-Oct-03	E4575	SMHU23	6.0	37	6.9	1.7	15.9	18	4.4												
21-Dec-03	E4730	SMHU23	6.9	53.5	6.8																
16-Mar-04	E4730	SMHU23																			
15-Jun-04	E4912	SMHU23																			
20-Sep-04	E6085	SMHU23	6.7	52.0	6.1	4.2			9.4	1.5	7.2	0.3	10.3	0.80	0.09	<0.01	<0.1	13.0	0.22	<0.01	<0.01
16-Dec-04	E6417	SMHU23																			
14-Jun-06	E6830	SMHU23	6.0	54.5	6.2		13.3	14.2	3	1.4	8.2	0.4	3.7	0.24	0.01	0.01	5.2	0.2	0.01	0.01	0.09
18-Sep-06	E4476	SMHU24	6.3	1206	170.0	5.2	336.7	156	106.8	17	14	110	152.4	111.5	0.04	0.2	76	0.02	0.32	<0.01	0.13
28-Oct-03	E4575	SMHU24	6.7	1767	234.0	1.7	623.6	213	160.7	54	160	190	215.6	64.9	0.01	0.06	176.6	0.11	0.89	<0.01	<0.01
21-Dec-03	E4730	SMHU24	7.4	1946	233.0	7.2	453.4	236	65	52.6	180	200	236.7	34.5	0.38	<0.01	205.7	0.27	1.1	<0.01	0.1
16-Mar-04	E4912	SMHU24	7.1	1173	900.0	2.5			91	30.3	130	120	125.2	300.7	0.1	0.49	84.7	0.86	0.39	<0.01	0.11
20-Sep-04	E6085	SMHU24	6.9	1062.0	1.3	4.2			90.0	29.0	84.0	94.0	134.9	9.39	0.23	0.09	78.9	0.99	0.37	<0.01	0.28
15-Dec-04	E6417	SMHU24	8.4	150	2290	3.7	425.6	170	107.3	36.3	150	130	185.1	20.5	0.18	0.14	118.1	0.07	0.17	<0.01	<0.01
18-Mar-06	E6812	SMHU24	8.1	2.3	3.1	4.3	295.1	100.8	72.0	28.0	81.1	95.0	123.8	164.4	0.02	0.54	73.8	2.3	0.13	0.02	<0.01
14-Jun-06	E6830	SMHU24	6.4	1059.0	133.7		571.2	212.7	143	52	190	170	241.1	455.1	0.03	0.01	206.9	0.09	0.06	0.01	0.01
18-Sep-06	E4476	SMHU26	7.3	2125	247	2.6	29.4	3	6.6	3.2	16	4.2	19.2	23.4	0.02	<0.01	0.5	0.01	0.15	0.03	0.16
28-Oct-03	E4575	SMHU26	4.9	116	16.0	1.6	31.8	10	7.8	3	18	3.6	16.7	27.7	0.03	<0.01	1	0.2	0.12	<0.01	<0.01
21-Dec-03	E4730	SMHU26	6.4	107	14.0																
16-Mar-04	E4912	SMHU26	6.1	131	120.0	5.5			9.7	4.4	38	34.1	14.1	49.8	0.01	<0.01	4.1	0.62	0.18	<0.01	0.03
16-Jun-04	E6085	SMHU26	6.1	115.0	0.2	3.5			6.3	3.3	17.0	3.7	14.2	22.4	0.09	<0.01	2.6	0.45	0.14	<0.01	0.03
20-Sep-04	E6417	SMHU26	7.5	100	160	3.8															
16-Mar-06	E6812	SMHU26	6.4	100	199.0	1.8	25.7	9.9	5	3.2	23	7	34.2	20.4	<0.01	0.03	7.9	0.49	0.14	<0.01	<0.01
14-Jun-06	E6830	SMHU26	6.3	167.0	21.0		38.6	7	8.2	4.4	18.0	5.8	17.3	34.9	<0.01	<0.01	5.5	0.59	0.22	<0.01	<0.01
18-Sep-06	E4476	SMHU26	6.1	145	20.1	3.8	10.5	19	6.7	3.9	27	7.2	25.6	11.4	0.01	0.01	9	0.18	0.03	0.01	0.07
28-Oct-03	E4575	SMHU26	6.1	45	6.3	3.8	10.6	9	2.9	0.8	7.8	1.2	2	4.21	0.04	<0.01	3.7	0.02	0.03	<0.01	6
21-Dec-03	E4730	SMHU26	6.9	64	9.2	2.2	19.2	22	5.7	1.2	8.6	1.1	4.9	1.41	<0.01	<0.01	1.2	0.83	0.07	<0.01	0.04
16-Mar-04	E4912	SMHU26																			
16-Jun-04	E6085	SMHU26	7.2	110	100.0	5.2			23.1	1.7	8.8	2.9	0.5	3.95	<0.01	0.02	10	1.47	0.05	<0.01	0.08
20-Sep-04	E6417	SMHU26	7.2	83.5	0.1	5.0			18.4	1.1	10.0	2.1	0.5	0.09	<0.01	<0.01	3.7	1.77	0.10	<0.01	0.39
16-Dec-04	E6812	SMHU26	7.6	100	120	3.7															
16-Mar-06	E6417	SMHU26	6.5	100	120.0	1.5	25.8	27.7	8.2	1.3	10.2	2	17.4	3.74	0.01	<0.01	4	0.82	0.1	<0.01	0.02
14-Jun-06	E6812	SMHU26	6.8	76	10.9		29.1	33.5	10	1	8.3	1.6	0.5	1.3	0.01	<0.01	3.1	1.4	0.03	<0.01	<0.01

Table 5.1: Physical Parameters - Continuation

5.6 Biological Parameter

Results of the biological analyses indicate various levels of both total and faecal coliform (See Table 5.6). All the wells had levels of faecal coliform exceeding the WHO (Appendix 2) limits for potable drinking water except the wells located in the Huniso Community. However *E. coli* was absent in all the samples analysed. This clearly rules out contamination of well water as a result of human excreta. According to Twort et al, (1974), absence of *E. coli* and presence of faecal coliform could be attributed to pollution primary arising from soil or vegetation.

Faecal coliform in the Ntebe community wells increased from a low value of 8 MPN/100 ml to high level of 500 MPN/100 ml from 2004 to 2005. A careful examination of these wells revealed that the metal plate basement was loose. Furthermore, a greater number (85-90 %) of the wells in this community are located in low lying areas which makes them susceptible to runoff infiltration. NTB4 well showed a consistent presence above the WHO limits over a two years period (refer to Table 5.2). This well is located near an oil palm extraction mill and this could be the main source of the pollution; since conditions at this mill are not very hygienic.

The wells located at Abekoase Community gave values between 4 MPN/100 ml and 170 MPN/100 ml. Observation of the area shows a high road elevation than the basement of the well and could be receiving storm water (Refer to Figures 5.4, 5.5, 5.6, 5.7 and 5.8).

The Camp 43 area, which is a typical farming community, also had values well above the WHO guideline as presented in Tables 5.2. and 5.6. It can be seen that the wells are contaminated with faecal coliform.

Table 5.2 Faecal coliforms Levels at Ntebe Community

Sampling Date	Sample ID	0/100 ml Faecal Coliform	Remarks
16/03/04	NTB2	8	
	NTB4	80	
15/06/04	NTB4	23	
	NTB3	17	
20/09/04	NTB1	70	
	NTB3	17	
	NTB4	50	
	NTB5	170	
	NTB5B	50	
18/09/05	NTB1	110	
	NTB2	70	
	NTB3	210	
	NTB4	500	

Most of the wells in the Samahu area are located in a very dense and populated area. A few samples from the Essuman and Pepesa wells indicate the presence of faecal coliform above the WHO guidelines. These wells are sited very close to roads or near lorry/taxi stations.

Consequently, these wells should be monitored more closely to ascertain the level of contamination in the bore holes.

Table 5.3 Presence of Faecal coliforms at Camp 43

Sampling Date	Sample ID	0/100 ml Faecal Coliform	Remarks
16/03/04	C28	4	
	C29	50	
	C30	13	
	C32	30	
	C33	2	
	C34	2	
	C35	50	
15/06/04	C27	4	
	C28	70	
	C29	70	
	C30	80	
20/09/04	C27	2	
	C28	110	
	C29	90	
	C30	170	
	C31	280	
	C32	90	
	C33	170	
	C34	7	
	C36	280	

Table 5.3 - Presence of Faecal coliforms at Camp 43 - Continuation

Sampling Date	Sample ID	0/100 ml Faecal Coliform	Remarks
11/03/05	C28	4	
	C29	50	
	C30	13	
	C31	13	
	C32	30	
	C33	2	
	C34	2	
	C35	50	
18/09/05	C28	23	
	C29	23	
	C32	4	
	C33	50	

Table 5.4 Faecal coliforms at Samahu

Sampling Date	Sample ID	0/100 ml Faecal Coliform	Remarks
16/03/04	SHMU22	17	
15/06/04	SHMU24	50	
	SHMU25	50	
	SHMU26	30	
20/09/04	SHMU23	8	
	SHMU24	23	
	SHMU25	23	
18/09/05	SHMU25	13	

Table 5.5 Faecal coliforms at Pepesa

Sampling Date	Sample ID	0/100 ml Faecal Coliform	Remarks
16/03/04	PSA09	50	
20/09/04	PSA8	14	
	PSA9	70	
	PSA10	8	

KNUST



BIOLOGICAL PARAMETERS

DATE	REF	DISTRIBUTION	Total Plate Count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using L TSB #1 35° C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 35° C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400		Absent		
16-Mar-04	E4730	ABK20	43 X 10		50	50			
16-Mar-04		ABK20			170	170			
16-Jun-04		ABK20			170	170			
20-Sep-04	E5086	ABK20							
20-Sep-04		ABK20			<2				
16-Dec-04		ABK20			<2				
19-Mar-06	E6612	ABK20			<2				
14-Jun-06		ABK20			50	50			
18-Sep-06		ABK20			50	50			
16-Jun-04	E4912	ABK20			50	50			
16-Mar-04	E4730	ABK21	52 X 10		4	4			
16-Mar-04		ABK21			<2				
16-Jun-04	E4912	ABK21			<2				
16-Jun-04		ABK21			140	90			
20-Sep-04	E6086	ABK21			140	90			
20-Sep-04		ABK21							
15-Dec-04		ABK21			4	4			
19-Mar-06	E6612	ABK21			2				
14-Jun-06		ABK21			<2				
18-Sep-06		ABK21-B			<2				
16-Mar-04	E4912	ABK21-B			<2				
16-Jun-04		ABK21-B			<2				
16-Jun-04	E6086	ABK21-B			90	50			
16-Sep-04		ABK21-B			90	50			
16-Dec-04		ABK21-B			<2				
19-Mar-06	E6612	ABK21-B			50				
14-Jun-06		ABK21-B			<2				
18-Sep-06	E4730	ABK21-B	92 X 10		<2				
16-Mar-04		C27			<2	4			
16-Mar-04	E4912	C27			80	4			
16-Jun-04		C27			80	2			
20-Sep-04	E6086	C27			50				
16-Dec-04		C27			<2				
19-Mar-06	E6612	C27			50				
14-Jun-06		C27			<2				
18-Sep-06		C28	54 X 10		4	4			
16-Mar-04	E4730	C28			17	70			
16-Mar-04		C28			110	110			
16-Jun-04	E4912	C28			220				
20-Sep-04	E6086	C28							

Table 5.6 – Biological Parameters

WATER QUALITY MONITORING - 2004

BIOLOGICAL PARAMETERS

DATE	REF	DESCRIPTION	Total Plate count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using LT8B at 35° C/48hrs	MPN/100ml for Coliform Using BGLBB at 35° C/48hrs	MPN/100ml for faecal Coliform Using E C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400	4	Absent		
19-Mar-08	E5612	C28			17				
14-Jun-08		C28			90	23			
18-Sep-08		C28			140	110			
20-Sep-08		C28			220				
18-Mar-04	E4730	C28	35 X 10		4				
16-Mar-04		C28			90	50			
16-Jun-04	E4912	C28			70	70			
18-Jun-04		C28			70	70			
20-Sep-04	E5085	C28			90	90			
20-Sep-04		C28			90	90			
16-Dec-04		C28			90				
19-Mar-08	E5612	C28			17	50			
14-Jun-08		C28			170	23			
18-Sep-08	E4730	C28(b)							
16-Mar-04		C28(b)			23	13			
12-Jun-04	E4912	C28(b)			23	80			
18-Jun-04	E5085	C28(b)			110	80			
20-Sep-04		C28(b)			110	170			
20-Sep-04		C28(b)			350	170			
18-Dec-04		C28(b)							
19-Mar-08	E5612	C28(b)			23	13			
14-Jun-08		C28(b)			4				
18-Sep-08	E4730	C30	22 X 10		90	8			
16-Mar-04		C30							
16-Jun-04	E4912	C30							
20-Sep-04	E5085	C30							
20-Sep-04		C30							
16-Dec-04		C30							
19-Mar-08	E5612	C30			23				
18-Jun-08		C30			4				
18-Sep-08	E4730	C31			90				
16-Mar-04		C31			170				
16-Jun-04	E4912	C31			170	280			
20-Sep-04		C31			350				
18-Dec-04		C31							
19-Mar-08	E5612	C31							
14-Jun-08		C31							
18-Sep-08		C31							
14-Mar-04		G32			90	30			

Table 5.6 – Biological Parameters - Continuation

BIOLOGICAL PARAMETERS

DATE	REF	DESCRIPTION	Total Plate count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using L TSB at 35° C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 35° C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs Cfu/ml
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400		Absent		
16-Sep-06	E6612	C34			<2				
14-Jun-06		C34			8				
16-Jun-04		C34			4				
16-Dec-04		C34			8	2			
16-Mar-04		C34			30	17			
20-Sep-04	E6086	C34			280	50			
19-Mar-06		C36			8				
16-Sep-06		C36			13				
14-Jun-06	E6612	C36			280				
18-Jun-04	E4912	C36			<2	50			
18-Dec-04		C36			<2				
20-Sep-04	E6086	C36			<2				
19-Mar-06		C38			<2				
18-Sep-06		C38			<2				
14-Jun-06	E6612	C38			90				
16-Jun-04	E4912	C38			<2				
16-Dec-04		C38			<2				
16-Mar-04	E6086	C38			<2	280			
19-Mar-06		C38			17				
18-Sep-06		C38			<2				
14-Jun-06	E6612	ESMN17			<2	17			
16-Jun-04	E4912	ESMN17			<2				
16-Dec-04		ESMN17			<2				
16-Mar-04	E6086	ESMN17			<2	13			
20-Sep-04		ESMN17			110	8			
19-Mar-06		ESMN18			23	4			
18-Sep-06		ESMN18			50				
14-Jun-06	E6612	ESMN18			<2				
16-Jun-04	E4912	ESMN18			50	13			
16-Dec-04		ESMN18			<2				
18-Mar-04	E6086	ESMN18			23	8			
20-Sep-04		HMSO16			<2				
19-Mar-06		HMSP16			<2				
18-Sep-06		HMSP16			<2				
14-Jun-06	E6612	HMSP16			<2				
16-Jun-04	E4912	HMSP16			<2				
16-Dec-04		HMSP16			<2				

Table 5.6 – Biological Parameters - Continuation

WATER QUALITY MONITORING - 2004

BIOLOGICAL PARAMETERS

DATE	REF	DISCRIPTION	Total Plate count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using LTB at 35° C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 35° C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400		Absent		
15-Dec-04		HMSPI18			<2				
16-Mar-04	E4730	HMSPI18	70 X 10		<2				
20-Sep-04		HMSPI18			<2				
19-Mar-08		HNSO11			90				
14-Jun-08	E6612	HNSO11			<2				
14-Jun-04	E4912	HNSO11							
16-Dec-04		HNSO11			50				
16-Mar-04	E4730	HNSO11			50				
20-Sep-04	E6088	HNSO11			<2				
20-Sep-04		HNSO12			<2				
19-Mar-08		HNSO12			<2				
18-Sep-08		HNSO12			<2				
14-Jun-08	E6612	HNSO12			<2				
16-Jun-04	E4912	HNSO12			<2				
16-Dec-04		HNSO12			<2				
16-03-04	E4730	HNSO12			<2				
16-03-04		HNSO12			<2				
20-Sep-04	E6088	HNSO12			<2				
20-Sep-04		HNSO12			<2				
19-Mar-08		HNSO13			<2				
18-Sep-08		HNSO13			<2				
14-Jun-08	E6612	HNSO13			<2				
14-Jun-04	E4912	HNSO13			<2				
16-Jun-04		HNSO13			<2				
16-Dec-04		HNSO13			<2				
16-03-04	E4730	HNSO13	24 X 10		<2				
16-03-04		HNSO13			<2				
20-Sep-04	E6088	HNSO13			110				
20-Sep-04		HNSO13			<2				
19-Mar-08		HNSO14			<2				
18-Sep-08		HNSO14			<2				
14-Jun-08	E6612	HNSO14			<2				
14-Jun-04	E4912	HNSO14			<2				
16-Jun-04		HNSO14			<2				
16-Dec-04		HNSO14			<2				
16-03-04	E4730	HNSO14			<2				
16-03-04		HNSO14			<2				
20-Sep-04	E6088	HNSO14			<2				
20-Sep-04		HNSO14			<2				
19-Mar-08		HNSO-CLINIC							
18-Sep-08		HNSO-CLINIC							
14-Jun-08	E6612	HNSO-CLINIC			<2				

Table 5.6 – Biological Parameters – Continuation

BIOLOGICAL PARAMETERS

Table 5.6 – Biological Parameters – Continuation

WATER QUALITY MONITORING - 2004

BIOLOGICAL PARAMETERS

DATE	REF	DISCRIPTION	Total Plate count Using Plate Count Agar at 35°C/48hrs	MPN/100ml for Presumptive Coliforms Using LTSB at 35°C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 35°C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5°C/24hrs	E.Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30°C/24hrs Gfu/ml
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400	70	Absent		
20-Sep-04	E5085	NTB1			140	70			
20-Sep-04		NTB1			<2				
19-Mar-05		NTB18B			<2				
18-Sep-05		NTB18B			<2				
14-Jun-06	E6612	NTB18B			<2				
18-Jun-04	E4912	NTB18B			<2				
18-Jun-04		NTB18B			<2				
15-Dec-04		NTB18B			<2				
16-03-04		NTB18B			170	23			
20-Sep-04	E5085	NTB18B			110	70			
20-Sep-04		NTB2			50				
19-Mar-05		NTB2			<2				
14-Jun-06	E5512	NTB2			<2				
18-Jun-04	E4912	NTB2			<2				
16-Dec-04		NTB2			50	8			
16-03-04	E4730	NTB2	67 X 10		170	23			
20-Sep-04	E5085	NTB2			23				
20-Sep-04		NTB2			130	23			
19-Mar-05		NTB3			260	210			
14-Jun-06	E5612	NTB3			50	17			
18-Jun-04	E4912	NTB3			50	17			
16-Dec-04		NTB3			50				
16-03-04	E4730	NTB3	54 X 10		<2	23			
18-03-04		NTB3			130	<17			
20-Sep-04	E5085	NTB3			50	<17			
20-Sep-04		NTB3			50	70			
19-Mar-05		NTB4			170	600			
18-Sep-05		NTB4			900	23			
14-Jun-06	E6612	NTB4			170	23			
18-Jun-04	E4912	NTB4			80	23			
18-Jun-04		NTB4			80				
16-Dec-04		NTB4			240	80			
16-03-04	E4730	NTB4	344 X 10		170	70			
20-Sep-04	E5085	NTB4			50	50			
20-Sep-04		NTB4			80	50			
18-Sep-05		NTB4			<2				
18-Mar-06		NTB43			<2				
18-Sep-06		NTB5			<2				

Table 5.6 – Biological Parameters – Continuation

WATER QUALITY MONITORING - 2004
BIOLOGICAL PARAMETERS

DATE	REF	DISCRIPTION	Total Plate count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using LTB at 35° C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 36° C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs Cfu/ml M
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400		Absent		
14-Jun-05	E6612	NTB5			170	4			
15-Jun-04	E4912	NTB5			170	4			
16-Jun-04		NTB5							
16-Dec-04	E4730	NTB5	36 X 10		<2				
16-03-04		NTB5							
20-Sep-04	E5086	NTB5			280	170			
20-Sep-04		NTB5(b)			280	170			
19-Mar-06		NTB5(b)			50	23			
18-Sep-06		NTB5(b)			23				
14-Jun-06	E6612	NTB5(b)			140	4			
16-Jun-04	E4912	NTB5(b)			50	4			
16-Jun-04		NTB5(b)			50				
16-Dec-04	E4730	NTB5(b)							
16-03-04		NTB5(b)			50	23			
16-03-04		NTB5(b)			110	50			
20-Sep-04	E5086	NTB5(b)			23	50			
20-Sep-04		NTB5(b)			110				
18-Sep-05	E6612	PSA 40			<2				
14-Jun-05		PSA 41			<2				
18-Sep-05	E6612	PSA 41			<2				
14-Jun-05		PSA 42			<2				
18-Sep-05	E6612	PSA 42			23	23			
14-Jun-05		PSA 10			<2				
18-Mar-06		PSA 10			70				
16-Sep-05	E6612	PSA 10			90				
14-Jun-05	E4912	PSA 10			90				
15-Jun-04		PSA 10							
16-Dec-04	E4730	PSA 10	55 X 10		<2	23			
16-03-04		PSA 10			23	8			
16-03-04		PSA 10			8	8			
20-Sep-04	E5086	PSA 10			4	4			
20-Sep-04		PSA 10			<2				
19-Mar-06		PSA 19			110				
19-Sep-05		PSA 19							
14-Jun-06	E6612	PSA 19							
16-Jun-04	E4912	PSA 19							
16-Jun-04		PSA 19							
16-Dec-04	E4730	PSA 19			4	4			
16-03-04		PSA 19							
16-03-04		PSA 19							
20-Sep-04	E5086	PSA 19							
20-Sep-04		PSA 19							

Table 5.6 – Biological Parameters – Continuation

WATER QUALITY MONITORING - 2004 BIOLOGICAL PARAMETERS

DATE	REF	DISCRIPTION	Total Plate count Using Plate Count Agar at 35°C/48hrs	MPN/100ml for Presumptive Coliforms Using LTB at 35°C/48hrs	MPN/100ml for Total Coliform Using BGLBB at 35°C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5°C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30°C/2hrs
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400		Absent		
19-Mar-05		PSA6			<2				
19-Sep-06		PSA6			80				
14-Jun-05	E6612	PSA6			170	4			
18-Jun-04	E4912	PSA6			50				
18-Jun-04		PSA6			50				
18-Dec-04	E4730	PSA6	68 X 10		23	23			
16-03-04		PSA6			<2				
20-Sep-04	E5085	PSA6			350	220			
20-Sep-04		PSA6			360	220			
19-Mar-06		PSA7			<2				
18-Sep-06		PSA7			<2				
14-Jun-06	E5612	PSA7			<2				
16-Jun-04	E4912	PSA7			<2				
15-Jun-04		PSA7			<2				
15-Dec-04	E4730	PSA7			<2				
16-03-04		PSA7			<2				
20-Sep-04	E5085	PSA7			<2				
20-Sep-04		PSA7			<2				
19-Mar-05		PSA8			23				
18-Sep-06		PSA8			<2				
14-Jun-06	E5612	PSA8			<2				
16-Jun-04	E4912	PSA8			<2				
16-Jun-04		PSA8			<2				
15-Dec-04	E4730	PSA8			<2				
16-03-04		PSA8			<2				
20-Sep-04	E5085	PSA8			30	14			
20-Sep-04		PSA8			30	14			
19-Mar-06		PSA9			17	4			
18-Sep-06		PSA9			<2	50			
14-Jun-06	E5612	PSA9			90				
16-Jun-04	E4912	PSA9			110				
16-Jun-04		PSA9			110				
16-Dec-04		PSA9			<2				
16-03-04	E4730	PSA9	68 X 10		130	60			
16-03-04		PSA9			17	4			
20-Sep-04	E5085	PSA9			110	70			
20-Sep-04		PSA9			110	70			
16-Jun-04	E4912	SHU22			8				
16-03-04	E4912	SHU22	42 X 10		17	17			
16-Jun-04	E4912	SHU23							
16-03-04	E4730	SHU23							

Table 5.6 – Biological Parameters - Continuation

WATER QUALITY MONITORING - 2004 BIOLOGICAL PARAMETERS

DATE	REF	DISCRIBTION	Total Plate count Using Plate Count Agar at 35° C/48hrs	MPN/100ml for Presumptive Coliforms Using L15B at 35° C/48hrs	MPN/100ml for Total Coliform Using BGLB8 at 38° C/48hrs	MPN/100ml for faecal Coliform Using E.C Medium at 44.5° C/24hrs	E-Coli Present/Absent	Salmonella Present/Absent	Yeast/Mould on Potato Dextrose Agar at 30° C/2hrs Cfu/ml M
		WHO Guideline Values			<2(0)	<2(0)	Absent	Absent	
		EPA Guideline Values			400 170 70	50	Absent		
16-Jun-04	E4912	SHU24	54 X 10						
15-03-04	E4730	SHU24							
15-Jun-04	E4912	SHU26							
16-03-04	E4730	SHU26							
16-Jun-04	E4912	SHU26							
16-03-04	E4730	SHU26							
19-Mar-08		SMHU22							
18-Sep-08		SMHU22							
14-Jun-08	E6612	SMHU22							
16-Jun-04		SMHU22							
15-Dec-04		SMHU22							
16-03-04		SMHU22							
20-Sep-04	E5085	SMHU22							
20-Sep-04		SMHU22							
19-Mar-08		SMHU23							
18-Sep-08		SMHU23							
14-Jun-08	E6612	SMHU23							
15-Jun-04		SMHU23							
16-Dec-04		SMHU23							
16-03-04		SMHU23							
20-Sep-04	E5086	SMHU23							
20-Sep-04		SMHU23							
19-Mar-08		SMHU24							
18-Sep-08		SMHU24							
14-Jun-08	E5512	SMHU24							
16-Jun-04		SMHU24							
16-Dec-04		SMHU24							
16-Mar-04		SMHU24							
20-Sep-04	E5088	SMHU24							
20-Sep-04		SMHU24							
18-Mar-08		SMHU25							
18-Sep-08		SMHU25							
14-Jun-08	E5612	SMHU25							
16-Jun-04		SMHU25							
15-Dec-04		SMHU25							
16-03-04		SMHU25							
20-Sep-04	E5085	SMHU25							
20-Sep-04		SMHU25							
19-Mar-08		SMHU26							
18-Sep-08		SMHU26							
14-Jun-08	E5612	SMHU26							
15-Jun-04		SMHU26							
16-Dec-04		SMHU26							
16-03-04		SMHU26							
20-Sep-04	E5085	SMHU26							
20-Sep-04		SMHU26							

Table 5.6 – Biological Parameters - Continuation



Figure 5.3 SMHU21 (Well at Samahu) –A raised platform with loose structure that can leak water into the well.

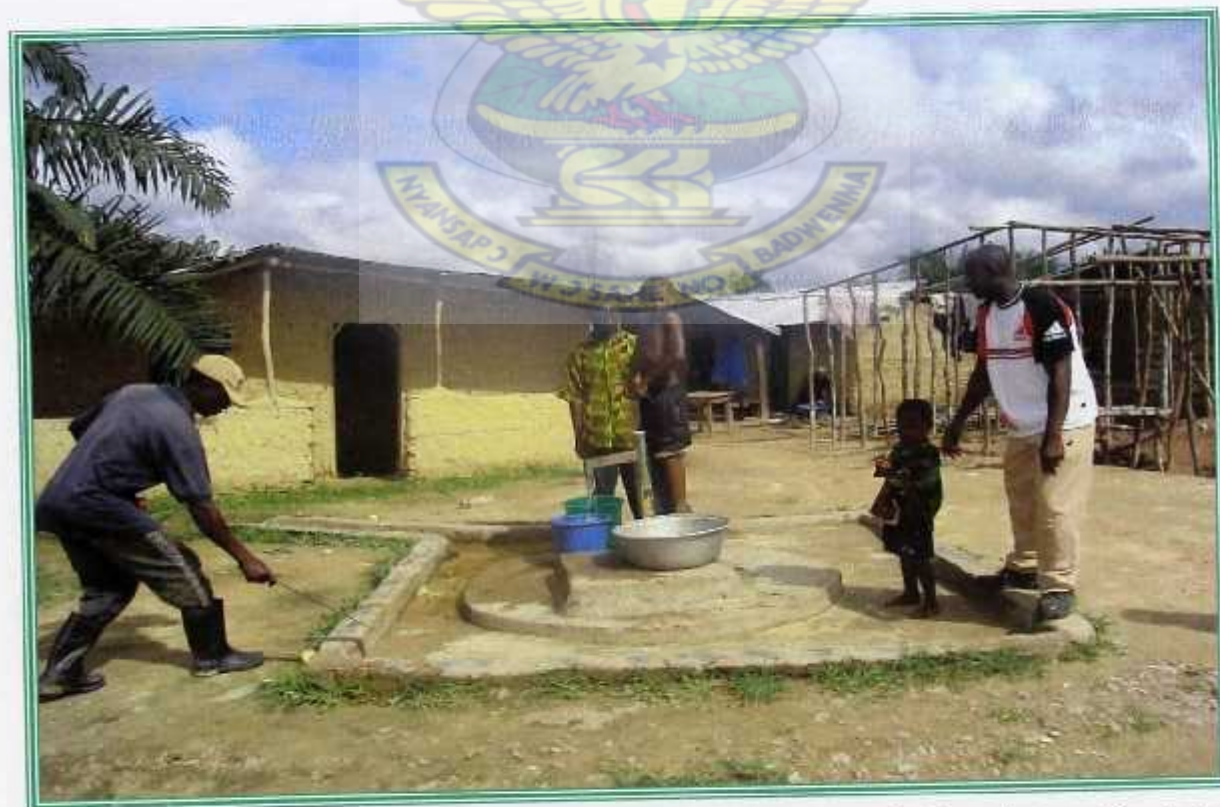


Figure 5.4 Well at Abekoase Community (ABK20) – Low lying platform that can flood during raining.



Figure 5.5 HNSO15 Well at Huniso Community – Located near road and cottage industry



Figure 5.6 HNSO14 Well at Huniso Community – Showing insanitary condition of well platform, a possible source of pollution



Figure 5.7 Well at Huniso (HNSO13) – Low lying platform, near access road and an unhygienic environment, which is a possible source of contamination.



Figure 5.8 Well at Huniso Community (HNSO12) – Low lying platform that can flood during rainfall.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study revealed that pH of the bore holes/wells was between 4.7 and 11.3. Out of the 359 samples analyzed, 3.6 percent were found to be basic and 8.1 percent being acidic. It was found out that, samples with high values were taken immediately after concrete works were undertaken and the impact of the cement used is a factor for this. Samples with low pH values were found to be from wells with unhygienic and unsanitary conditions. The following are specific monitoring points for such occurrences.

- High values of pH were recorded in newly constructed wells; HNSO-Clinic, C27 and C31.
- Acidic values were recorded at Abekoase (ABK20) and Ntebe (NTB-5B, NTB-3 and NTB-4) which were wells located in low lying areas that are prone to flooding during rainy periods.

From the data analyzed and other observations made, mining activities of Gold Fields Ghana Limited, Tarkwa Mine have not impacted negatively on the quality of the borehole and well water in its surrounding communities. The high pH values in some samples were mainly due to cement soon after construction.

All the Communities recorded some levels of faecal coliforms exceeding the WHO standards for potable drinking water except the wells located in the Huniso Community.

- Faecal coliforms in the Ntebe community wells (NTB-4) increased from a low value of 8 MPN /100 ml to an alarming level of 500 MPN/100 ml from 2004 to 2005.
- Other wells at Ntebe, notably NTB-3 had values up to 250 MPN/100 ml.
- ABK21, which is very close to the main Huniso/Samahu road, showed a faecal coliform value of 170 MPN/100 ml.
- Other wells at Essuman (ESMN18), Camp 43 (C28, C30, C33, and C36) had values between 110 and 170 MPN/100 ml. These wells are located in low lying areas.

High values of Manganese were recorded mainly in the Huniso wells. The values at Huniso exceeding the WHO guideline of 0.33 mg/l ranged from 0.37 mg/l to 5.0 mg/l. Out of the 12 wells at Huniso, three had consistent elevated values of Mn. Well HNSO13 increased from 2.54 mg/l in 2003 to 5.0 mg/l in 2005, while HNSO16 increased from 1.0 mg/l in 2003 to 1.48 mg/l in 2005.

Total Dissolved Solids ranged between 0.3 mg/l and 2125 mg/l. Well SMHU24, located at Samahu recorded values above the EPA and WHO guidelines of 1000 mg/l for potable drinking water.

Conductivity values were very low, confirming the low metal dissolution of the Tarkwaian rock.

6.2 Recommendations

The following recommendations will mitigate the impact of contamination in community wells in the northern sector of GFGL's operation:

- The presence of coliforms exceeding both the WHO and EPA standards in some of the boreholes indicates seepage from runoff. The location of the wells should be investigated indepth and moved to higher elevation and boreholes should be drilled to minimum depth of 30m instead of wells averaging 8.5m in depth. It was observed that most of the wells were sunk in the rainy season which basically implies the capturing of water held in clay layers instead of aquifers;
- The consistent high nitrate values recorded at Samahu and Huniso should be investigated since there are little agricultural activities in the area. The geological formation should be looked at critically;
- Wells should not be located in flood plains or low lying areas as they will be prone to contamination. Consequently, newly constructed water facilities should not be used immediately. The water quality must be monitored until the pH stabilizes before they are commissioned. Hygienic conditions of the wells should be improved to avoid contamination. It was observed that wells located near access roads and cottage industries had elevated faecal coliforms values;

- Wells close to roads and cottage industries should be moved to avoid contamination of the water quality. An induction on keeping clean and hygienic environmental for the communities should be organized by GFGL to mitigate the impact of pollution;
- Periodic purging and cleaning of the wells should be carried out;
- The place should be kept hygienic;
- Wells should not be sited at low lying areas; and
- The borehole and wells water must be closely monitored so that contamination levels can be addressed.



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APPENDIX 1

RAINFALL DATA

Rainfall Data_2004, 2005 & 2006 GFGL-TGM

Month	Rainfall/mm		
	2004	2005	2006
Jan	69.3	42.8	30.0
Feb	30.1	68.0	79.5
Mar	71.1	101.0	137.0
Apr	127.5	202.5	195.0
May	141.7	131.5	303.5
Jun	155.8	280.4	278.1
Jul	188.2	37.5	128.3
Aug	48.3	10.6	27.5
Sep	231.3	38.5	114.0
Oct	210.5	22.1	
Nov	142.3	208.3	
Dec	119.5	86.5	
Total	1535.6	1229.7	1292.9



APPENDIX 2

GUIDELINE VALUES

ENVIRONMENTAL PROTECTION AGENCY

**(Environmental Quality Standards for Industrial Effluents,
Air quality and Noise levels)**

REGULATIONS 199.....

In the exercise of the powers conferred on the Minister responsible for the Environmental Science and Technology by Section 28 of the Environmental Protection Agency Act, 1994 (Act 490) and on the advice of the Environmental Protection Agency Board these Regulations are hereby made this day of 199.....

1. These Regulations may be cited as Environmental Protection Agency (Standards for Industrial Discharges into Water Bodies and Water Courses, Standards for Noise) Regulations 1999.
2.
 - (1) The national environmental standards in relation to effluent limitations in general, shall be as set out in schedule 1.
 - (2) Paragraph (1) shall apply to effluents discharged into Water Bodies or Water Courses by Industry
 - (3) Any effluent which:
 - (a) Has one or more of the parameters specified in the first column of the schedule.
 - (b) Does not comply with the corresponding limit specified in the second or third column of the schedule, as the case may be; and
 - (c) Is discharged from industry, shall be deemed to be a pollutant.
3.
 - (1) The national environmental standards for the emission of pollutants from stacks into the atmosphere shall be those set out in Schedule 2.
 - (2) Every factory and mine shall comply with the emission standards set out in Schedule 2.
 - (3) Existing factories and mines shall comply with the emission standards set out in Schedule 2 as from one year of coming into force of the Regulation.
4.
 - (1) The enforcing agency may require that a chimney serving an industrial process be fitted with an aperture for the insertion of a probe to measure the composition, characteristics and quantities of emissions.

- (2) The aperture shall be in the chimney wall and shall be of such size and within such height as the enforcing agency may require.
- (3) The enforcing agency may require that a safe means of access to the aperture be provided for the purpose of monitoring emissions from the chimney.
- (4) Notwithstanding the other provisions of these Regulations, the enforcing agency may decide that certain parameters in Schedule 2 shall not apply to any specific chimney.
5. (1) The national environmental standards for ambient air quality shall be those set out in Schedule 3.
- (2) In exercising its powers under these Regulations, the enforcing agency may take account of the national environmental quality standards set out in Schedule 3.
6. (1) The enforcing agency may use International Standards Organization (ISO) methods or other standard measuring instruments for the purpose of assessing the quality of air.
- (2) Measuring instruments shall, for the purpose of these Regulations include-
- (a) Any standard apparatus for separation any air impurity from the gas or liquid medium in which it is carried;
 - (b) Any standard device to indicate or record air pollution or give warning or excessive air pollution; and
 - (c) Any other device used for the purposes of preventing or limiting air pollution.
7. The environmental noise quality standards shall be the standards specified in Schedule 4.
8. Section 7 shall not, for a period of 1 year as from the commencement of these Regulations, apply to industrial noise if the activity generating such noise has already started before commencement of these Regulations.
9. (1) Noise measurements shall, as far as practicable, be effected at a minimum distance of one meter from the nearest opening of any residential building facing the noise source or from the factory fence and at 1.2 to 1.5 meters above the ground or floor level and away from walls, buildings or at least 3.5m from other sound reflecting surfaces.
- (2) The measurement methods and equipment used shall be those approved by the enforcing agency.
10. (1) Every factory and mine shall submit monitoring returns every month on the quality of industrial effluents, air, noise levels and solid wastes.
- (2) The environmental monitoring report shall be in such form and contain such particulars as the Agency may direct.

Gazette Publication

11. The Agency shall cause to be published in the Gazette notification of any sector-specific standards, guidelines and codes of practice in connection with:

- (a) Matters provided for under these Regulations for the purpose of giving guidance.
- (b) Matters relating to the management of the environment.

Offences and penalty

12. Any person who

- (a) Exceeds the general effluent limitations for industry, standards for noise and standards for air quality contrary to the Regulations;
 - (b) Fails to comply with directives of the Agency to take ameliorative actions;
 - (c) Submit or provides the Agency with information required under any provision of these Regulation which he knows to be false.
 - (d) Fails to submit monitoring report as required under Regulation 10; or
 - (e) Contravenes any provision of these Regulations;
- Commits an offence and is liable on summary conviction to a fine not exceeding ₦2 million or imprisonment for a term not exceeding **one year** or to both and in the case of a continuing offence to a further fine not exceeding ₦200,000 for each day the offence is continued.

13. Interpretation

In these Regulations unless the context otherwise requires:

“Act” means the Environmental Protection Agency, 1994 (Act 490)

“Agency” means the Environmental Protection Agency established by the Environmental Protection Act 1994 (Act 490)

“chimney” means a structure or opening from or through which a product of combustion or an air pollutant is emitted into the atmosphere.

“enforcing agency” means the Environmental Protection Agency, Factories Inspectorate, District Assemblies or Mines Department.

“factory” has the same meaning as in section 83(I) and (II) of the Factories Offices and Shops Act, 1970 (Act 328).

“industrial effluent” means water sullied or contaminated by any matter, in solution or suspension that may cause harm or damage to the environment, derived from its use in connection with an industrial activity.

“industrial process” means any process operated at a factory or mine which may entail a pollutant being emitted into the environment.

“Mine” has the same meaning as in section 84(a) of the Minerals and Mining Law, 1986, PNDCL 153.

“Noise” means any undesirable sound that is intrinsically objectionable or that can cause adverse effects on human health or the environment.

“Industrial noise” means noise generated by a factory or mine.

“smoke” includes all fine, strong, light absorbing particulate matter emitted from or through a chimney, exhaust or from open burning that eventually become suspended in the ambient atmosphere.

“Waterbody” includes underground water, stream, river, canal, lake, pond, reservoir, estuary, lagoon and sea.

“Watercourse” means any natural or artificial channel, pipe or conduit carrying or that may carry water and discharging directly or indirectly into a water body.

SCHEDULE 1
(Regulation.....)
General Effluent Quality Standards for Discharges into Water Bodies or Water Courses

PARAMETER / DESCRIPTION	MAXIMUM PERMISSIBLE LEVEL
1. pH	6 – 9
2. Temperature	<3 ⁰ C above ambient
3. Colour (TCU)	200
4. Oil and Grease (mg/l)	100
5. BOD ₅ (mg/l)	50
6. COD (mg/l)	250
7. Total Dissolved Solids (mg/l)	1000
8. Total Suspended Solids (mg/l)	50
9. Turbidity (NTU)	75
10. Conductivity (µS/cm)	1500
11. Total Coliforms (MPN/100ml)	400
12. E. Coli (MPN/100ml)	10
13. Ammonia as N (mg/l)	1.0
14. Nitrate (mg/l)	50
15. Fluoride (mg/l)	10
16. Phenol (mg/l)	1.0
17. Sulphide (mg/l)	1.5
18. Total phosphorus (mg/l)	2.0
19. Total Cyanide (mg/l)	1.0
20. Free Cyanide	0.2
21. Cyanide as Weak Acid Dissociable (mg/l) -	0.6
22. Total Arsenic (mg/l)	0.5
23. Soluble Arsenic (mg/l)	0.1

24. Cadmium (mg/l)	-	<0.1
25. Chromium (+6) (mg/l)	-	0.1
26. Total Chromium	-	0.5
27. Copper (mg/l)	-	2.5
28. Lead (mg/l)	-	0.1
29. Nickel (mg/l)	-	0.5
30. Selenium (mg/l)	-	1.0
31. Zinc	-	5
32. Mercury	-	0.005
33. Silver (mg/l)	-	0.1
34. Tin (mg/l)	-	5
35. Aluminum (mg/l)	-	5.0
36. Antimony (mg/l)	-	1.5
37. Benzo (a) pyrene (mg/l)	-	0.05
38. Chloride (mg/l)	-	250
39. Sulphate (mg/l)	-	300
40. Chlorine (mg/l)	-	250
41. Trichlorethylene (µg/l)	-	7
42. Total Hardness (mg/l)	-	500
43. Barium (mg/l)	-	0.7
44. PCBs (Trichloronebezene) (µg/l)	-	20
45. Manganese (Mn) (mg/l)	-	0.1
46. Perchloroethylene (mg/l)	-	40
47. Benzene (µg/l) (mg/l)	-	10
48. Influent raw water	-	I** + 15% of influent parameter

Special Standards (Industry)

The threshold value for parameter (s) contained in effluents arising from any operation involving the use of untreated water (i.e. sea, river water, ground water, etc) shall not be of a quality that is 15% worse than the intake water (influent) quality for all measurable parameters of interests, irrespective of the sector industry. Companies operating under the special standards should first seek permission form EPA with regard to the effluents quality.

****Where I** is influent raw water**

SCHEDULE 2

(Regulation.....)

Stack Emission Standards

The following standards are maximum limits for the corresponding pollutant

Pollutant	Applicable to	Standard
(i) Smoke	All stationary fuel burning source	Ringlemann No. 2 or equivalent opacity (not to exceed more than 5 minutes in any period of one hour)
(ii) Solid particles	Any trade, industry or process (other than combustion processes and plants for the manufacture of sulphuric acid)	120mg/m ³
(iii) Sulphuric acid mist or sulphur trioxide	a) Any trade, industry or process (other than combustion processes and plants for the manufacture of sulphuric acid)	120 mg/m ³ as sulphur trioxide
	b) Any trade, industry or process in which sulphuric acid is manufactured.	30,000mg/m ³ as sulphur trioxide
(iv) Fluorine compounds	Any trade, industry or process in the operation of which fluorine, hydrofluoric acid or any inorganic fluorine compounds are emitted.	100mg/m ³ as hydrofluoric acid
(v) Hydrogen Chloride	Any trade, industry or process	200mg/m ³ as hydrogen chloride
(vi) Chlorine	Any trade, industry or process	100mg/m ³ as chlorine
(vii) Hydrogen Sulphide	Any trade, industry or process	5 ppm as hydrogen sulphide gas

(viii)	Nitric acid or oxides or nitrogen	Any trade, industry or process in which the manufacture or nitric acid is carried out	2000 mg/m ³ as nitrogen dioxide
(ix)	Nitric acid or oxides of Nitrogen	Any trade, industry or process other than nitric acid plant	1000 mg/m ³ as nitrogen dioxide
(x)	Carbon monoxide	Any trade, industry or process	1000 mg/m ³ as carbon monoxide

SCHEDULE 3

(Regulation.....)

Ambient Air Quality Standards

Substance	Time Weighted Average (TWA)		Averaging Time
Sulphur Dioxide (SO ₂)	900 µg/m ³	Industrial	1 hr
	700 µg/m ³	Residential	1 hr
	150 µg/m ³	Industrial	24 hr
	100 µg/m ³	Residential	24 hr
	80 µg/m ³	Industrial	1 yr
	50 µg/m ³	Residential	1 yr
Nitrogen Oxides	400 µg/m ³	Industrial	1 hr
	200 µg/m ³	Residential	1 hr
	150 µg/m ³	Industrial	24 hr
	60 µg/m ³	Residential	24 hr
Total Suspended Particulate	230 µg/m ³	Industrial	24 hr
	150 µg/m ³	Residential	24 hr
	75 µg/m ³	Industrial	1 hr
	60 µg/m ³	Residential	1 hr
PM ₁₀	70 µg/m ³		24 hr
Smoke	150 µg/m ³	Industrial	24 hr
	100 µg/m ³	Residential	24 hr
	50 µg/m ³	Industrial	1 hr
	30 mg/m ³	Residential	1 hr
Carbon Monoxide	100 mg/m ³		15 min
	60 mg/m ³		30 min

	30 mg/m ³	1 hr
	10 mg/m ³	8 hr
Hydrogen Sulphide	150 µg/m ³	24 hr
Mercury	1 µg/m ³	1 yr
Lead	2.5 µg/m ³	1 yr
Cadmium	10 – 20 ng/m ³	1 yr
Manganese	1 µg/m ³	24 hr
Dichloromethane (Methylene Chloride)	3 mg/m ³	24 hr
1,2-Dichloroethane	0.7 mg/m ³	24 hr
Trichloroethane	1 mg/m ³	24 hr
Tetrachloroethene	5 mg/m ³	24 hr
Toluene	8 mg/m ³	24 hr
Arsenic trioxide	6 mg/l	Industrial 24 hr
	3 mg/l	Residential 24 hr
Fluoride	10 µg/l	24 hr

SCHEDULE 4

(Regulation)

Ambient Noise Level Standards

ZONE	DESCRIPTION OF AREA OF NOISE RECEPTION	PERMISSIBLE NOISE LEVEL IN dB(A)	
		DAY 0600 - 2200	NIGHT 2200 - 0600
A	Residential areas with low or infrequent transportation	55	48
B1	Educational (school) and health (hospital, clinic) facilities	55	50
B2	Areas with some commercial or light industry	60	55
C1	Areas with some light industry, places of entertainment or public assembly, and places of worship located in this zone	65	60
C2	Predominantly commercial areas	75	65
D	Light industrial area	70	60
E	Predominantly heavy industrial areas	70	70

SCHEDULE 4

Permissible adjustment to measured noise level for intermittent noise

Cumulative period for which intermittent noise is present in any hour	Maximum allowable adjustment above the permissible ambient level (dB _A)
More than 15 minutes	±0
Exceeding 5 minutes but not exceeding 15 minutes	-5
Exceeding 1 minutes but not exceeding 15 minutes	-10
Not exceeding 1 minute	-15

Note 1 : Schedule 4 is for the calculation (of noise level) from its duration of the potential annoyance level where any noise present and measured is intermittent and not measured by statistical method.

Note 2 : These duration adjustments are not applicable when noise being assessed includes discrete noise impulses or consists of repetitive noise with an impulsive character e.g. hammering or riveting.

