ASSESSMENT OF DRINKING WATER QUALITY IN SHALLOW WELLS IN KOITOROR LOCATION OF UASIN GISHU COUNTY, KENYA

BY

MUGUN KIBIWOTT KIPCHUMBA (B. Sc. CHEMISTRY)

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DECLARATION

This thesis is my original work and has not been presented for a degree or award in any other University.

MUGUN KIBIWOTT KIPCHUMBA
N50/CTY/PT/24604/2010

Department of Environmental Sciences

Kenyatta University

.... 29/06/2015

Signature Date

Declaration by supervisors

I/we confirm that the work was carried out under my/our supervision.

Dr. ESTHER L. KITUR

Department of Environmental Sciences

Kenyatta University

.... 29/06/2015

Signature Date

Dr. GLADYS GATHURU

Department of Environmental Sciences

Kenyatta University

.... 29/06/2015

Signature Date

DEDICATION

To my father Philip Kipserem Mugun and late mother, Agnes Jepkurgat Mugun for their love for education.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADC	Agricultural Development Company
ANOVA	Analysis of Variance
APHA	American Public Health Association
ASDS	Agricultural Sector Development Strategy
CAN	Calcium Ammonium Nitrate
DAP	Di-Ammonium Phosphate
DNAPL	Dense Non Aqueous Phase Liquid
EC	Electrical Conductivity
FAO	Food and Agriculture Organization of the United Nations
GOK	Government of Kenya
IARC	International Agency for Research on Cancer
IARC	International Agency for Research on Cancer
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
KARI	Kenya Agricultural Research Institute
KEBS	Kenya Bureau of Standards
KSC	Kenya Seed Company
MDG	Millennium Development Goals
MOWD	Ministry of Water Development
MWI	Ministry of Water and Irrigation
NAAIAP	National Accelerated Agricultural Inputs Access Programme
NCPB	National Cereals and Produce Board
NEMA	National Environment Management Authority
NLCPD	National Leaders Conference on Population and Development

NWC	National Water Commission
NWMP	National Water Master Plan
SPSS	Statistical Package for Social Science
TDS	Total Dissolved Solids
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United State Environmental Protection Agency
WHO	World Health Organization

ABSTRACT

Information on the quality of water in water bodies is important as it forms a vital baseline for among others the detection of undesirable change in water quality. Water supply in the study area is mainly from shallow wells whose quality is influenced by human activities which cause pollution at the land surface. It is unfortunate that the water is used for drinking in the assumption that it is safe for intended use. This is compounded further by the fact that there is no alternative source of water and at the same time data on the status of water in shallow wells within Koitoror location is totally absent. The levels of physicochemical parameters in shallow wells in Koitoror location, Uasin Gishu County, Kenya were investigated over a period of six months between November 2012 to April 2013. The aim of the study was to find out the levels and variations of physicochemical parameters in shallow wells. Water samples from 11 Shallow Wells were collected during the dry and wet season. The physical parameters including Total Dissolved Solids, Electrical Conductivity, temperature and pH were measured on site by the use of HQD40 Multi parameter Meter. Concentrations of nitrate, phosphorus, nitrite and cadmium were determined by the use of DR5000 spectrophotometer in Aquatech Industries Ltd, Nairobi. Data was analyzed using SPSS and the results presented in form of tables and graphs. The study revealed that during the dry season the mean levels of Total Dissolved Solids were 39.08±0.62 mg/L; Electrical Conductivity (μS/cm) 81.97±1.41, Temperature (°C) 14.96±0.28, Phosphorus (mg/L) 0.56±0.02, Nitrate (mg/L) 7.46±0.18, Nitrite (mg/L) 0.05±0.002, pH 5.99±0.03. During the wet season the mean values were, Total Dissolved Solids (mg/L) 41.63±0.66, Electrical Conductivity (μS/cm) 87.39±1.47, Temperature (°C) 14.64±0.35, Phosphorus (mg/L) 0.64±0.02, Nitrate (mg/L) 8.18±0.17, Nitrite (mg/L) 0.06±0.002 and pH 6.10±0.03. There were seasonal variations in the levels of concentrations in the measured parameters other than cadmium which was found to be nil. During the wet season the concentrations were higher in all the measured parameters. Also the study revealed that, the levels of nitrite in both dry and wet season were above the set specifications for drinking water based on KEBS Standards. Based on the tested parameters, the shallow wells in Uasin Gishu County (Koitoro Location) do not meet the threshold values for drinking water as prescribed by KEBS. Residences of Koitoror are therefore advised to seek alternative source of water for drinking purposes. The water can also be treated so as to render it fit for domestic use.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Water has always been an important and life-sustaining drink to humans and other organisms (Alison, 2001). Water quality is one dimension of the human right to safe water which was reconfirmed in 2010 by the United Nations. According to (Rosenstock, 2003) environmental pollution has become a part of our everyday life and that the significance of our environmental factors to the health and well-being of human pollution is increasingly apparent. In fact (Khan, 2004) confirms that environmental pollution is tangled with the unsustainable anthropogenic activities, resulting in substantial public health problems. Environmental pollution is a worldwide problem and its potential to influence the health of human population is great (Feradoum *et al.*, 2007).

Since time immemorial groundwater has been traditionally considered to be a pure form of water because of its filtration through soil and its long residence time on the ground (Emagbetere & Molua, 2012). Water is a universal solvent and contains lots of dissolved constituents and groundwater is therefore not as pure as traditionally assumed and that is why it has been suggested that water pollution is the leading worldwide cause of death and diseases (Pink, 2006).

Improved access to water supply is fundamental to the elimination of poverty and achievement of the Millennium Development Goals. Further, the water we drink is essential ingredients for our wellbeing and a healthy life. Unfortunately according to European Public Health Alliance, (2009) polluted water and air are common throughout the world. In agreement to this, in 1974, the government of Kenya launched the National Water Master Plan whose primary aim was to ensure availability of potable water, at reasonable distance, to all households by the year 2000. It is unfortunate that some people are yet to experience potable water at their homes as of now. For instance, residences in Koitoror location of Uasin Gishu County rely heavily on the shallow wells for both drinking and other domestic use.

Farmers in Uasin Gishu County have invested heavily in mechanized and intensive agriculture and the use of fertilizer so as to boost food production. However, this brings other challenges including pollution of the water resources which has impacts on the soils and the users.

According to World Health Organization (WHO, 2010), the quality of drinking water is an important environmental determinant of health. Therefore it is important to monitor the status of the aquifers as they are continually used.The primary objective of this investigation was to find out the quality of water in the shallow wells in Koitoror Location. Conversely, to explore their suitability for human consumption and domestic use. The physical parameters that were measured included pH, temperature, Electrical Conductivity and Total Dissolved Solids while chemical parameters were nitrate, phosphorus, nitrite and cadmium.

1.2 Problem Statement and Justification

The shallow wells are heavily utilized for socio-economic activities such as for watering livestock, drinking, laundry as well as irrigation. It is unfortunate that the water is used for drinking in the asumption that it is safe for intended use. This is compon further by the fact that there is no alternative source of water and at the same time data on the status of water in shallow wells within Koitoror location is totally absent. Also the shallow wells are vulnarable to human activities and therefore it is important to have data on their quality. This information will enhance formulation of management strategies for these water resources.

The basis of water quality monitoring is to obtain information which will be useful in management of water resources in the country and not the county level alone. It would therefore prove useful in management, control and investigation of pollution cases, classification of water resources, collection of baseline data, water quality surveillance and forecasting water quality. Improved water management, including pollution control and actions to ensure access to adequate and safe water are needed in Koitoror Location.

1.3 Research questions

The research questions which were used during the study are;

1. How do the levels of physicochemical parameters in shallow wells in Koitoror location compare to those of Kenya Bureau of Standards (KEBS)?
2. What is the relationship between the variations in levels of physicochemical parameters and season?

1.4 Hypotheses

The hypotheses which guided the study are;

1. The levels of physicochemical parameters of the shallow wells in Koitoror location are not above the set KEBS standards.
2. There is no relationship between variations in the levels of physicochemical parameters and seasons.

1.5 Objectives of the study

The general objective of the study was:

1. Assessment of drinking water quality in shallow wells in Koitoror Location, Uasin Gishu County Kenya.

1.5.1 Specific objectives

The specific objectives were:

1. To determine the levels of physicochemical parameters in the shallow wells in the study area.
2. To find out whether there is a relationship between variations in levels of physicochemical parameters and seasonal changes.

1.6 Significance and anticipated output of the study

Regular national water quality monitoring, is the backbone of water quality management. Major roles played by Water Resource Management Authority (WARMA) are to establish a water quality data base, produce regular water quality reports depicting the water quality status of the water resources in the different catchment, and disseminate this information. Based on these reports, further management decisions can be made, pollution control measures taken, and rules and regulations governing water use and protecting water sources developed. The results generated from this study will thus be of benefit to WARMA as it will indicate the status of the quality of the shallow wells.

The study makes a contribution to new information on the levels of physicochemical parameters (pH, temperature, EC, TDS, nitrates, nitrites, phosphorus and cadmium). This information is a very useful tool in the formulation of economic resource management strategies in the water sector.

The results generated from the study will be used by other scholars as a source of literature.

The development of the National Water Quality Management Strategy (NWQMS) has been undertaken as a part of developing an updated National Water Resources Management Strategy. This is part of the reforms which the Ministry of Water and Irrigation (MWI), has been undertaking since 2003 following the enactment of the Water Act, 2002 Ministry of Water and Irrigation (2012). The NWQMS comes at a time when most of the water resources in Kenya are threatened with serious water quality degradation. The results generated from this research will thus act as baseline information in terms of quality of the shallow wells in Uasin Gishu County.

Decision makers in the MWI, civil society in Kenya and on the international level will also benefit from the availability of current information on water resources in terms of quality.

The data generated from the research will be of great benefit to the county government of Uasin Gishu more so to the ministry of health and also ministry of water and irrigation. The results will give the actual status of the quality of water on the ground. This will be able to help the relevant authority make informed decision in terms of providing tangible solutions. The county government will be better placed to either provide alternative source of water or provide treatment solution to the residence of Koitoror location.

1.7 The scope, limitation and assumptions of the study

The study concentrated in Koitoror location and looked at the water quality of the shallow wells within a period of six months and as such it did not capture the long term changes. The study was undertaken on the assumption that the shallow wells selected were representatives of all other shallow wells within the same area.

1.8 Definition of terms

a) **Blue baby syndrome:** A disease that affects the oxygen carrying capacity of infant's blood, usually resulting from the consumption of high levels of Nitrate. Also known as methemoglobinemia.

b) **Contaminant:** Any chemical substance that degrades water quality.

c) **Groundwater:** Is water located beneath the earth's surface in soil pore spaces.

d) **Nonpoint source pollution:** source of water contamination from diffuse sources such as agricultural fields.

e) **Shallow Well:** it is a hand dug water well of 16 feet to 65 feet deep and about 3 feet in diameter.

f) **Dry season:** is a season where the amount of rainfall received was between 3 mm to 60 mm.

g) **Wet season:** is a season where the rainfall amount received was between 100 mm to 300 mm.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter looks at the nature of water pollution globally, in particular the ground water and the status of the same in Kenya. This chapter also outlines review of literature on the effects of ground water pollution as influenced by human activities and more so the negativity of fertilizer application.

2.2 Global water situation

Water is a finite and life sustaining resource and covers about 70 % of the physical environment, Fresh water resources are scarce and unevenly distributed. The amount of water available globally is about 1.4 billion cubic kilometers. Of this amount, 97 % is saline, and is in seas and oceans and is a habitat to diverse marine ecosystems. Of the 3 % fresh water, only less than 1 % is found in lakes and rivers, supporting all our developmental activities. About 2 % of the available fresh water resources is locked up in glacial ice at the poles, Ministry of Water and Irrigation (2012). According to the Millennium Development Goals Report, 11% or 783 million people globally, remain without access to improved sources of drinking water. Such sources include shallow wells, household connections, public standpipes, boreholes, protected springs and rainwater collections, (United Nations, 2012).

Kenya has an area of 582,646 km2 out of which 11,230 km2 is covered by water and 571,416 km2 by land. The mean annual rainfall is 621mm, ranging from 250 mm to 750 mm in ASAL areas to 1000 mm to 1690 mm in the coastal belt the central highlands and in the Lake Victoria Basin. The total annual volume of rainwater has been estimated at 360,000 million cubic meters (MCM), contributing to both surface water and groundwater (NWMP, 1992).

Kenya's annual water availability has been estimated to be about 647 m^3 per capita of water (NWMP, 1992) and is expected to drop to about 250 m^3 per capita in 2030 when population is expected grow to 64 million (NLCPD, 2010). Countries with less than 1,000 m^3 per capita of water are regarded as water scarce and so Kenya is considered a water scarce country. Kenya has a population of about 38 million (KNBS, 2009), and it faces enormous challenges in managing its limited water resources. Sustainable integrated water resources management is critical because poor water quality can aggravate water scarcity, Ministry of Water and Irrigation (2012).

Clean, safe and adequate fresh water is vital to the survival of all living organisms and the smooth functioning of ecosystems communities and economies. Declining water quality has become a global issue of concern as human population grows, industrial and agricultural activities expand. Water quality issues are complex and diverse, and deserve urgent national and global attention and action, (UN, 2011).

One of the most important milestones has been the recognition in July 2010 by the United Nations General Assembly of the human right to water and sanitation. The Assembly recognized the right of every human being to have access to sufficient water for personal and domestic uses (between 50 and 100 litres of water per person per day), which must be safe, acceptable and affordable (water costs should not exceed 3 per cent of household income), and should be physically accessible; the water source has to be within 1,000 metres of the home and collection time should not exceed 30 minutes, (UN, 2010).

2.3 Ground water

Groundwater is an important source of water for both drinking and domestic use in many regions of the world. In most parts of the world, groundwater source is the most important supply for the production of drinking water, especially in areas with limited or polluted surface water sources. Groundwater is water located in the saturated zone below the earth's surface. Groundwater is actually surface water that has migrated from the surface through the ground and become stored in porous soils and rocks, (National Water Commission, 2012).

For some communities groundwater may be the only economically viable option because groundwater is typically of more stable quality and also of better microbial quality than surface waters. Groundwater often requires little or no treatment to be suitable for drinking whereas surface waters generally need to be treated, often extensively. It is vital therefore that the quality of groundwater is protected if public health is not to be compromised (WHO, 2006).

Groundwater supplies nearly half of all drinking water in the world UNESCO, (2009). The large volumes of water stored underground in most aquifers have a considerable buffer capacity allowing for water to be withdrawn during periods of drought or little rainfall. This is crucial for people that live in regions that cannot depend on precipitation or surface water as a supply alone, instead it provides reliable access to water all year round, UNESCO (2012).

In 2010, the world's aggregated groundwater abstraction was estimated at approximately 1,000 km^3 per year, with 67% used for irrigation, 22% used for domestic purposes and 11% used for industrial purposes. The top ten major consumers of abstracted water include countries such as India, China, United States of America, Pakistan, Iran, Bangladesh, Mexico, Saudi Arabia, Indonesia, and Italy and this make up 72% of all abstracted water use worldwide, UNESCO, (2009). Groundwater has become crucial for the livelihoods and food security for 1.2 to 1.5 billion rural households in the poorer regions of Africa and Asia, Comprehensive Assessment of Water Management in Agriculture, (2007).

One concern of increased groundwater usage is the diminished water quality of the source over time, reduction of natural outflows, decrease in stored volumes, and decline in levels and water degradation. It is noted with concern that groundwater depletion may result in many negative effects such as increased cost of groundwater pumping, induced salinity and other water quality changes due to human activities, UNESCO, (2009).

2.4 Types and sources of water pollution

Water pollution may be defined as any chemical, biological or physical change in water quality that has a harmful effect on living organisms and makes water unsuitable for drinking and other domestic uses.

There are two main sources of water pollution i.e. point sources and non-point sources. Point sources include those from factories, wastewater treatment facilities, and septic systems. Non-point sources on the other hand are more difficult to identify, because they cannot be traced back to a particular location. These are sources resulting in runoff including fertilizer, sediments, chemicals, construction sites, mines and animal wastes from farms and fields. Landfills can also be a non-point source of pollution, if substances leach from the landfills into the water supplies.

2.4.1 Mining

Mining can have adverse effects on surrounding surface and ground water if protective measures are not taken. The result can be unnaturally high concentrations of some chemicals, such as arsenic, sulfuric acid, and mercury over a significant area of surface or subsurface (http://ngm.nationalgeographic). Dissolution and transport of metals and heavy metals by run-off and ground water is another example of environmental problems with mining, such as the Britannia Mine, a former copper mine near Vancouver, British Columbia. Tar Creek, an abandoned mining area in Picher, Oklahoma that is now an Environmental Protection Agency superfund site, also suffered from heavy metal contamination. Water in the mine containing dissolved heavy metals such as lead and cadmium leaked into local groundwater, contaminating it (http://www.health.state.ok.us – 15th May 2014).

2.4.2. Tetrachloroethylene

Tetrachloroethylene, also known as tetrachloroethene, or perchloroethylene is a chlorocarbon i.e. it contains carbon and chlorine elements. It is a colorless liquid widely used for dry cleaning of fabrics and according to Rossberg *et al.,*(2006) worldwide production was about one million metric tons in 1985.

Tetrachloroethene is a common soil contaminant and it will be present as a dense nonaqueous phase liquid (DNAPL) if sufficient quantities are released. Because of its mobility in groundwater, its toxicity at low levels and its density, cleanup activities are more difficult than for oil spills (Ryoo, 2001; Deckard, *et al.,* 1994).

2.4.3 Nutrients

Plant nutrients such as Phosphates and Nitrates may enter the water through fertilizer runoff, sewage, and livestock and are also found in industrial wastes. These can cause excess vegetation in the water such as algae and weeds, which use up the oxygen in the water and destroy the surrounding marine life and other organisms in the water. Decomposing plants use up the oxygen in the water, disrupting the aquatic life, reducing biodiversity, and even killing aquatic life. This process, called eutrophication, is a natural process, but generally occurs over thousands of years (USEPA, 2009).

2.4.4 Heat (Thermal) Pollution in water

Thermal pollution is the rise or fall in the temperature of a natural body of water caused by human influence. Thermal pollution, unlike chemical pollution, results in a change in the physical properties of water. A common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers. Elevated water temperatures decreases oxygen levels, which can kill fish, and can alter food chain composition, reduce species biodiversity, and foster invasion by new thermophilic species (Goel, 2000).

2.4.5 Sediment Pollution

Sediment pollution consists of mineral or organic solid matter that is washed or blown from land into water sources. This kind of pollution is difficult to identify, as it comes from non-point sources, such as construction sites, agricultural and livestock operations, logging, flooding, and from runoff. Sediment can cause large problems, as it can clog water treatment systems, smother aquatic life, and cause water to become increasingly turbid. And, turbid water can cause thermal pollution, because cloudy water absorbs more solar radiation (http://www.cleanwaterpartnership).

2.4.6 Toxic and Hazardous chemicals

Toxic waste may be liquid, solid, or sludge and may contain chemicals, heavy metals, and dangerous pathogens. They are poisonous byproducts of manufacturing, farming, city septic systems, construction, automotive garages, laboratories, hospitals and other industries. Even households generate hazardous waste from items such as batteries, used computer equipment, and leftover paints or pesticides (http://environment.nationalgeographic./toxic waste-overview/). It is toxic waste material that can cause death, injury or birth defects to living creatures, (Briggs & David, 2012).

2.4.7 Radioactive

This kind of pollution includes wastewater discharges from hospitals, factories and mining sites such as uranium and titanium mines. These pollutants can also come from natural isotopes, such as radon. Radioactive pollutants can be dangerous, and they take many years until radioactive substances are no longer considered dangerous. (http://environment.nationalgeographic./toxic waste-overview/).

2.4.8 Microbial Pollution

Microbiological pollution is the natural form of water pollution that is caused by microorganisms in the raw water i.e. untreated water. Most of these organisms are harmless but some bacteria, viruses, and protozoa can cause serious diseases such as amoeba, dysentery, cholera and typhoid (USEPA, 2009). Microbial and chemical contaminants have been detected in groundwater. The sources of contamination are numerous and include the land disposal of sewage effluents, sludge and solid waste, septic tank effluent, urban runoff, agricultural, mining and industrial practices , (Elizabeth., *et al* 2010). The use of untreated or inadequately treated groundwater has been responsible for waterborne diseases including gastroenteritis, cholera, hepatitis, typhoid fever and giardiasis. The causative agents of these diseases are bacterial and viral pathogens as well as protozoan parasites. In contrast to chemical hazards that may pollute groundwater, resulting in a long-range influence on public health in terms of time, microbiological pollution of groundwater sources has an immediate effect on large numbers of people (Pedley & Howard, 1997; Gerba & Bitton, 1984; Close *et al.,* 2008; Emmanuel *et al*., 2009). Outbreaks of cryptosporidiosis have also been linked to groundwater sources, despite being usually regarded as a surface water problem. A large outbreak of cryptosporidiosis occurred in 1998 in Brush Creek, Texas, USA from the use of untreated groundwater drawn from the Edwards Plateau karst aquifer (Bergmire-Sweat *et al*., 1999)

Lee *et al*., (2002) identified that of 39 outbreaks of waterborne disease in the USA between 1999 and 2000, 17 were due to consumption of untreated groundwater, although approximately half of these outbreaks were reported from individual water supplies, which are not operated by a utility and served less than 15 connections or less than 25 persons. An outbreak of waterborne viral gastroenteritis in the Finnish municipality of Noormarkku affected some 1500-3000 people, i.e. between 25 and 50 per cent of the exposed population. Laboratory investigations confirmed that adenovirus, Norwalk-like virus and group A and C rotaviruses were the principal causative agents. The source of the outbreak was thought to be a groundwater well situated on the embankment of a river polluted by sewage discharges Kukkula (1997).

A detailed analysis of the incidence of waterborne disease in the USA was published in the mid-1980s by Craun (1985). In his summary of data from the period between 1971 and 1982, Craun reports that untreated groundwater was responsible for 51 per cent of all waterborne disease outbreaks and 40 per cent of all waterborne illness.

Between 1971 and 1994, 58 per cent of all waterborne outbreaks were caused by contaminated groundwater systems, although this is in part is due to the higher number of water supplies using groundwater than those using surface water (WHO, 2006).

2.5 Groundwater protection

The use of groundwater as a source of drinking-water is often preferred because of its generally good microbial quality in its natural state. Nevertheless, it is readily contaminated and outbreaks of disease from contaminated groundwater sources are reported from countries at all levels of economic development. However, understanding the impact of groundwater on public health is often difficult. This is made more difficult as many water supplies that use groundwater are small and outbreaks or background levels of disease are unlikely to be detected, especially in countries with limited health surveillance. Furthermore, in outbreaks of infectious disease, it is often not possible to identify the cause of the outbreak and many risk factors are typically involved (WHO, 2006).

Other chemical contaminants of concern in groundwater may also lead to health problems. These include nitrate, uranium and selenium. Of these, nitrate is of concern as it is associated with an acute health effect (methaemoglobinaemia or infantile cyanosis). The scale of the health burden derived from nitrate remains uncertain although it has been suggested to cause significant health problems in some low-income countries where levels in groundwater reach extremely high values (Melian *et al.*, 1999). Nitrate is also of concern given that it is stable once in groundwater with reasonably high oxygen content where it will not degrade. This therefore means that it may accumulate with time in a water resource and this is a long term problem that is expensive and difficult to remediate and whose effect may not be noticed until concentrations become critical (WHO, 2006).

2.5.1 Socioeconomic status on groundwater protection

Socioeconomic status is of great importance when considering the level of investment in groundwater protection which individuals, communities and societies are willing and able to make. Socioeconomic conditions influence the capacity for different groups to protect their environment. For instance, in some communities short-term priorities for resource exploitation supersedes the need for resource protection necessary to secure a long-term livelihood, despite the recognition in the communities of the need for such protection (WHO, 2006).

The poor are usually at greater risk from the adverse effects of poor resource management and it is essential that their needs be properly addressed when developing groundwater strategies. Critical to this approach is to avoid disadvantage for the poor caused by the implementation of groundwater protection policies and strategies. Such disadvantage may occur, for instance, because agricultural use of land is restricted in order to protect groundwater, which may result in reduced incomes and decreased security for poor farmers. Consideration must be given to compensation, financial support, the creation of alternative employment opportunities or provision of new land when no restrictions apply. However, the latter is often difficult to implement and should only be considered where there is strong evidence from consultations that such an approach is acceptable to the communities affected and that the proposed land for relocation is at least the same quality as the land being left, (Howard *et al.*, 2006).

The implementation of groundwater protection measures will sometimes have significant implications for the livelihoods of the households affected and this applies to all countries. For instance, significant changes in land use regulations in developed countries will also have a profound impact on the users of land, water and other resources. Changes may have both positive and negative impacts on some or all of the components of livelihoods. The implications of such impacts in terms of compensation, social services and environmental protection should be taken into account when reaching a decision about what and how land use regulations are applied. Also the population affected must be fully consulted and be willing to accept any restrictions as part of the process of establishing protection procedures (WHO, 2006).

For instance, after the political changes in Germany in 1990, the connection of rural areas in eastern Germany to central water supplies was rapidly developed. This was particularly urgent in some mountainous areas of Erzgebirge, Thuringia, as the supply from individual wells was highly unsatisfactory because aquifers in fractured bedrock fell dry at intervals. They were also vulnerable to short-circuiting with surface water and sewage. Connection to central supplies of high quality and reliable quantity in the 1990s was therefore warmly welcomed by the population. Individual wells were abandoned and sometimes illegally misused as undrained sewage pits. As local aquifers were no longer needed for feeding household wells, their protection was no longer perceived as a priority. However, the introduction of cost recovery for drinking-water significantly increased prices within a few years. At the same time, unemployment rates were very high and available work often poorly paid. As a result, many households struggled financially. This made individual supplies attractive again, and a large number were re-activated illegally (Howard *et al.*, 2006).

The socioeconomic status of communities is likely to influence the type of interventions that will be feasible for groundwater protection. For instance, in low income communities in developing countries with shallow groundwater, the use of pit latrines may not be the preferred technical solution for excreta disposal, as they lead to an increased risk of contamination. However, alternative technologies may be too expensive for the majority of the population to sustain. In this case, some degree of contamination of groundwater may be tolerated in order to reduce a greater health risk caused by the lack of excreta disposal. In urban areas, if contamination is deemed unacceptable, then it is often more cost-effective to provide an alternative (often piped) water supply that uses water from a more distant and protected water source (Franceys *et al.,* 1992).

2.5.2 Population and population density

Population growth often provides an impetus and an avenue for improving protection strategies as the need to secure and conserve high-quality water resources for domestic supply becomes increasingly important. This can provide a strong argument for the need to protect groundwater against pollution. Therefore, increasing population and population density can increase the risk to groundwater from pollution and unsustainable abstraction. Harmonizing the needs for protection of resources against demands from rapidly increasing populations is a key element in groundwater protection (Howard *et al.*, 2006).

The protection of particular groundwater resources is also dependent on whether it is considered a key source of domestic water in the long term. In some cases therefore, other resources (either surface water or more remote groundwater) can satisfy demands for water and the threatened groundwater will not form a key part of the water resources used for supply. This is common particularly in wetter countries where urban groundwater has been abandoned. In other situations, typically much drier counties, alternatives may not exist and groundwater resources will therefore need to be protected (WHO, 2006).

2.5.3 Consultation

In order for policy to be effectively implemented, it is important that there is general support for the overall policy and strategy framework within the country and particularly at the county level. This is an ongoing process and not something that is engaged in only at the start of policy development. It should be seen as a necessary process which supports the development and implementation of resource management policy and strategy (WHO, 2006).

It is essential therefore that there is proper consultation with stakeholders in the development of policy and implementation of groundwater protection plans. A key activity in the initial stages of policy development is to ensure that the views and needs of different stakeholders are properly reviewed and incorporated into the policy being developed as far as possible. The stakeholders and especially water users should also have an opportunity to comment on the policy and strategies developed to ensure that these reflect a position of agreement among key stake holding groups (Howard *et al.,* 2006).

Perceptions and cultural values attached to water are also important to understand in the context of groundwater quality management and protection. Many of these concepts provide a foundation upon which to build effective protection strategies as they attach important religious as well as cultural values on the protection of the water resources including groundwater. Examples include some aboriginal beliefs about the origins and sacred nature of water in Australia. In other examples traditional beliefs may hamper the development of groundwater protection strategies. For instance in Uganda beliefs about the use of certain springs by ancestral spirits prevented action being taken to improve water sources (WHO, 2006).

Consultation should therefore bring in the views of Government, affected interest groups and the views of the broader society. For that reason various consultation exercises may need to be undertaken to ensure that the views of all concerned and in particular those groups whose livelihood may be directly affected are collected and concerns addressed. Very often, these groups are those most directly affected by water resource management through lack of access to safe drinking-water supplies, contamination of water sources and limited water for irrigation (Howard *et al.,* 2006).

An important approach to protection of groundwater is to put an economic and social value on groundwater resources. Most environmental protection activities will result in some increase in the cost of production and distribution of drinking-water and more generally in terms of overall environmental protection. For instance, there may be a requirement to pay compensation to existing land-users or to purchase land in drinking-water catchment areas. The community as a whole should decide what needs to be protected and how much protection it can afford. The introduction of obligatory environmental impact studies in Chile, for example, has included the whole community of affected interests into the decision-making process for the first time (Garcés, 2000).

2.5.4 Legal framework

Legal issues related to water ownership, the means used to control abstraction and polluting activities, and the enforcement of such legislation becomes important now that we are experiencing a lot of water pollution. The protection of groundwater requires an adequate legal framework (Caponera, 1992; Soulsby *et al.,* 1999). As governments move towards the strategic management of the country's water resources, it is often necessary to replace basic common law and property rights with statutory provisions regulating the use, development and protection of water (Caponera, 1992). The framework must be supported by appropriate institutions that are capable of implementing the policies and enforcing the relevant laws and regulations, and these organizations must also have the necessary legal status and powers. The willingness to enforce compliance with pollution control measures and whether regulatory frameworks create incentives for potential polluters to comply are critical in ensuring effective regulation (Lane *et al.,* 1999). Within the general considerations of the scope of environmental legislation, the legitimate demands of economic development must be considered to ensure that a sensible balance is struck between the two (Lane *et al.,* 1999).

2.6 Impacts of water pollution

Globally, nearly one quarter of all deaths and of the total disease burden can be attributed to environmental issues. In children, environmental risk factors account for slightly more than one-third of the disease burden. These findings have important policy implications as the environmental risk factors can be prevented, modified or mitigated by establishing cost-effective interventions (WHO 2008).

Humans are using more and more materials and products that are polluting the water sources that is used for both drinking and other domestic purposes. The problem is further compounded in this 21st century where swelling demand and changing climate patterns are draining rivers and aquifers and pollution is threatening the quality of what remains. Water treatment is often impractical in rural areas, as it usually requires skilled supervision and can be very expensive. It is therefore preferable to select sources that can be protected against contamination (WHO, 2012).

2.6.1 Nitrate

Nitrate, an essential nutrient for plant growth, becomes very dangerous to human health when ingested at high levels. The toxicity of nitrate is thought to be due to its reduction to nitrite. Methaemoglobinaemia, the most commonly reported toxic effect of the ingestion of nitrate-contaminated drinking water, is a condition resulting from the oxidation (by nitrite) of reduced iron, Fe^{2+} in haemoglobin, the oxygen carrier of mammalian blood, to its oxidized form, Fe^{3+}. The resulting methae-moglobin (MeHb) is unable to release oxygen to body tissues because of its high dissociation constant Adam (1980). Infants less than three months of age are more susceptible to methaemoglobinaemia than older infants, children or most adults. Reasons for the greater susceptibility of young infants include their readily oxidizable foetal haemoglobin, their depressed methaemoglobin reductase activity and their incompletely developed capacity to secrete gastric acid and increased susceptibility to gastroenteritis, both of which permit nitrate-reducing bacteria in the gastrointestinal tract to convert nitrate to nitrite Craun *et al.*, 1981. Additionally, in infants under one year of age the relatively low acidity in the stomach allows bacteria to form nitrite. Nitrate also competes with iodine uptake into the thyroid, disrupting thyroid function. (Bloomfeld *et al.*, 1961; Van *et al.*, 1994).

According to the National Institutes of Health American Association of Retired Persons Diet and Health study, it was found that in men, increasing nitrate intake was associated with a more than doubled risk of developing thyroid cancer (Kilfoy *et al.*, 2011). In a second study of a cohort of more than 21,000 Iowa women 55-69 years old who had used the same water supply for more than 10 years, those who drank water with more than 2.5 mg/L of nitrate were more than twice as likely to have thyroid cancer as women whose tap water contained less than 0.36 mg/L nitrate, (Ward *et al.*, 2010).

Thyroid cancer incidence in the United States and worldwide has been on the rise since the 1970s, particularly among women. Since nitrate contamination of drinking water supplies is widespread, the possible link between nitrate and thyroid related health problems are a significant concern (Kilfoy *et al.*, 2009). Human epidemiological studies also point to a link between long-term nitrate ingestion and higher risk of colon and stomach cancer (IARC, 2010).

2.6.2 Phosphorus

Cyanobacteria (blue-green algae), can cause severe water quality problems when waterways are overloaded with phosphorus. Cyanobacteria pose a particular threat because they synthesize a variety of highly toxic chemicals known as cyanotoxins. In aquatic environments, cyanotoxins usually remain contained within the cells of Cyanobacteria and are only released in substantial amounts when the cells die. This occurs when algal blooms die off naturally, and, paradoxically, when chemicals such as copper sulfate are applied to reservoirs to kill algae. Chlorination and other water treatment processes also break open Cyanobacteria cells and release cyanotoxins. (Hitzfeld *et al.*, 2000). These toxins can affect the nervous system, produce intestinal illness and kidney disease, trigger allergic responses and damage the liver (Carmichael, 2000). They may also lead to liver cancer and promote tumor growth

(Falconer, 2005). Even at low levels or following an occasional exposure, cyanobacterial toxins can cause skin rashes, eye irritation and respiratory symptoms. Cyanotoxins that become airborne and are inhaled can cause trouble in breathing. (Backer *et al.*, 2010).

In water, inorganic phosphorus primarily occurs as orthophosphate, which carries a negative charge. Although orthophosphate is soluble in water, it can bind or adsorb onto soil particles. The two types of minerals primarily responsible for orthophosphate adsorption in soils are clays and metal oxides, with fine-grained iron oxides responsible for most orthophosphate adsorption in the soil subsurface. Additionally, soils rich in calcium carbonate can limit phosphorus movement as a result of the formation of calcium phosphate minerals. The amount of orthophosphate that can be adsorbed is limited by the amount of total surface area of the oxides or clays in a soil. When the sorption sites on the mineral surfaces become saturated with orthophosphate or other ions, any additional orthophosphate will remain in solution. When a soil nears or reaches saturation, dissolved phosphorus can be transported to deeper portions of the unsaturated zone and into the underlying aquifer as soil water moves downward, (Domagalski *et al.*, 2012).

Lakes and reservoir sediments serve as phosphorus sinks. Phosphorus-containing particles settle to the substrate and are rapidly covered by sediment. Continuous accumulation of sediment will leave some phosphorus too deep within the substrate to be reintroduced to the water. If an excess of phosphate enters the waterway, algae and aquatic plants will grow wildly, choke up the waterway and use up large amounts of oxygen. This condition is known as eutrophication or over-fertilization of receiving waters. This rapid growth of aquatic vegetation eventually dies and as it decays it uses up oxygen. This process in turn causes the death of aquatic life because of the lowering of dissolved oxygen levels (Kotoski, 1997).

2.6.3 Cadmium

Fertilizers produced from phosphate ores constitute a major source of diffuse cadmium pollution. The solubility of cadmium in water is influenced to a large degree by its acidity. Suspended or sediment bound cadmium may dissolve when there is an increase in acidity (Ros & Slooff, 1987). In natural waters, cadmium is found mainly in bottom sediments and suspended particles (Friberg *et al.,* 1986). Cadmium contained in soil and water can be taken up by certain crops and aquatic organisms and accumulate in the food chain, (WHO, 2007). High intake of cadmium can lead to disturbances in calcium metabolism and the formation of kidney stones. Cadmium has a high renal toxicity, which is not only due to its mode of action but also to its irreversible accumulation in the kidney. The health based guideline value for cadmium in drinking-water is 3 µg/l (WHO, 2004).

2.6.4 pH

Water pH is a measure of its acidity or basicity. It ranges from 0 – 14 pH Units, with 7 being neutral. A pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base. The term pH is really a measure of the relative amount of free hydrogen and hydroxyl ions present in the water at any given time. Water that has more free hydrogen ions (H^+) is acidic, whereas water that has more free hydroxyl ions (OH^-) is basic(http://water.epa.gov/type/rsl/monitoring/vms54.cfm) .

The water pH is affected by chemical constituents in the water and therefore is an important indicator of water that is changing chemically. The pH of water determines both the solubility and biological availability of chemical constituents such as nitrates, phosphorus, nitrogen, and carbon as well as heavy metals such as lead, copper and cadmium. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at acidic pH as opposed to the higher pH levels because they are more soluble in acidic medium. Low pH values may be as a result of the production of CO_2 from microbial respiration, which leads to the lowering of pH of the water (Pelig-Ba *et al.*, 2004). Water pH pollution in stream and groundwater can arise from increased acidity from acid rain, acid groundwater discharge to streams, acid mine drainage, and from industrial and municipal discharges, (http://www.cees.iupui.edu/).

2.6.5 Electrical Conductivity (EC)

Conductivity is a measure of the ability of water to pass an electrical current. It is also an approximate measure of dissolved solids in water. Conductivity is highly dependent on the amount of dissolved solids such as Chlorides, Nitrates, Sulfates, Phosphates, Sodium, Magnesium, Calcium and Iron. Distilled water generally has a very low EC, while sea water has a high conductance. Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature:

the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius, (http://water.epa.gov/).

2.6.6 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in water and can act as an aggregate indicator of the presence of a broad array of chemical contaminants.The most common source of dissolved solids in water is basically from weathering of rocks and general erosion of the earth's surface. Since many minerals are water soluble, high concentrations can accumulate over time in a given water body. Groundwater usually has higher levels of TDS than surface water, since it has a longer contact time with the underlying rocks and sediments (WHO, 2003).

CHAPTER THREE: METHODS AND MATERIALS

3.1 Introduction

This chapter focuses on the location, soil relief, drainage, economic activities and population of the study area; procedures of collection of samples and the analysis of water samples and data.

3.2 Study Area

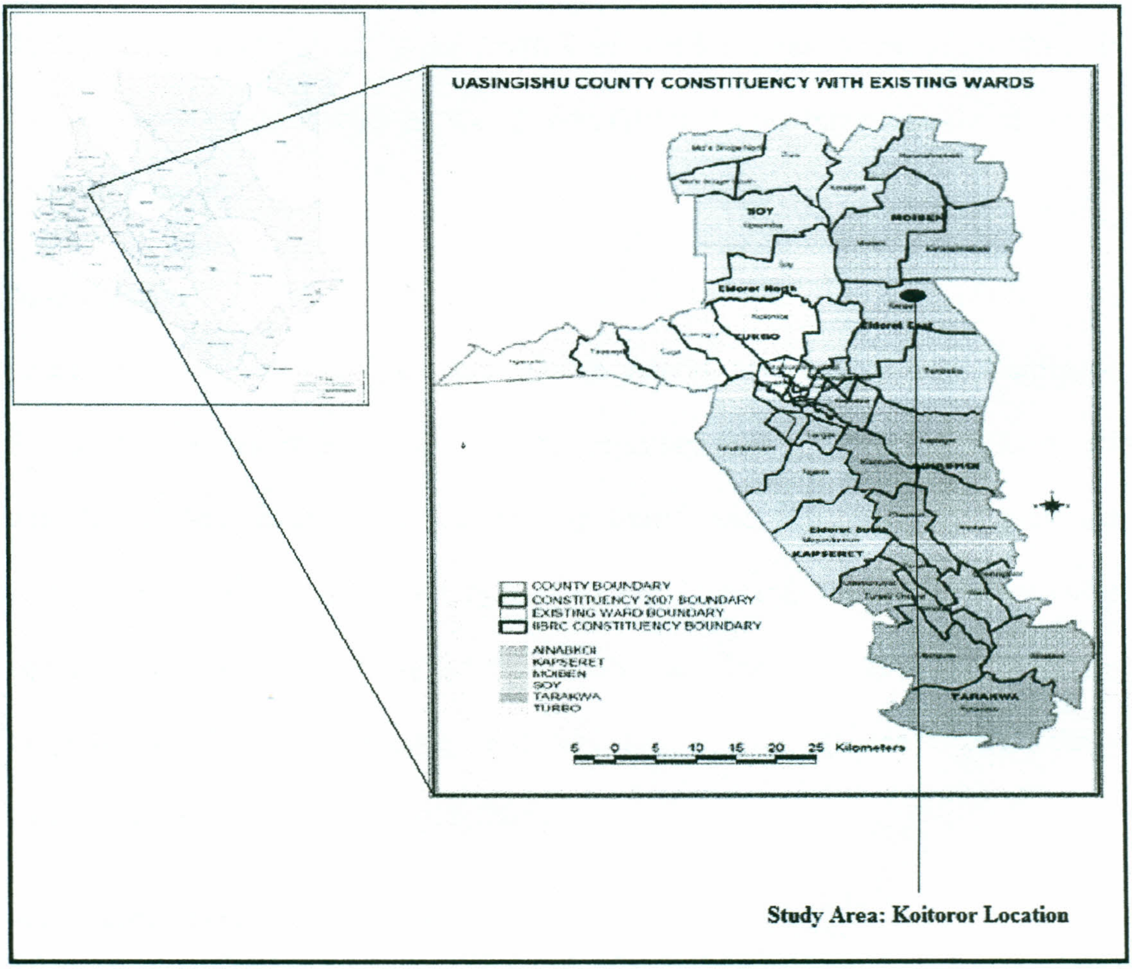

Figure 3.1: Map showing Koitoror location in Uasin Gishu County the study area.

3.2.1 Location

The study area is Koitoror Location in Uasin Gishu County 15 kilometers from Eldoret town. Eldoret town is located about 300km North West of Nairobi on the Trans- African highway and 65km north of the equator. Uasin Gishu County lies between longitudes 34 degrees 50“ east and 35 degrees 37“ West and latitudes 0 degrees 03“ South and 0 degrees 55“ North. The county shares common borders with Trans Nzoia to the North, Elgeyo Marakwet to the East, Baringo to the South East, Kericho to the South, Nandi to the South West and Kakamega to the North West. It covers a total area of 3,345.2 Sq. Km, (Uasin Gishu County Integrated Development Plan 2013-2018).

3.2.2 Climate

Uasin Gishu experiences high and reliable rainfall which is evenly distributed throughout the year. The average rainfall ranges between 624.9 mm to 1,560.4 mm with two distinct peaks occurring between March and September; and May and August. Dry spells occur between November and February. The temperatures range between 7 degrees Celsius and 29 degrees Celsius. Generally these conditions are favorable for livestock keeping, crop and fish farming, (Uasin Gishu County Integrated Development Plan 2013-2018).

3.2.3 Soils, Relief and Drainage

Uasin Gishu is in the Rift Valley Basin an area of internal drainage discharging water into Lake Turkana in the north and Lake Natron in the south. Within this area are several sub-drainage areas discharging water into a number of smaller lakes including Lake Baringo and Bogoria. Much of the Uasin-Gishu is apparently arable, but many areas are interrupted by sub-surface duricrust which causes poor drainage. Areas in the west and north have been deeply dissected by the head waters of the River Nzoia which exposes the basement rock system giving rise to undulating or hilly topography. The Geology is mainly composed of basalt rock outcrops of Pre-Cambrian formations. The top layer of soil is mainly red loam soils and underlying is a layer of murram. The rocks are hard and their extraction requires blasting and heavy machinery. The main soil types are red loam, red clay brown clay and brown loam soils. (Uasin Gishu, Environment Action Plan 2009-2013).

3.2.4 Economic Activities

The main economic activity is agriculture. Agriculture sector comprises of livestock production, veterinary and fisheries. Characteristics of agricultural sector varies widely from predominantly small scale with low external inputs to highly mechanized large scale farming with very high levels of external inputs. Uasin Gishu has a rich agricultural resource base with 80% of the land tenure being privately owned. Private ownership of land has encouraged investment in permanent and long term improvements of development on farms. Small scale farming subsector (0-30 acres) accounts for 75% of the total agricultural produce. (Uasin Gishu Development Plan, 2008 – 2015).

3.2.5 Population

Uasin Gishu County has a population of 828,274 with 135,629 households according to the 2009 census. Koitoror location on the other hand has a population of 4,850 with 896 households. The location has a total area of 20.89 km^2 (Uasin Gishu Development Plan, 2008 – 2015).

3.3 Selection of the wells

Actual study was preceded by a preliminary survey that was done between the months of December 2011 to April 2012. The aims of the survey were: (i) to find out the background information such as the number of shallow wells and fertilizers used in growing of crops in the area, (ii) sources of water for irrigation and for domestic uses, (iii) establish how the water resources are protected from pollution by fertilizers during planting season.

The preliminary study done by the researcher found out that well water is used for drinking, cooking, and washing. The sources of water for domestic and irrigation is from surface water and the shallow wells as there is no piped water. The surface water sources are two streams namely Koitoror and Soin. The two streams are seasonal and therefore the main source of water for irrigation and domestic use is from shallow wells. It was established that there were fifty three shallow wells across Koitoror location. All the farms surrounding the water resources use DAP, CAN and MAP fertilizers to increase their productivity. Out of the fifty three shallow wells, twelve were found to be seasonal as they dried up during the period of December to March, five were inaccessible as the home owners had warned against trespassing, while ten wells were protected as they had a perimeter of concrete wall around them.

Of concern were the remaining twenty six wells which were found to be open without any protection and were at the heart of intensively cultivated farms.

Consequently, out of the twenty six wells, eleven wells were found to have a depth of between 30 to 60 feet deep and about 3 feet in diameter and were distributed out in the agricultural area. The remaining fifteen wells were found to have a depth of above 60 feet which did not meet the threshold of a shallow well. The eleven wells therefore were purposely chosen for the study (Figure 3.2).

3.4 Sampling Points and Frequency

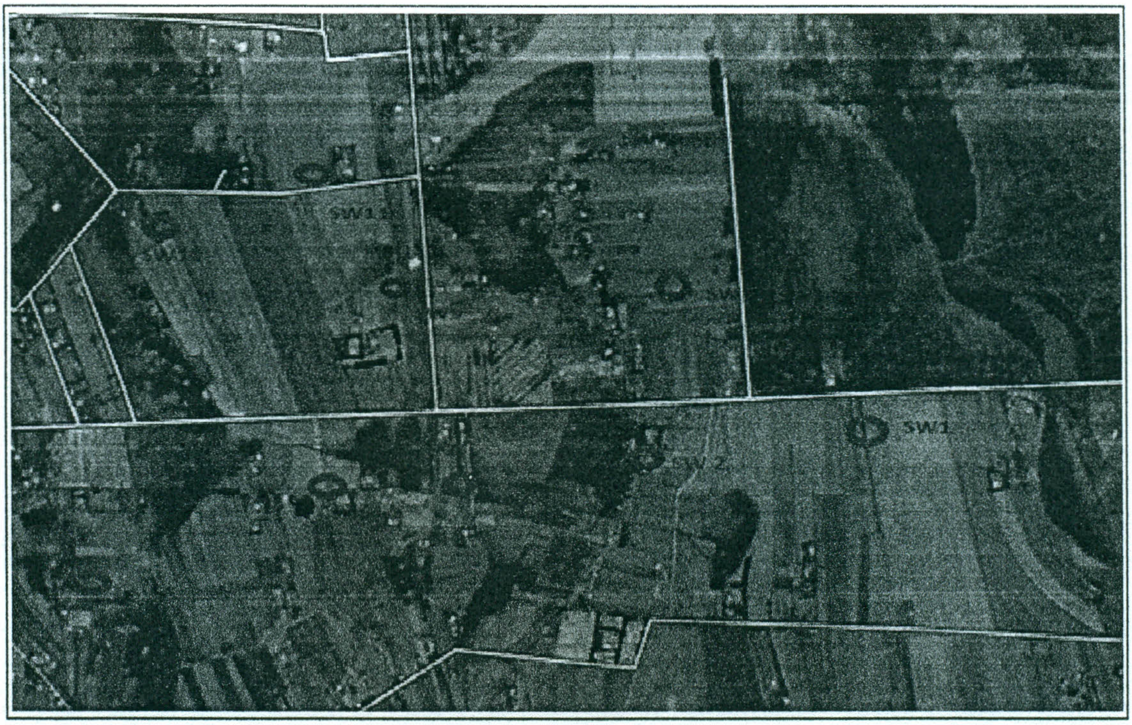

Figure 3.2: Diagrammatic representation of the distribution of the eleven shallow wells

Sampling was carried out twice every month for six months i.e. from November 2012 through to April 2013. Water samples were collected from the shallow wells using a bucket and a rope so as to reach shallow water. A total of 132 water samples were collected and analyzed during the study period.

3.5 Sample Processing and Storage

A bucket tied to a rope was lowered into the well to draw a water sample. Immediately the water was drawn pH, temperature, Total Dissolved Solids (TDS) and Electrical Conductivity were measured before the water was transferred into 500 ml plastic bottles (PET) and capped. The plastic bottles were used as they are uncreative with the water sample and are not as fragile as glass. Since sample analysis for chemical parameters did not commence within forty-eight hours, the samples were preserved in 2M nitric acid. The samples were then placed in a cooler box with a temperature of 4°C and transported to the laboratory for analysis.

3.6 Field and laboratory analysis

Sample analyses were carried out in Aquatech Industries Limited laboratory situated in Nairobi, Kenya. At the laboratory, water samples for analysis of nitrate, nitrite and phosphorus were filtered through distilled water washed 47mm diameter filter (APHA, 1998). Calibration of the SensIon5 meter for pH, TDS, EC and temperature analysis was calibrated on site before commencement of analysis. The spectrophotometer (DR5000) on the other hand was calibrated in the laboratory before the analyses were carried out.

3.6.1 Temperature

Water temperature was measured by the use of a portable meter (SensIon5) from HACH. The probe was immersed in water and allowed to stabilize for about one minute before the reading was taken in °C.

Figure 3.3: The researcher drawing water from one of the wells using a rope and a plastic container.

3.6.2 Total Dissolved Solids (TDS)

The TDS was measured using a multi- parameter meter (SensIon5) from HACH. The probe was immersed in water and allowed to stabilize for a few minutes before the reading was taken in mg/L.

Figure 3.4: Onsite measurements of the physical parameters (pH, TDS, EC & Temperature) at the sampling sites.

3.6.3 Electrical Conductivity (EC)

Water EC was measured using a multi parameter meter (SensIon5) from HACH. The probe was immersed in water and allowed to stabilize for a few minutes before the reading was taken in μS/cm and the reading was taken at that temperature.

3.6.4 pH

Water pH was measured with a portable pH meter with automatic temperature compensation at 25 °C (SensIon1) from HACH. The probe was lowered directly into the water sample allowed to stabilize for about one minute and the pH read and the reading was taken at that temperature.

3.6.5 Nitrate (NO_3-N)

Nitrate-Nitrogen concentration was determined calorimetrically by the Cadmium Reduction Method. A volume of 10 ml of the sample was measured into a sample cell where the reagent (NitraVer5) was added capped and it was shaken for one minute. Cadmium metal reduces nitrates in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution proportional to the amount of nitrate present in the sample. Color intensity was measured using a spectrophotometer at 500 nm. Standards of known NO_2-N concentrations i.e. 10 and 50 mg/L were subjected to the same treatment as water samples and the readings used to determine actual concentration of nitrate.

3.6.6 Phosphorus (PO_4-P)

Phosphorus was determined calorimetrically by the Ascorbic Acid method. A volume of 10 ml of the sample was measured and transferred into a sample cell. One powder pillow of PhosVer3 was then added, capped and then swirled for thirty seconds. Orthophosphate reacts with molybdate in an acid medium to produce a mixed phosphate/ molybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue color. Color intensity was measured using a spectrophotometer at 880 nm. Phosphate Standard, 50 mg/L PO_4^{3-} was subjected to the same treatment as water samples and the readings used to determine actual concentration of phosphorus.

3.6.7 Cadmium

Cadmium was determined calorimetrically using TNT852 Cadion method. A volume of 2 ml of the sample was measured and transferred into the TNT vial. Cadion forms a complex with cadmium. The reduction in the color intensity of the cadion was used for the determination of cadmium. Test results were measured at 552 nm. Cadmium Standard of 0.02 mg/L was subjected to the same treatment as water samples and the readings used to determine actual concentration of cadmium.

3.6.8 Nitrite (NO_2-N)

It was determined calorimetrically by USEPA Diazotization Method 8507 where 10 ml of the sample was measured and transferred into a 10 ml sample cell. One powder pillow of NitriVer3 was then added and the mixture shaken until all the powder had dissolved. Nitrite in the sample reacts with sulfanilic acid to form an intermediate diazonium salt. This couples with chromotropic acid to produce a pink colored complex which is directly proportional to the amount of Nitrite present in the water sample. Test results were measured at 507 nm. Nitrite Standard of 0.150 mg/L was subjected to the same treatment as water samples and the readings used to determine actual concentration of Nitrite in the sample.

3.7 Data analysis and presentation

The data obtained were the concentrations of (NO_3-N, NO_2-N, PO_4-P and Cd) which were then analyzed using computer package (SPSS) upon which one way ANOVA, T-Test and Pearson Correlation were computed. The analyzed data were then presented using bar charts, graphs and tables that served as useful means of bringing out various comparisons between the test variables in the data collected.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents findings on the physicochemical characteristics of the shallow wells investigated. A comparison of the levels in concentrations of the nutrients and Cadmium recorded in the shallow wells is also presented. At the end of the chapter, conclusions drawn from the investigation as well as the recommendations on the way forward are outlined.

4.2 Physicochemical Parameters

4.2.1 Total Dissolved Solids (TDS mg/L)

The mean TDS of the eleven shallow wells investigated were 39.08±0.62 (mg/L) and 41.63±0.66 (mg/L) during dry and wet season respectively (Table 4.1).

Table 4.1: Mean values of the Physical parameters of the wells during the wet and dry season during the study period: November 2012 to April 2013.

Parameter	Dry Season Mean±SE	Wet Season Mean±SE	p-value
TDS(mg/L)	39.08±0.62	41.63±0.66	0.005
EC(μS/cm)	81.97±1.41	87.39±1.47	0.009
Temperature (°C)	14.96±0.28	14.64±0.35	0.471
pH	5.99±0.03	6.10±0.03	0.018

The TDS measured in the shallow wells showed modest variations throughout the study period (Fig. 4.1). The TDS recorded ranged from 33.2 mg/L in shallow well 9 in February 2013 (rainfall of 3.5 mm) to 55.6 mg/L in shallow well 2 (Table 4.2) in April 2013 (rainfall of 262.9 mm). The mean TDS recorded at the wells during the study ranged from 34.53 mg/L in shallow well 10 to 49.63 mg/L in shallow well 2. High mean TDS levels were recorded during the wet season.

Table 4.2: Total Dissolved Solids during the study period (Nov 2012- April 2013).

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	36.2	49.9	47.8	44.8	42.7	39.3	38.9	38.2	34.8	35.2	33.7
Dec	35.8	48.7	46.3	44.3	43.6	38.7	39	38.9	35.9	34.6	34.8
Jan	34.9	47.1	45.8	42	42.8	36.5	38.2	35.4	33.5	33.2	33.9
Feb	34.8	46.9	45.2	42	43.2	35.5	38	35.1	33.2	34	34.2
Mar	36.7	49.6	47.8	45.1	44	39.2	40.1	39.6	36.9	34.9	36.5
Apr	38.3	55.6	49.6	47.8	46.8	42	43.9	44.2	38.1	35.3	38.6
Aver	36.12	49.63	47.08	44.33	43.85	38.53	39.68	38.57	35.4	34.53	35.28

The levels of TDS in all the wells decreased in concentration from November to February and suddenly increased in the months of March and April (Fig. 4.1). For instance in SW2 (Table 4.2) the levels of TDS was 46.9 mg/L in February which was the driest month with rainfall of 3.5 mm (Table 4.3), while it was 55.6 mg/L in April (Table 4.2) which was the wettest month with 262.9 mm of rainfall (Table 4.3).

Table 4.3: Amount of rainfall during the study period

Time	Nov	Dec	Jan	Feb	Mar	April
Rainfall (mm)	32.2	152.8	58.7	3.5	122.8	262.9

Table 4.4: Mean concentrations of the measured parameters during the Dry season.

SW	TDS mg/L	EC µS/cm	Temp(°C)	PO$_4$ mg/L	NO$_3$ mg/L	NO$_2$ mg/L	pH
KS	1000	NS	NS	2.2	50	0.003	6.5 – 8.5
SW1	35.32 ± 0.34^{ab}	72.45±1.33a	15.98±0.14ab	0.37±0.05a	7.57±0.10c	0.045±0.004b	5.72±0.03a
SW2	48.02 ± 0.59^{g}	100.37±1.45e	16.62±0.07b	0.96±0.05d	10.18±0.38e	0.060±0.004c	6.33±0.06cd
SW3	46.37 ± 0.48^{f}	98.08±0.87e	13.18±0.25a	0.36±0.02a	8.48±0.14c	0.063±0.001b	5.88±0.06ab
SW4	43.18 ± 0.54^{e}	93.52±0.31d	15.20±1.08	0.71±0.03c	7.40±0.13b	0.023±0.002a	5.75±0.07a
SW5	42.88±0.09e	90.73±0.20d	14.35±1.60ab	0.64±0.01c	7.00±0.20b	0.062±0.003c	5.87±004ab
SW6	37.07±0.77cd	77.88±1.86bc	17.07±1.13b	0.70±0.01c	8.72±0.17d	0.066±0.002c	5.90±0.04ab
SW7	38.33±0.15d	80.98±0.37c	16.68±0.30b	0.34±0.01a	6.73±0.29c	0.048±0.002	6.01±0.04b
SW8	36.47±0.62bc	76.50±1.41b	15.13±0.41ab	0.52±0.04b	5.63±0.24b	0.070±0.002c	5.75±0.07a
SW9	33.87±0.30a	69.85±1.42a	12.78±0.20a	0.43±0.02ab	4.93±0.23a	0.040±0.002b	6.24±0.04c
SW10	34.28±0.37a	70.50±1.32a	13.62±0.11ab	0.66±0.02c	8.47±0.14d	0.072±0.003c	5.96±0.08ab
SW11	34.05±0.19a	70.82±0.24a	13.97±1.00ab	0.52±0.05b	6.90±0.23c	0.051±0.005b	6.46±0.08d
Pvalue	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

NB: Mean values followed by the same small letter(s) within the same column are not significantly different both for dry and wet season (one-way ANOVA).

Table 4.5: Mean concentrations of the measured parameters during the Wet season.

SW	TDS mg/L	EC µS/cm	Temp(oC)	PO$_4$ mg/L	NO$_3$ mg/L	NO$_2$ mg/L	pH
KS	1000	NS	NS	2.2	50	0.003	6.5 – 8.5
SW1	36.87±0.53	76.98±0.87a	14.67±0.12e	0.46±0.04a	7.50±0.06c	0.048±0.002b	5.81±0.01a
SW2	51.27 ± 1.45^{e}	111.25±4.13e	15.48±0.06f	1.05±0.05c	10.82±0.16g	0.067±0.001de	6.39±0.04cd
SW3	47.85 ± 0.57^{d}	101.33±1.43d	10.83±0.13a	0.50±0.03a	8.88±0.14de	0.067±0.002de	5.89±0.02ab
SW4	45.88 ± 0.64^{cd}	97.23±0.73cd	13.52±0.14c	0.76±0.01b	7.92±0.12c	0.028±0.003a	5.93±0.02ab
SW5	44.95 ± 0.62^{c}	93.43±051c	10.75±0.07a	0.74±0.04b	7.55±0.12c	0.070±0.002e	6.05±0.06ab
SW6	40.10 ± 0.78^{b}	82.47±0.81b	19.62±0.05h	0.83±0.02b	9.38±0.14f	0.078±0.002f	6.01±0.05ab
SW7	41.17 ± 0.85^{b}	85.08±0.68b	19.40±0.11h	0.48±0.04a	7.65±0.08c	0.057±0.001c	6.23±0.07c
SW8	41.23 ± 1.02^{b}	84.45±1.38b	13.32±0.07c	0.56±0.01a	6.55±0.11b	0.079±0.002f	5.99±0.06ab
SW9	36.92 ± 0.44^{a}	77.27±0.71a	14.23±0.10d	0.44±0.02a	5.90±0.15a	0.047±0.002b	6.32±0.07c
SW10	35.07 ± 0.19^{a}	75.17±0.67a	16.57±0.09g	0.73±0.02b	9.28±0.15ef	0.082±0.001f	5.94±0.10ab
SW11	36.68 ± 0.66^{a}	76.67±1.08a	12.63±0.11b	0.54±0.03a	8.57±0.24d	0.062±0.002cd	6.53±0.02d
Pvalue	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

NB: Values expressed as (Mean±SE), KS: Kenya Bureuea of Standards 3rd Edition- 2007, NS: No set Standard, <: Less Than.

Using ANOVA one way, there was a significant difference between the dry and wet season at p-value of 0.005 (Table 4.1) and also among the wells (p <0.001). both for dry and wet season. For instance, in shallow well 6 TDS ranged from 37.07±0.77

mg/L(rainfall of 94.4 mm) to 40.10±0.78 mg/L (rainfall of 538 mm) with a mean of 38.59±0.78 mg/L. Whereas for shallow well 8 the TDS ranged from 36.47±0.62 mg/L(rainfall of 94.4 mm) to 41.23±1.02 mg/L (rainfall of 538 mm) with a mean of 38.85±0.82 mg/L. Also, TDS in shallow well 10 ranged from 34.28±0.73 mg/L (rainfall of 94.4 mm) to 35.07±0.19 mg/L (rainfall of 538 mm) with a mean of 34.68± 0.46 mg/L.

Variations in TDS in water are determined by the type of soils at the catchment area, the geological nature of the drainage basin and human activities (Payen, 1986; Adeniji and Mbagwu, 1990; Maitland, 1994). The low soil organic matter content in Uasin Gishu County results in low water holding capacity and may lead to soil erosion by runoff water during the rains (NAAIAP, 2014)

The high TDS concentrations during the wet season can be linked to human activities which take place in Uasin Gishu around the months of March and April. This is the climax of planting season where farmers prepare themselves in terms of land preparation (tilling/ digging), availability of the necessary inputs including seeds and fertilizer and ultimately takes advantage of the heavy rainfall to plant the various crops.

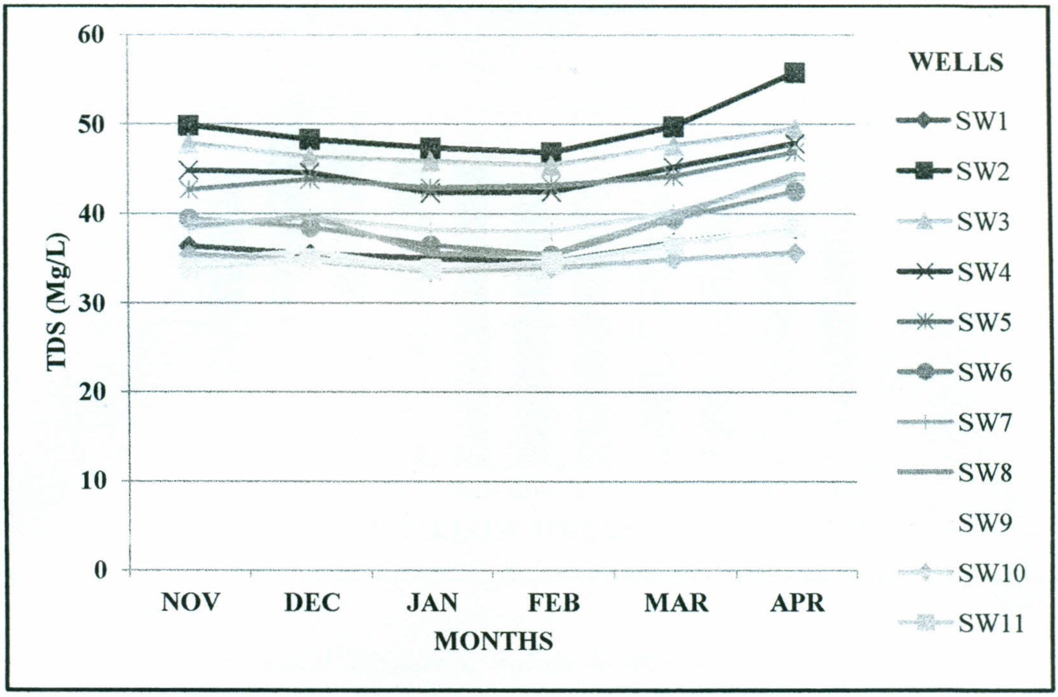

Figure 4.1 Average variations in TDS values in all the wells investigated during the study period.

The high values of TDS in SW2 could be attributed to the fact that the well is located at the heart of cultivated piece of land. The well has no vegetation cover around it which implies that during rainy season there will be a lot of runoff directly into the well. It is also a family well and as such not mainly used by many people hence it is not disturbed most of the time which means that during the dry season the water is stagnant in nature.

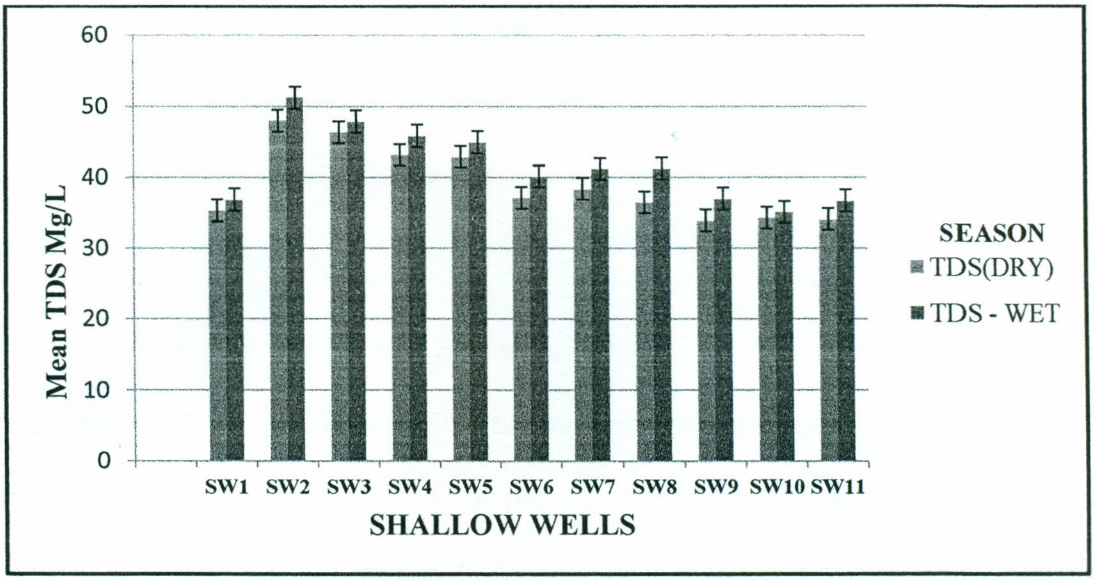

Figure 4.2 Mean Total Dissolved Solids in the shallow wells studied between November 2012 to April 2013, Vertical bars indicate ±SE.

It was noted that SW1, SW6, SW8, SW9, SW10 and SW11 exhibited some variations during the study period. Also SW6 has a buffer region of about one meter stretch that is rich in vegetation without any cultivation. This could therefore slow down the flow of the runoff reaching the well directly. For SW8 the northern region is a grazing area for livestock whereas the southern part is cultivated land. The fluctuations in TDS values in this well can therefore be attributed to the mixture of fertilizer runoff and animal droppings.

Total Dissolved Solids ranges at the study area do not differ appreciably from those of other shallow wells in the world. According to a study done by Emagbetere *et al.*, 2014, in Delta State, Nigeria the levels of TDS were much lower than those from the study area but within the same range with values ranging from 8.5 mg/L to 111.5 mg/L. The quality of groundwater from 129 boreholes in the Sawla-Tuna-Kalba district in the Sahelian region of northern Ghana established that the levels of TDS ranged from 42.3 – 740 mg/L (Cobbina *et al*., 2012). Similarly, between the years 1992 – 2009 the levels of TDS in ground water ranged from 14.5 – 1,000 mg/L in 48 wells investigated in river basin and aquifer systems throughout the United States (Gross *et al*., 2012).

The values of TDS in the study area were found to be quite low compared to those from North–East zone of Bhiwadi industrial area (Alwar) Rajasthan in India where it ranged from 366 to 2200 mg/L in the pre monsoon period (Yadav *et al,*. 2012). Also those from upper Bhatsai region in Maharastra in Malaysia, the TDS ranged from 181.55 to 690.96 mg/L (Pradhan and Pirasteh, 2011). A study done by Zhou Xun *et al.,* 2007, showed that the levels of TDS in groundwater in the coastal plain near Beihai, Guangxi, China had a mean value of 10 mg/L which was low as compared to that of the study area with mean value of 39.08 mg/L. The permissible limit of TDS of drinking water is 1000 mg/L. The observation shows that the TDS is within the permissible range as prescribed by Kenya Bureau of Standards (KS 459-1, 2007).

4.2.2 Electrical Conductivity (μS/cm)

Electrical Conductivity showed modest variations during the study period (Table 4.6). Mean Electrical Conductivity varied from 105.87 μS/cm in shallow well 2 to 72.77 μS/cm in shallow well 10 (Table 4.6). High electrical conductivity was recorded during the time of high rainfall. The highest value of electrical conductivity recorded was in shallow well 2 in April 123 μS/cm (rainfall of 262.9 mm) while the lowest was 66.0 μS/cm in shallow well 9 and this was in February (rainfall of 3.5 mm) (Table 4.3).

Table 4.6: Values of Electrical Conductivity during the study period (Nov 2012 – April 2013).

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	76.6	105	100.7	94.4	90.1	83.0	82.2	80.8	73.8	74.5	71.5
Dec	75.3	101	98.7	95.3	91.7	80.2	82.9	81.1	75.6	73.2	73.9
Jan	70.3	98.9	97.3	93.1	90.9	77.9	80.6	75.1	69.8	69.1	70.6
Feb	70.4	97.3	96.1	92.8	91.2	72.9	80.3	73.4	66.0	67.7	70.3
Mar	76.1	110	99.3	96.9	93.7	82.6	85.9	83.3	77.0	75.1	76.1
Apr	79.6	123	106	99.3	94.6	84.5	86.4	88.6	79.3	77.0	79.8
Aver	74.72	105.87	99.68	95.3	92.03	80.18	83.05	80.38	73.58	72.77	73.7

Using one way ANOVA (Table 4.4 and 4.5 on page 44), there was a significant difference in electrical conductivity among the wells and also between wet and dry seasons ($p<0.001$).

The high levels of electrical conductivity recorded during the wet season in the wells (Fig. 4.3) could be attributed to the seasonal variations in rainfall and human activities responsible for an increase in total dissolved solids. During the wet season, a lot of water enters the wells and it is also the season where the farmers are ploughing and planting and a lot of fertilizers are used which may be carried into the wells. The high value in electrical conductivity recorded in shallow well 2 is due to the fact that the well has no vegetation cover and it is also at the heart of cultivated land while low values in shallow well 10 (Fig. 4.3) could be attributed to less water runoff reaching the well as it has a concrete slab on top. Variations in electrical conductivity in wells is attributed to marked season variations in rainfall, human activities water residence in the reservoir, and types of soil in catchment area (Payne, 1986, Adeniji and Mbagwu 1990).

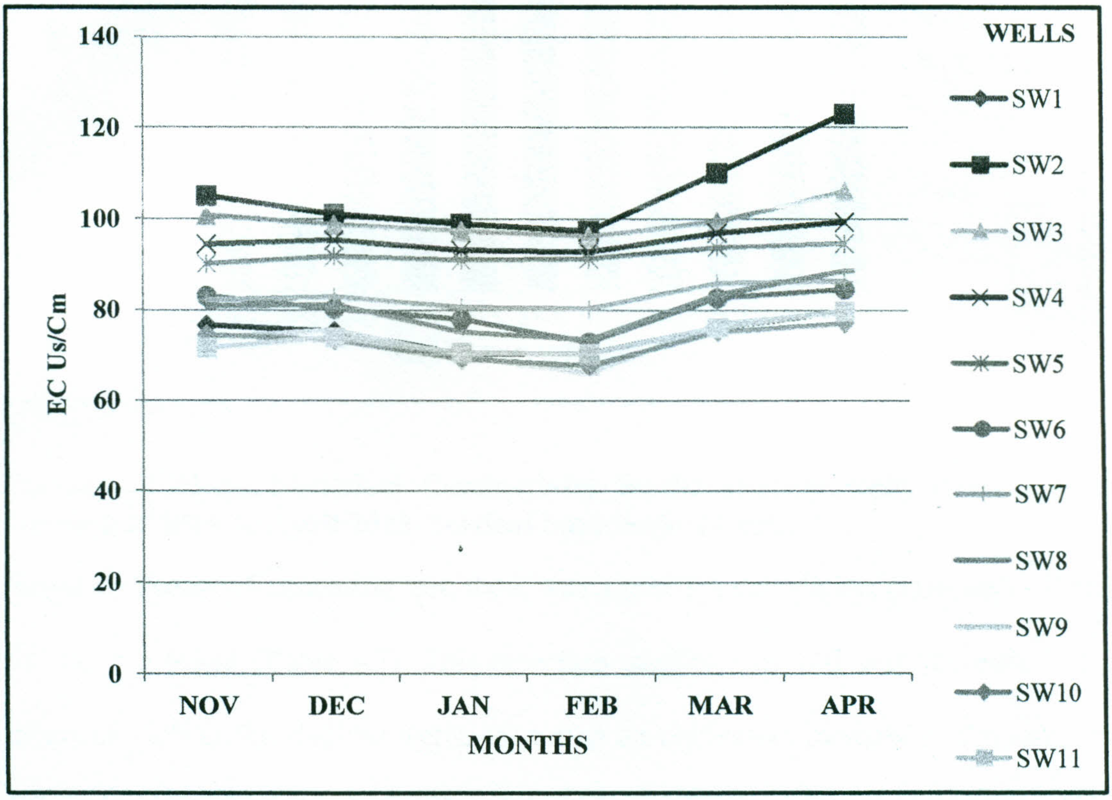

Figure 4.3 Average variations in EC values in all the wells investigated during the study period.

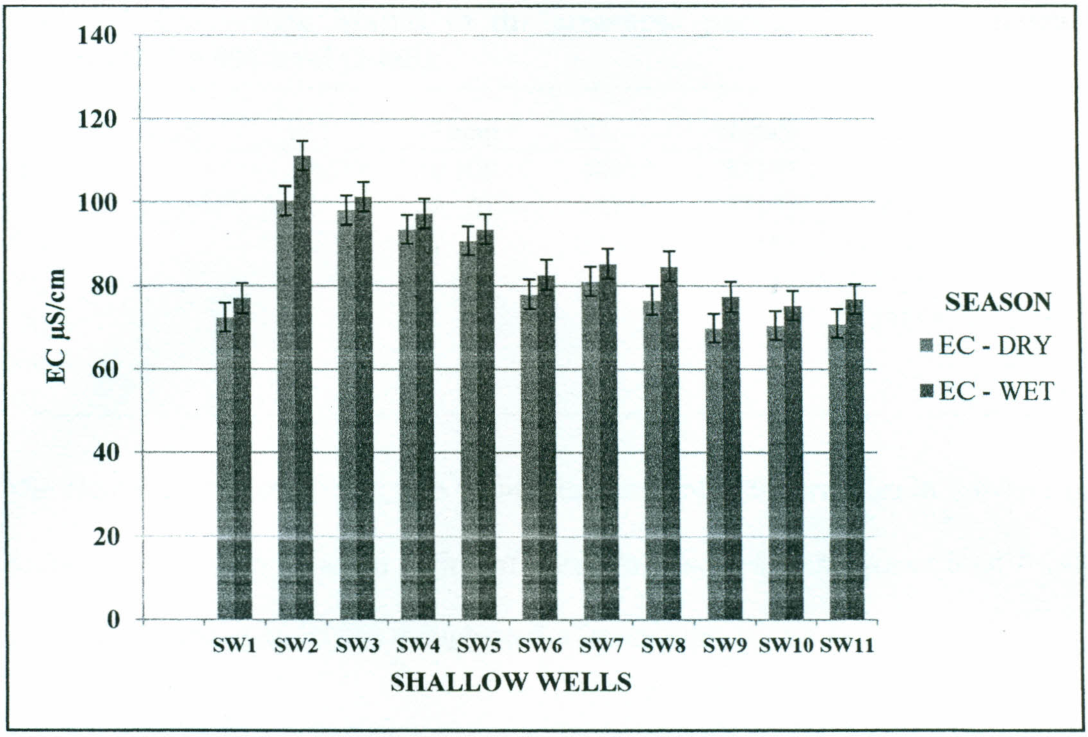

Figure 4.4 Mean Electrical Conductivity in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

Based on Pearson Correlation test, there was a positive correlation between TDS and EC i.e. r = 0.985 (Table 4.7). This therefore implies that with any increase in the levels of TDS in the shallow wells, there was an equivalent increase in the levels of EC in the respective shallow well and vice versa. For instance, SW11 had levels of TDS at 34.05±0.19 mg/L and 36.68±0.66 mg/L while EC of 70.82±0.24 µS/cm and 76.67±1.08 µS/cm for dry and wet season respectively.

Electrical conductivity in the study area compares well with those of other studied wells. The mean conductivity range of 81.97±1.41 µS/cm to 87.39 µS/cm is higher but within the range to that of ground water in Poovalur area of Lalgudi Taluk in India which ranges from 50 - 110 µS/cm (Kiruthikal *et al.,* 2012).

Table 4.7 Correlation Matrix of the measured parameters, **correlation is significant at 0.001 level (2-tail).

	TDS	EC	Temp	PO_4	Nitrate	Nitrite	pH
TDS	1	.985**	0.108	.488**	.521**	0.068	0.083
EC		1	0.102	.487**	.533**	0.045	0.063
Temp			1	0.147	.228**	0.103	-0.035
PO_4				1	.651**	.252**	.223**
Nitrate					1	.391**	0.167
Nitrite						1	0.088
pH							1

The electrical conductivity is also within the range of 129 boreholes in Sawla-Tuna-Kalba district in the Sahelian region of northern Ghana with ranges of 84.8 – 148.6 µS/cm (Cobbina *et al*,. 2012) though on the lower side.

The EC in the studied shallow wells is much lower compared to those of North–East zone of Bhiwadi industrial area (Alwar) Rajasthan in India which ranged from 400 - 1700 µS/cm Yadav *et al.,*(2012). It is also lower as compared to EC of shallow wells in Maharastra where EC ranged from 283.67 to 1079.62 µS/cm, Pradhan and Pirasteh (2011). This can be attributed to the fact that water being an excellent solvent tends to dissolve the minerals in the geological system. Also the chemical nature of the ground water is influenced by several factors such as chemical weathering of the country rocks and interaction with the country rocks, Pradhan and Pirasteh (2011).

4.2.3 Temperature (°C)

The temperature recorded at the study wells showed modest variations. The values ranged from 11.82 °C to 18.32 °C. The highest mean temperature was recorded in shallow well 6 with 18.32 °C and the lowest mean in shallow well 3 with temperature of 11.82 °C (Table 4.8).

Table 4.8: Values of Temperature (°C) during the study period.

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	15.6	16.9	12.3	11.7	19.3	20.8	15.8	16.3	12.5	13.5	10.9
Dec	14.8	15.7	10.4	13.1	10.9	19.6	19.8	13.1	14.2	16.7	12.8
Jan	15.9	16.6	13.2	16.9	11.7	15.9	17.3	14.2	12.9	13.6	15.3
Feb	16.1	16.4	13.5	16.6	11.3	14.6	16.6	14.3	12.7	13.3	15.5
Mar	14.6	15.3	10.5	13.2	10.5	19.4	19.0	13.3	14.1	16.5	12.3
Apr	14.3	15.5	11.0	13.6	10.9	19.6	19.3	13.1	14.6	16.3	12.5
Aver	15.22	16.01	11.82	14.18	12.43	18.32	17.97	14.05	13.5	14.98	13.22

Using an independent t-test at 95% confidence, there was no significant difference in temperature both for dry and wet season ($P < 0.471$) (Table 4.1). There was however significant difference between wells. For instance SW3 had a temperature reading of 13.18±0.25 °C while SW6 had a value of 17.07±1.13 °C and this was during the dry season. At the same time SW3 had a value of 10.83±0.13 °C while SW6 had a reading of 19.62±0.05 °C and this was during the wet season. Using Pearson correlation matrix there was a negative correlation between temperature and pH (Table 4.7). This can be attributed to the fact the shallow wells were located in the same geographical area and as such there wasn't any much variation in the temperatures save for SW5 with lowest temperature of 12.78 °C during the dry season.

The temperature values were found to be quite low compared to other studies. For instance according to (Kiruthikal *et al.,* 2012) a study of ground water quality in Poovalur area of Lalgudi Taluk, Tiruchirappalli District, Tamilnadu the temperature ranged from 27 °C to 29 °C. A study of ground water quality in and around Sidcul industrial area, Haridwar, Uttarakhand, India by Deepali *et al*., (2012), showed that the temperature ranged from 31 °C to 31.5 °C. The composition of surface and groundwater is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) in the drainage basin and varies with seasonal difference in runoff volumes, weather conditions and water levels Muller, (2001).

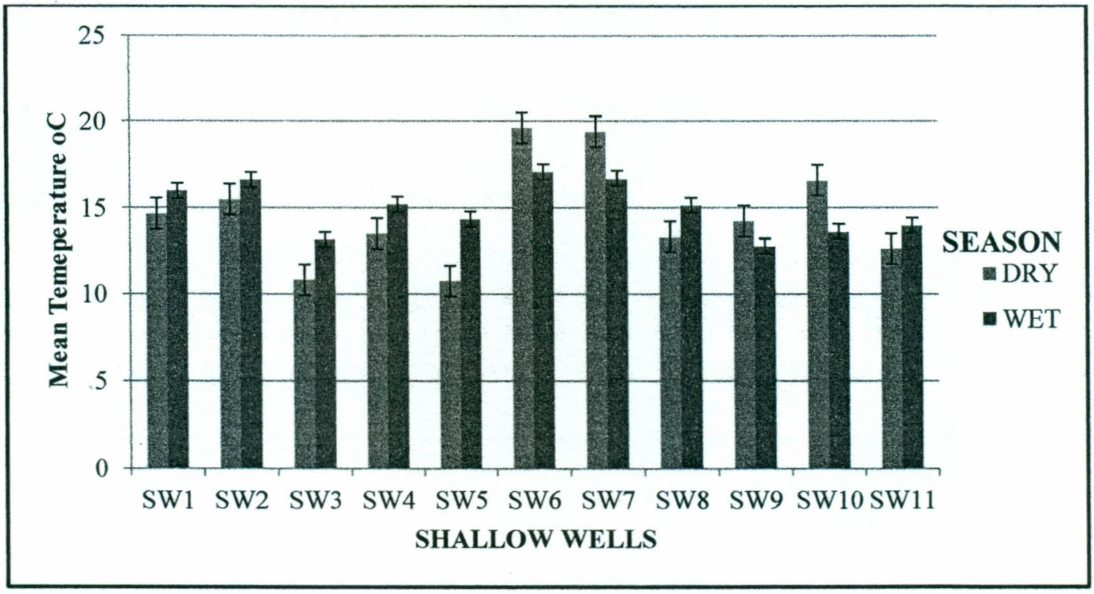

Figure 4.5 Mean Temperature values in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

4.2.4 Phosphorus (mg/L)

Phosphorus concentrations recorded in all the shallow wells showed wide variations during the study period (Fig. 4.7 and Table 4.9). The values ranged from 0.03 mg/L in shallow well 11 to 1.11 mg/L in shallow well 2. High values of phosphorus were recorded during the wet season. The mean concentration was 0.56 mg/L during the dry season and 0.64 mg/L in wet season (Table 4.9).

Table 4.9: Values of Phosphorus (in mg/L) during the study period.

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	0.40	1.08	0.38	0.80	0.62	0.74	0.29	0.66	0.36	0.71	0.04
Dec	0.32	1.11	0.40	0.72	0.65	0.77	0.38	0.51	0.40	0.68	0.07
Jan	0.28	0.96	0.36	0.69	0.61	0.69	0.34	0.47	0.41	0.61	0.03
Feb	0.33	0.81	0.33	0.65	0.63	0.66	0.38	0.43	0.44	0.60	0.09
Mar	0.52	0.96	0.51	0.75	0.78	0.83	0.51	0.59	0.48	0.73	0.08
Apr	0.54	0.97	0.56	0.77	0.81	0.86	0.55	0.57	0.46	0.77	0.09
Aver	0.398	0.982	0.423	0.730	0.683	0.758	0.408	0.538	0.425	0.683	0.067

Table 4.10: Mean values of the Chemical parameters of the wells during the wet and dry season during the study period: November 2012 to April 2013

Parameter	Dry Season Mean±SE	Wet Season Mean±SE	p-value
Phosphorus(mg/L)	0.56±0.02	0.64±0.02	0.019
Nitrate(mg/L)	7.46±0.18	8.18±0.17	0.004
Nitrite(mg/L)	0.05±0.002	0.06±0.002	0.006

The mean phosphorus concentration ranged from 0.34±0.01 mg/L in SW7 to 0.96±0.05 mg/L in SW2 and this was in dry season (Table 4.4) whereas for wet season it ranged from 0.44±0.02 mg/L in SW9 to 1.05±0.05 mg/L in SW2 (Table 4.5) . High values were recorded in December which recorded high rainfall (152.8 mm) and this was in SW2 (Figure 4.7 and Table 4.4).

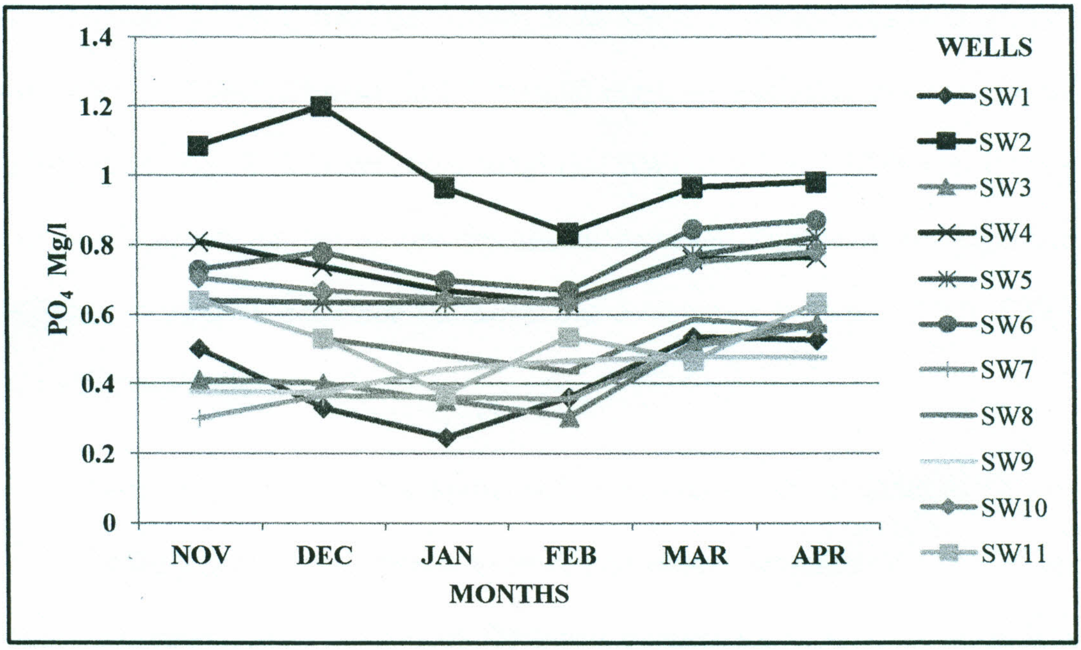

Figure 4.6 Average variations in PO_4 values in all the wells investigated during the study period.

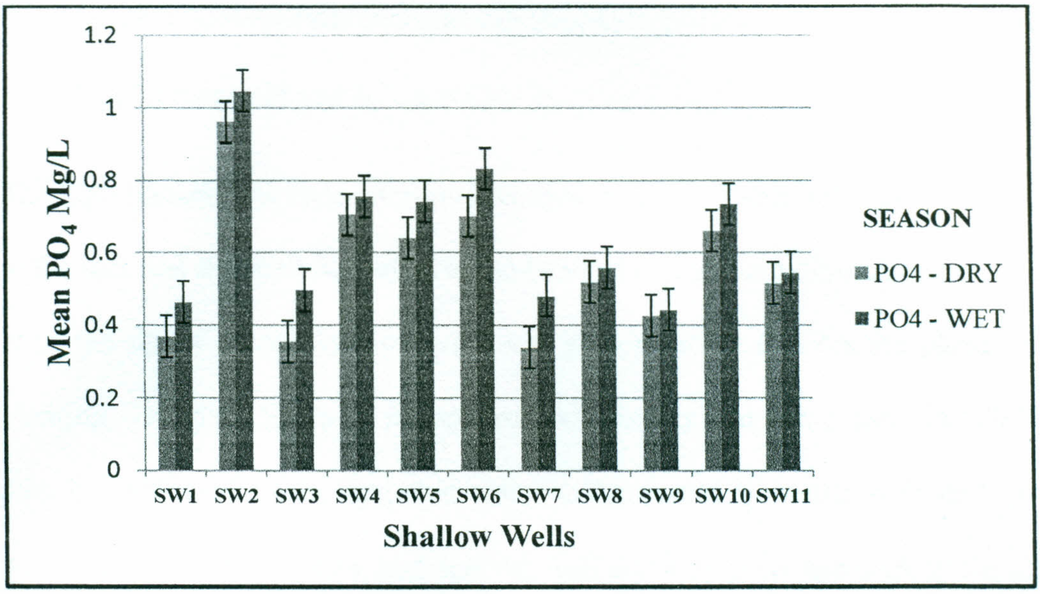

Figure 4.7 Mean Phosphorus in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

Using the one way ANOVA test (Table 4.4 and 4.5 on page 44), mean values for the shallow wells investigated were significantly different ($P<0.001$). For instance shallow well 2 (SW2) had significantly high levels of phosphorus both in dry and wet seasons (0.96±0.05 mg/L and 1.05±0.05 mg/L respectively) as compared to the other wells (Fig. 4.7). It was also noted that SW1, SW3 and SW7 had the lowest levels of phosphorus during the dry season however; they were not significantly different from each other and the same was established for SW4, SW5, SW6 and SW10 (Table 4.4).

The amount of phosphorus that aquifer sediments can adsorb is related to the amount of iron oxides present, pH, total amount of phosphorus present as a result of human activities, run-off, the amount of dissolved oxygen in water, and other ions in solution. When phosphorus concentrations in an aquifer are low, the oxide surfaces probably are undersaturated and can adsorb more. Higher concentrations of phosphorus in groundwater indicate that the oxide surfaces are saturated or becoming saturated, Domagalski and Johnson (2012).

The high phosphorus concentration recorded in SW2 (Table 4.9) could be attributed to the fact that the shallow well is at the heart of maize plantation and receives runoff from the farms especially during the wet season where farmers are ploughing and planting. The high levels of phosphorus both in dry and wet season in SW2 could also be attributed to the fact that water is harvested from the well and used for washing clothes and bathing just near the well and may percolate back to the well.

There was a positive correlation between phosphorus and both TDS as well as EC at r = 0.488** and r = 0.487** respectively. As TDS and EC increase in the water samples there was a positive increase in the concentration of phosphorus (Table 4.7). This suggested that presence of phosphorus in the study area greatly influence the levels of TDS and EC. Water quality is based on the physical and chemical soluble constituents due to weathering of parent rocks and anthropogenic activities Akinbile, (2011).

Phosphorus ranges at the study area do not differ much from those of other shallow wells. A study by Dutta *et al.,* (2012) showed that the levels of phosphorus in Sonitpur District, Assam, India ranged from 0.0 to 0.688 mg/L which compares well with the phosphorus in the study area which is between 0.56±0.02 mg/L and 0.64±0.02 mg/L. Values of phosphorus were recorded between 0.06 - 0.16 mg/L according to a study done in Uttarakhand, India (Deepali *et al*., 2012). It was however quite low compared to studies regarding polluted water in a rural area in

Romania (Cornelia *et al.,* 2006) which established that levels varied from 0.0 to 5.0 mg/L. The permissible limit of phosphorus of drinking water is 2.2 mg/L. The observation shows that the levels of phosphorus are within the permissible range as prescribed by Kenya Bureau of Standards (KS 459-1, 2007).

4.2.5 Nitrate (mg/L)

Nitrate concentrations recorded in all the shallow wells showed a modest variation during the study period (Figure 4.9). A mean concentration of 7.46±0.18 mg/L was computed during the dry season (Table 4.4) and 8.18±0.17 mg/L was recorded during the wet season (Table 4.5).

Table 4.11: Values of Nitrate (in mg/L) during the study period.

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	7.9	11.1	8.9	7.1	7.3	9.1	7.6	6.1	5.4	8.8	0.06
Dec	7.5	10.2	8.5	7.6	7.1	8.9	7.5	6.2	5.5	8.9	0.09
Jan	7.3	9.6	8.3	7.3	7.0	8.5	6.1	5.3	4.6	8.1	0.04
Feb	7.3	9.5	8.2	7.1	6.9	8.2	6.3	5.1	4.4	8.1	0.06
Mar	7.7	11.1	8.9	7.8	7.7	9.3	7.6	6.5	5.8	9.2	0.07
Apr	7.4	10.9	9.1	8.1	7.9	9.6	7.9	6.8	6.3	9.5	0.05
Aver	7.52	10.4	8.65	7.5	7.32	8.93	7.17	6.0	5.33	8.77	0.06

Nitrate concentration ranged from 0.04 mg/L in SW11 to 11.1 mg/L in SW2 (Table 4.11). Mean concentration of 4.93 mg/L was observed in SW9 while 10.18 mg/L was exhibited by SW2 during the dry season (Table 4.4) while 5.90 mg/L in SW9 and 10.82 mg/L in SW2 were observed during the wet season (Table 4.5).

In general, high values were recorded in the months which recorded the highest rainfall (538.5 mm) and low values were recorded during the dry months (94.4 mm) (Figure 4.9).

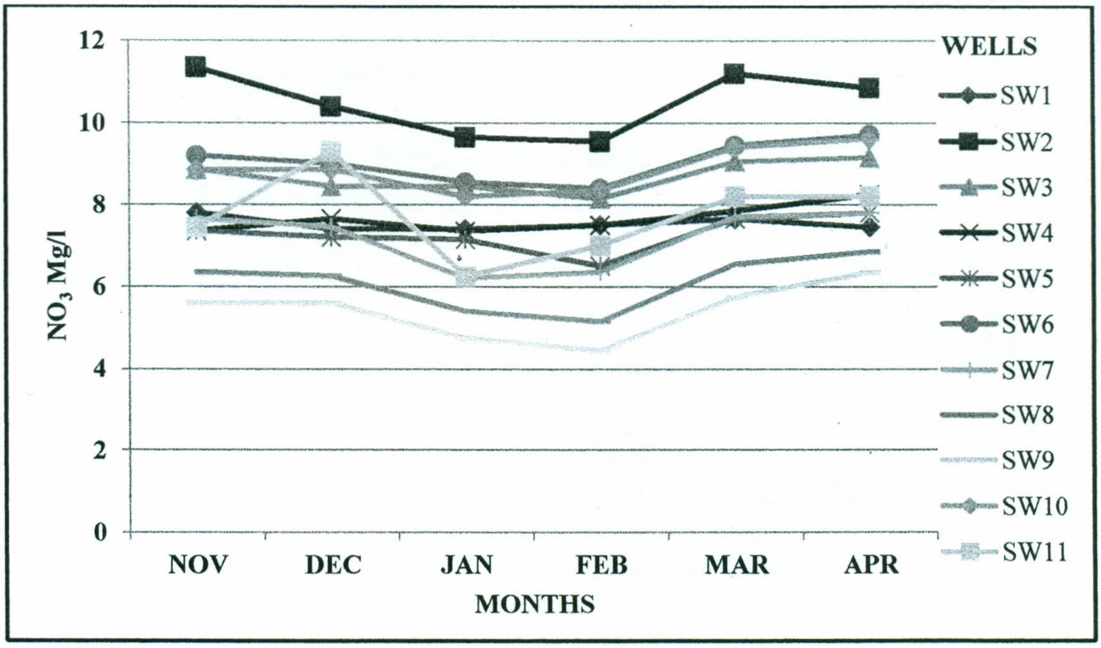

Figure 4.8 Average variations in NO_3 values in all the wells investigated during the study period.

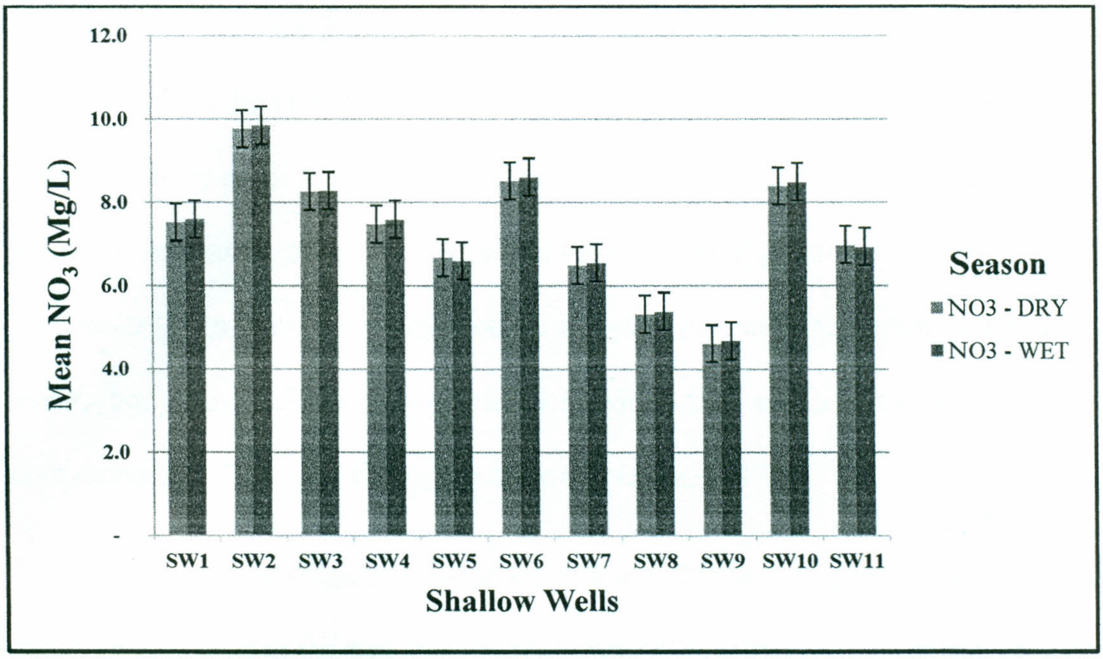

Figure 4.9, Mean Nitrate in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

Using one way ANOVA test, the mean values for the shallow wells were significantly different ($P<0.004$). It was noted that shallow well 2 (SW2) had significantly high levels of Nitrates both in dry and wet seasons (10.18±0.38 mg/L and 10.82±0.16 mg/L respectively as compared to the other wells (Figure 4.9, Figure 4.10). On the other hand, SW6 and SW10 had slightly high levels of Nitrates during the dry and wet months whereas SW8 and SW9 had the lowest levels during both seasons.

Nitrate contamination of groundwater under agricultural fields is a common problem in many parts of the world (Bergström & Kirchman, 1999). Many studies have shown that anthropogenic activities, involving nitrogenous compounds such as mineral fertilizers and products of organic compounds from agriculture, septic systems and cattle manure, are the major factor leading to the increase of nitrate pollution, (Power and Schepers, 1989; Kaçaroglu and Gunay, 1997; Rao, 2006). According to Todd, (1980) approximately one-half to two-thirds of the water applied for irrigation of crops is consumed by evapotranspiration and the remainder, which is termed as irrigation return flow, drains to the underlying ground water. The resulting deep percolation water not only contains the slats that were present in the irrigation water, but also fertilizer and pesticide residues that are a potential source of contamination of the underlying ground water (Jenke, 1974).

The high nitrate concentration recorded in SW2 (Table 4.4) during the wet season could be attributed to the fact that the shallow well is at the heart of maize plantation and receives runoff from the farms especially during the wet season where farmers are ploughing their farms and thus making the soil to become loose and subsequently planting of their respective plants.

Using correlation matrix it was revealed that there was a positive correlation between Nitrates and TDS, EC and Phosphorus at r = 0.521**, r = 0.533** and r = 0.228** respectively (Table 4.7). The positive correlation between Nitrates and TDS, EC and PO_4 can be attributed to previous farming activities that included secondary cultivation (weeding) and top dressing by the use of UREA and CAN that is rich in Nitrates. Due to its high mobility, Nitrate also can leach into groundwater and this is facilitated with short rains that occurred in the months of September and October.

The levels of nitrate in the studied wells compares well with those of other studies. For instance the values of nitrate in Roorkee town in northern India were between 0.12 to 14.5 mg/L (Seleem *et al.,* 2008). The values were lower but within the range of 10 – 45 mg/L recorded in groundwater wells in Tulare County, California USA, (Ekdahl *et al.,* 2009) and also within the range of between 7.10 and 160 mg/ L in wells in rural village of Sri Ganganagar District India, (Suthar *et al.,* 2009). They were however much lower compared to a study done by (Li *et al.*, 2008) in Northern China where the nitrate concentrations ranged from 0.1 to 449.2 mg/L with a mean value of 42.2 mg/L. The permissible limit of Nitrate in drinking water is set at 45 mg/L as NO_3 by Kenya Bureau of Standards. The observation shows that the levels of Nitrate are within the threshold values for drinking water.

4.2.6 Nitrite (mg/L)

The values of Nitrite recorded in the shallow wells showed wide variation during the study period (Fig. 4.11, Fig. 4.12).

Table 4.12: Values of Nitrite (in mg/L) during the study period.

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	0.050	0.070	0.065	0.019	0.070	0.070	0.054	0.074	0.044	0.082	0.004
Dec	0.041	0.062	0.063	0.020	0.066	0.071	0.055	0.073	0.041	0.077	0.003
Jan	0.039	0.051	0.060	0.021	0.057	0.063	0.048	0.069	0.033	0.070	0.002
Feb	0.037	0.052	0.061	0.022	0.055	0.060	0.042	0.064	0.035	0.066	0.004
Mar	0.048	0.066	0.067	0.028	0.069	0.078	0.059	0.078	0.047	0.081	0.003
Apr	0.053	0.069	0.071	0.033	0.073	0.085	0.057	0.082	0.051	0.084	0.004
Aver	0.045	0.062	0.065	0.023	0.065	0.071	0.053	0.073	0.042	0.077	0.003

It ranged from 0.002 mg/L in SW11 to 0.085 mg/L in SW6 (Table 4.12). Mean of 0.050 mg/L was recorded during the dry season while 0.060 mg/L was recorded during the wet season (Table 4.10). A mean concentration of 0.023 mg/L was recorded in SW4 while 0.072 mg/L was recorded in SW10 during the dry season (Table 4.4). Also a mean concentration of 0.028 mg/L was recorded in SW4 and 0.082 mg/L recorded in SW10 during the wet season (Table 4.5).

From the one way ANOVA test, mean values for the shallow wells investigated were significantly different ($P<0.006$). It was observed that SW10 had significantly high levels of Nitrites both in dry and wet seasons (0.072±0.003 mg/L and 0.082±0.001 mg/L respectively) as compared to the other wells (Figure 4.11, Figure 4.12). On the other hand, SW2, SW6 and SW7 had slightly high levels of Nitrites during the dry months whereas SW2, SW3 and SW5 had slightly high levels in the wet season compared to the other wells during the study period (Table 4.4, Table 4.5).

In soil, fertilizers containing inorganic nitrogen and wastes containing organic nitrogen are first decomposed to give ammonia, which is then oxidized to nitrite and nitrate. The nitrate is taken up by plants during their growth and used in the synthesis of organic nitrogenous compounds. Surplus nitrate readily moves with the groundwater (USEPA, 2009; Van Duijvenboden & Matthijsen, 1989). This could have contributed to the high levels of nitrite in SW2, SW6 and SW7 which had slightly high levels of nitrites during the dry months whereas SW2, SW3 and SW5 had slightly high levels in the wet season compared to the other wells during the study period (Table 4.3, Table 4.4). This can be attributed to the fact that the wells are at the heart of cultivation area and is likely to receive a lot of runoff during the wet season.

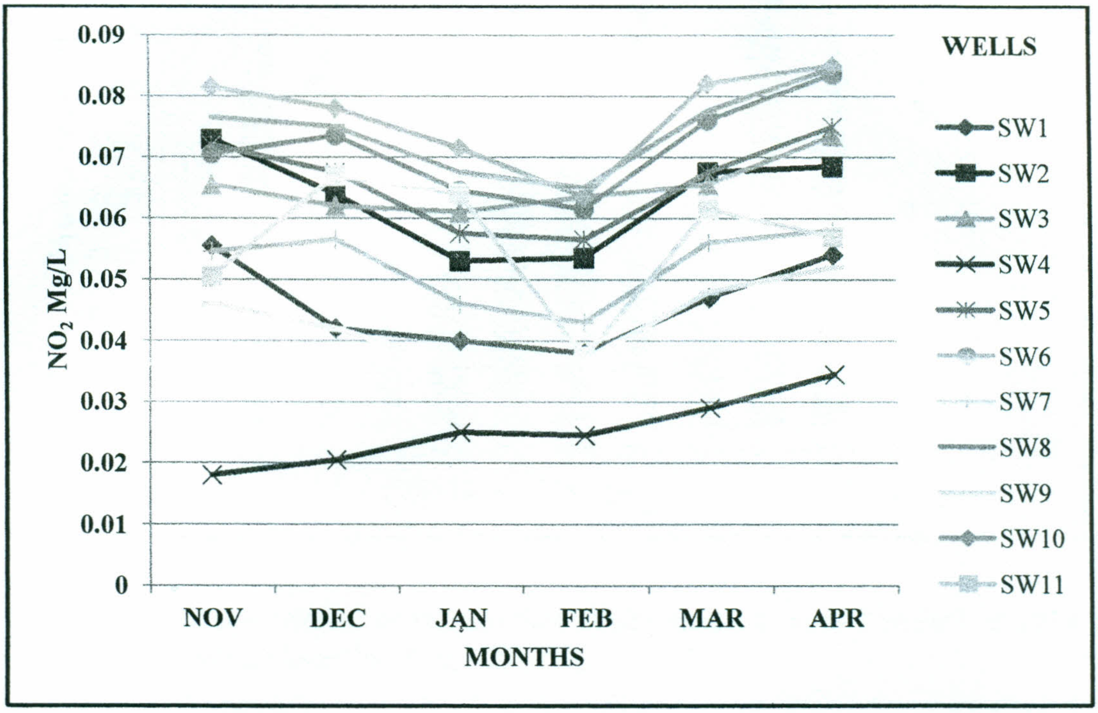

Figure 4.10 Average variations in NO_2 values in all the wells investigated during the study period.

It was observed that again throughout the study, the levels of nitrite concentration were higher during the wet season 0.06±0.002 mg/L and lower during the dry season 0.05±0.002 mg/L.

Using correlation matrix, it was revealed that there was a positive correlation between Nitrites and Nitrates at r = 0.391** (Table 4.7). This shows that there was a great dependence of nitrite on nitrate. They are reactions in the same soil process of nitrification and denitrification.

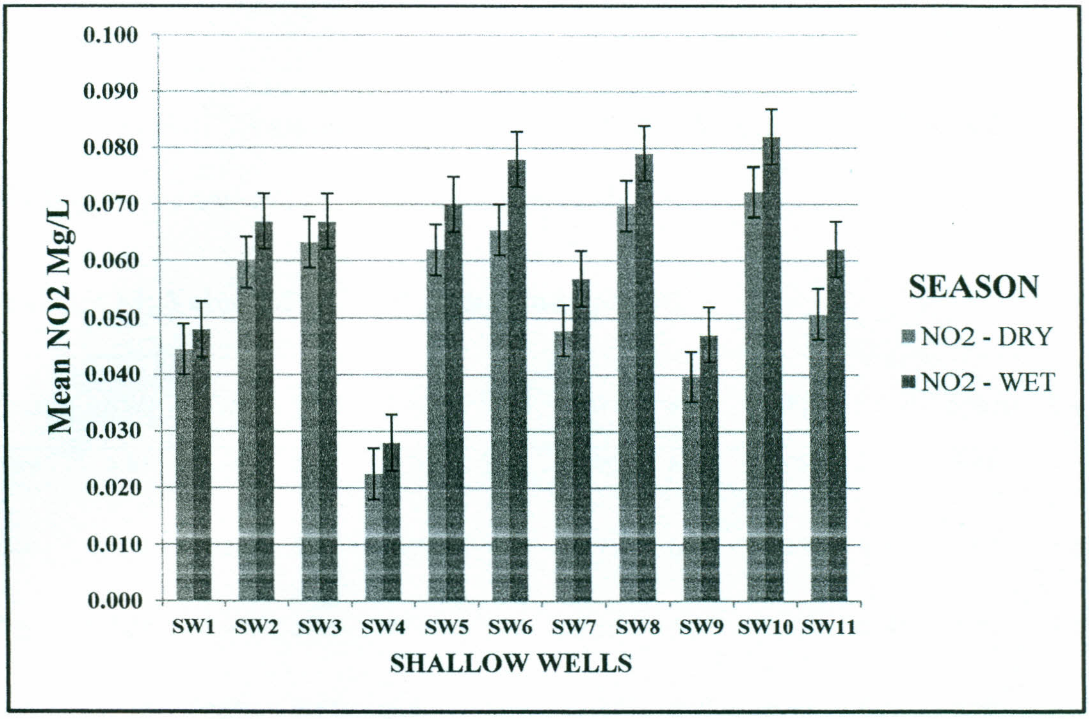

Figure 4.11 Mean Nitrite in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

Nitrite ranges at the study area do not differ appreciably from those of other shallow wells in the world. According to a study done in Saudi Arabia, the levels of nitrite in the village of Al-Mahareth ranged between 0.006 mg/L to 0.36 mg/L which is within the range of the study area that was between 0.05±0.002 mg/L and 0.06±0.002 mg/L (Khanfar, 2010). However, it was found to be quite low compared to those from Netherlands that ranged from 0.0 Mg/L to 0.21 mg/L (RIVM, 1993). The permissible limit of nitrite of drinking water is set at 0.003 mg/L. The observation shows that the levels of nitrite are above the permissible range as prescribed by Kenya Bureau of Standards. This therefore indicate that the shallow wells do not meet the threshold value for drinking water and thus not safe for drinking.

4.2.7 pH

The mean pH of the eleven shallow wells investigated were 5.99±0.03 and 6.10±0.03 during the dry and wet season respectively (Table 4.1).

Table 4.13: Values of pH during the study period.

Months	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11
Nov	5.81	6.16	5.90	5.96	5.96	5.90	6.02	5.95	6.10	6.05	6.52
Dec	5.79	6.28	5.83	5.88	5.99	5.91	6.03	5.87	6.15	5.90	6.56
Jan	5.64	6.30	5.75	5.61	5.83	5.88	5.97	5.62	6.20	5.81	6.44
Feb	5.65	6.38	5.77	5.62	5.79	5.82	5.95	5.60	6.28	5.82	6.60
Mar	5.82	6.35	5.88	5.91	5.94	5.96	6.11	5.89	6.20	5.94	6.49
Apr	5.77	6.50	5.93	5.98	6.02	6.06	6.35	6.10	6.45	6.11	6.55
Aver	5.75	6.33	5.84	5.83	5.92	5.92	6.07	5.84	6.23	5.94	6.52

The pH measured in the shallow wells varied throughout the study (Fig. 4.13). For instance pH values ranged from 5.60 in SW8 to 6.60 in SW11 (Table 4.13). The mean pH of the wells ranged from 5.99 in dry season to 6.10 during the wet season (Table 4.1). A pH value of 5.72 was recorded in SW1 even as SW11 recorded a pH value of 6.46 during the dry season (Table 4.4). On the other hand, a pH value of 5.81 was recorded in SW1 while in SW11 the pH was 6.53 during the wet season (Table 4.5). High values were recorded in the months which recorded the highest rainfall (538.5 mm) and the contrary is observed for the dry months (94.4 mm) (Table 4.4).

Using ANOVA one way, there was a significant difference among the wells and also between the dry and wet season at p-value of <0.001 and 0.018 respectively (Tables 4.1, 4.5 and 4.6). For example, 6.46±0.08 was observed in SW10 during the dry season while 5.72±0.03 for SW1. At the same time SW10 had 6.53±0.02 while SW1 had 5.81±0.01 during the wet season respectively. It was established that SW11 had significantly high levels of pH both in dry and wet seasons (6.46±0.08 and 6.53±0.02 respectively) as compared to the other wells (Fig. 4.13).

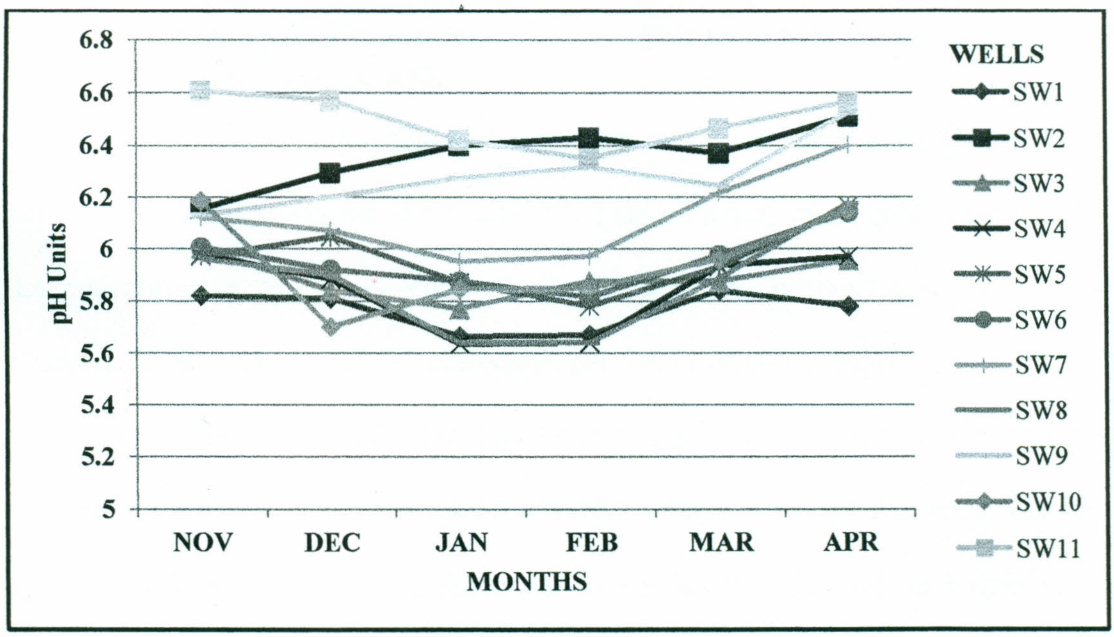

Figure 4.12 Average variations in pH values in all the wells investigated during the study period.

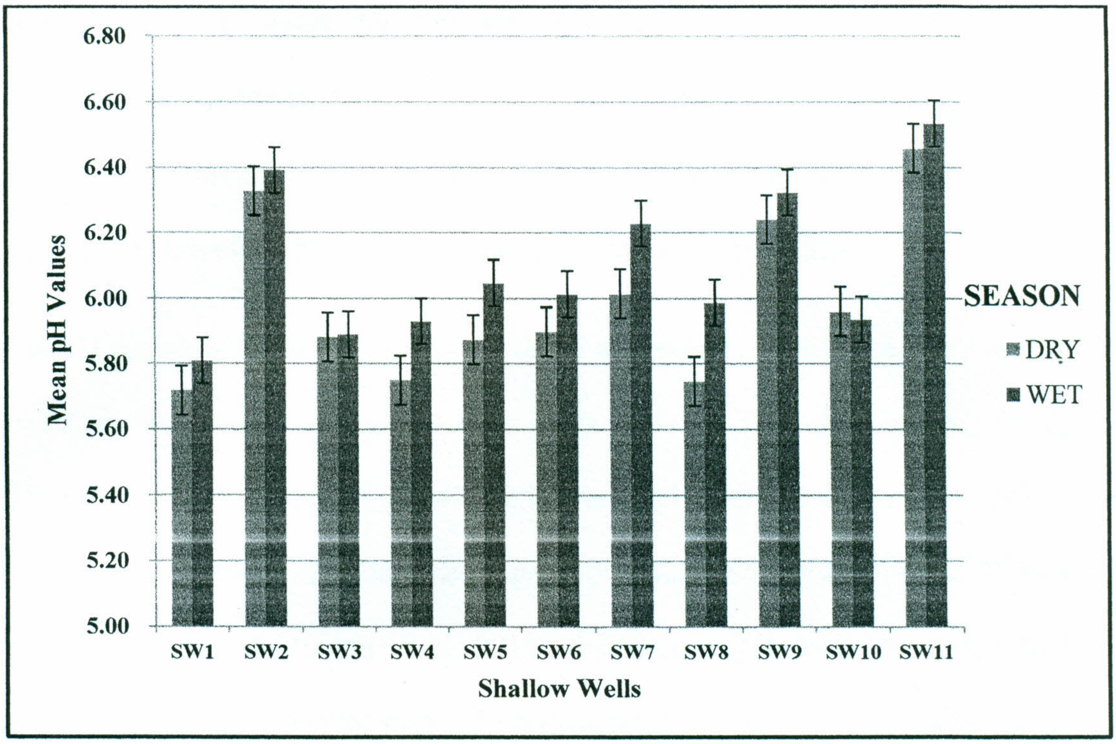

Figure 4.13 Mean pH in the shallow wells studied from November 2012 to April 2013, vertical bars indicate ±SE.

The correlation matrix table (Table 4.7) reveals that there was a positive correlation between pH and phosphorus at r = 0.223**. This is an indication of the role of pH in the concentration of phosphorus. For instance it is observed that the level of phosphorus is high in SW2 with high pH i.e. 1.05±0.05 Mg/L and 6.39±0.04 respectively. Conversely SW1 has low level of phosphorus concentration with low pH values i.e. 0.46±0.04 Mg/L and 5.81±0.01 respectively (Table 4.5). The high values of pH in SW2 could be attributed to the fact that the well is located at the heart of cultivated piece of land and it receives surface runoff from the farms which use fertilizer to increase production. The well is also bear with no vegetation cover which implies that during rainy season there will be a lot of runoff directly into the well.

According to a report by National Accelerated Agricultural Inputs Access Programme (NAAIAP, 2014) in collaboration with Kenya Agricultural Research Institute Department of Kenya Soil Survey, the soil pH in Uasin Gishu County is acidic. This therefore contributes to the acidic nature of the water.

The pH ranges at the study area do not differ appreciably from those of other shallow wells in the world. According to a study done by (Kiruthika *et al.,* 2012), in Tiruchirappalli District, Tamilnadu the levels of pH were slightly higher than those from the study area but within the range with values ranging from pH 6.55 to 6.74. Also a study done by (Dutta *et al.,* 2010), the levels of pH ranged from 6.00 to 8.21. The quality of groundwater from 129 boreholes in the Sawla-Tuna-Kalba district in the Sahelian region of northern Ghana established that the levels of pH ranged between 6.09 – 9.81 (Cobbina *et al*., 2012) which is not far from those of the study area.

The values of pH however, were found to be quite low compared to those from Gulbarga District, Karnataka where it ranged from pH 7.0 – 9.84 (Srinivas and Padaki, 2011). According to a study done by Shah *et al*., 2006, the pH value of water samples of North, Central and South region of Kalol ranged from 7.49 to 8.34, 7.41 to 8.02 and 7.60 to 8.87 respectively. This was done in groundwater of North, Central and South regions of Kalol Taluka in Gandhinagar district of Gujarat state, India.

The permissible limit of pH for drinking water is between 6.5 – 8.5. The observation shows that the levels of pH are way below the permissible range as prescribed by

Kenya Bureau of Standards. This therefore indicate that the shallow wells are slightly acidic and so do not meet the threshold value for drinking water and thus not safe for drinking.

4.2.8 Cadmium

Based on the chemical analysis that was performed on the water samples it was observed that there was no Cadmium detected. This could be attributed to the fact that the levels of Cadmium in the samples were much lower than the Lower Detection Limit of the spectrophotometer. According to a study done in Kentucky, approximately 80% of the statewide results were reported as being below analytical detection limits which ranged from 0.0001 to 0.006 mg/L. The results indicate that the groundwater that were analyzed for cadmium but none was detected, Bart and Stephen (2005).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. The levels of Total Dissolved Solids ranged from 39.08±0.62 mg/L during the dry season to 41.63±0.66 mg/L during the wet season. The levels of Electrical Conductivity on the other hand ranged between 81.97±1.41µS/cm and 87.39±1.47 µS/cm during the dry and wet season respectively. While temperature values were between 14.96±0.28 °C in dry season and 14.64±0.3 °C in wet season those of pH were between 5.99±0.03 to 6.10±0.03 during the dry and wet season respectively. Most of the physical parameters were found to be within the prescribed permissible limit save for pH whose values were found to be below 6.5 as recommended by KEBS.
2. The levels of phosphorus varied between 0.56±0.02 mg/L in dry season and 0.64±0.02 mg/L in wet season. Those of nitrate were between 7.46±0.18 mg/L and 8.18 mg/L during dry and wet season respectively. The levels of nitrite ranged between 0.05±0.002 mg/L to 0.06±0.002 mg/L during dry and wet season respectively. Again most of the chemical parameters were within the set guideline values for drinking water except for nitrite whose values were above 0.003 mg/L as set by KEBS. A distinct seasonal variation was noted in all the shallow wells investigated.
3. During the wet season, the levels of the physicochemical properties were high in all the wells while they were low during the dry season.

5.2 RECOMMENDATIONS

5.2.1 Research

1. The present study focused on the shallow wells and a few physicochemical parameters in Uasin Gishu County. More work needs to be done on the comprehensive water analysis including bacteriological and other chemical parameters on the various water bodies so as to look at their suitability in line with the seventh millennium development goals of ensuring safe drinking water to all by 2015.

5.2.2 Management

1. The shallow wells investigated have a modest amount of nutrients save for nitrite levels which were higher than the recommended threshold for drinking water according to KEBS. There is therefore need to formulate appropriate programs to manage the shallow wells in terms of water quality monitoring.
2. Based on the tested parameters only the water samples do not meet the set guideline values for drinking water. Treatment by the use of reverse osmosis or chlorination and use of pH plus is therefore recommended so as to render them fit for domestic use.

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APPENDICES

Appendix 1: Description of the Shallow Wells in Koitoror Location during study period.

WELL	NAME OF OWNER	DEPTH IN FEET	YEAR DUG
SHALLOW WELL 1	WILLIAM CHERARUS	15	1986
SHALLOW WELL 2	MOSES CHERARUS	23	1987
SHALLOW WELL 3	JAMES ARAP RONOH	12	1991
SHALLOW WELL 4	CHARLES CHELULE	27	1986
SHALLOW WELL 5	DR. CHRISTOPHER KIPLIMO	26	2011
SHALLOW WELL 6	JONAH ARAP MALAKWEN	12	1995
SHALLOW WELL 7	MALAKWEN SINGOE	16	1990
SHALLOW WELL 8	DANIEL CHEPKOK	14	2006
SHALLOW WELL 9	REUBEN KENDAGOR	19	1994
SHALLOW WELL 10	SAMUEL ARAP CHELULE	18	1986
SHALLOW WELL 11	PHILIP KIPSEREM	45	1990

Appendix 2: Values of the measured parameters in November 2012(Dry Season)

SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	PH
SW1	36.2	76.6	15.6	0.4	7.9	0.050	5.81
SW2	49.9	105	16.9	1.08	11.1	0.070	6.16
SW3	47.8	100.7	12.3	0.38	8.9	0.065	5.90
SW4	44.8	94.4	11.7	0.8	7.1	0.019	5.96
SW5	42.7	90.1	19.3	0.62	7.3	0.070	5.96
SW6	39.3	83	20.8	0.74	9.1	0.070	5.90
SW7	38.9	82.2	15.8	0.29	7.6	0.054	6.02
SW8	38.2	80.8	16.3	0.66	6.1	0.074	5.95
SW9	34.8	73.8	12.5	0.36	5.4	0.044	6.10
SW10	35.2	74.5	13.5	0.71	8.8	0.082	6.05
SW11	33.7	71.5	10.9	0.04	0.06	0.004	6.52

KEY:

TDS: Total Dissolved Solids

EC: Electrical Conductivity

PO_4: Phosphorus

NO_3: Nitrates

NO_2: Nitrites

Temp: Temperature

Appendix 3: Values of the measured parameters in January 2012(Dry Season)

SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4(mg/L)	NO_3(mg/L)	NO_2(mg/L)	PH
SW1	34.9	70.3	15.9	0.28	7.3	0.039	5.64
SW2	47.1	98.9	16.6	0.96	9.6	0.051	6.3
SW3	45.8	97.3	13.2	0.36	8.3	0.06	5.75
SW4	42	93.1	16.9	0.69	7.3	0.021	5.61
SW5	42.8	90.9	11.7	0.61	7.0	0.057	5.83
SW6	36.5	77.9	15.9	0.69	8.5	0.063	5.88
SW7	38.2	80.6	17.3	0.34	6.1	0.048	5.97
SW8	35.4	75.1	14.2	0.47	5.3	0.069	5.62
SW9	33.5	69.8	12.9	0.41	4.6	0.033	6.20
SW10	33.2	69.1	13.6	0.61	8.1	0.07	5.81
SW11	33.9	70.6	15.3	0.03	0.04	0.002	6.44

Appendix 4: Values of the measured parameters in February 2012(Dry Season)

SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4(mg/L)	NO_3(mg/L)	NO_2(mg/L)	pH
SW1	34.8	70.4	16.1	0.33	7.3	0.037	5.65
SW2	46.9	97.3	16.4	0.81	9.5	0.052	6.38
SW3	45.2	96.1	13.5	0.33	8.2	0.061	5.77
SW4	42	92.8	16.6	0.65	7.1	0.022	5.62
SW5	43.2	91.2	11.3	0.63	6.9	0.055	5.79
SW6	35.5	72.9	14.6	0.66	8.2	0.06	5.82
SW7	38	80.3	16.6	0.38	6.3	0.042	5.95
SW8	35.1	73.4	14.3	0.43	5.1	0.064	5.60
SW9	33.2	66	12.7	0.44	4.4	0.035	6.28
SW10	34	67.7	13.3	0.6	8.1	0.066	5.82
SW11	34.2	70.3	15.5	0.09	0.06	0.004	6.60

Appendix 5: Values of the measured parameters in December 2012(Wet Season)

SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4(mg/L)	NO_3(mg/L)	NO_2(mg/L)	PH
SW1	35.8	75.3	14.8	0.32	7.5	0.041	5.79
SW2	48.7	101	15.7	1.11	10.2	0.062	6.28
SW3	46.3	98.7	10.4	0.4	8.5	0.063	5.83
SW4	44.3	95.3	13.1	0.72	7.6	0.02	5.88
SW5	43.6	91.7	10.9	0.65	7.1	0.066	5.99
SW6	38.7	80.2	19.6	0.77	8.9	0.071	5.91
SW7	39	82.9	19.8	0.38	7.5	0.055	6.03
SW8	38.9	81.1	13.1	0.51	6.2	0.073	5.87
SW9	35.9	75.6	14.2	0.4	5.5	0.041	6.15
SW10	34.6	73.2	16.7	0.68	8.9	0.077	5.9
SW11	34.8	73.9	12.8	0.07	0.09	0.003	6.56

Appendix 6: Values of the measured parameters in March 2013(Wet Season)

SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4(mg/L)	NO_3(mg/L)	NO_2(mg/L)	PH
SW1	36.7	76.1	14.6	0.52	7.7	0.048	5.82
SW2	49.6	110	15.3	0.96	11.1	0.066	6.35
SW3	47.8	99.3	10.5	0.51	8.9	0.067	5.88
SW4	45.1	96.9	13.2	0.75	7.8	0.028	5.91
SW5	44	93.7	10.5	0.78	7.7	0.069	5.94
SW6	39.2	82.6	19.4	0.83	9.3	0.078	5.96
SW7	40.1	85.9	19	0.51	7.6	0.059	6.11
SW8	39.6	83.3	13.3	0.59	6.5	0.078	5.89
SW9	36.9	77	14.1	0.48	5.8	0.047	6.20
SW10	34.9	75.1	16.5	0.73	9.2	0.081	5.94
SW11	36.5	76.1	12.3	0.08	0.07	0.003	6.49

Appendix 7: Values of the measured parameters in April 2013(Wet Season)

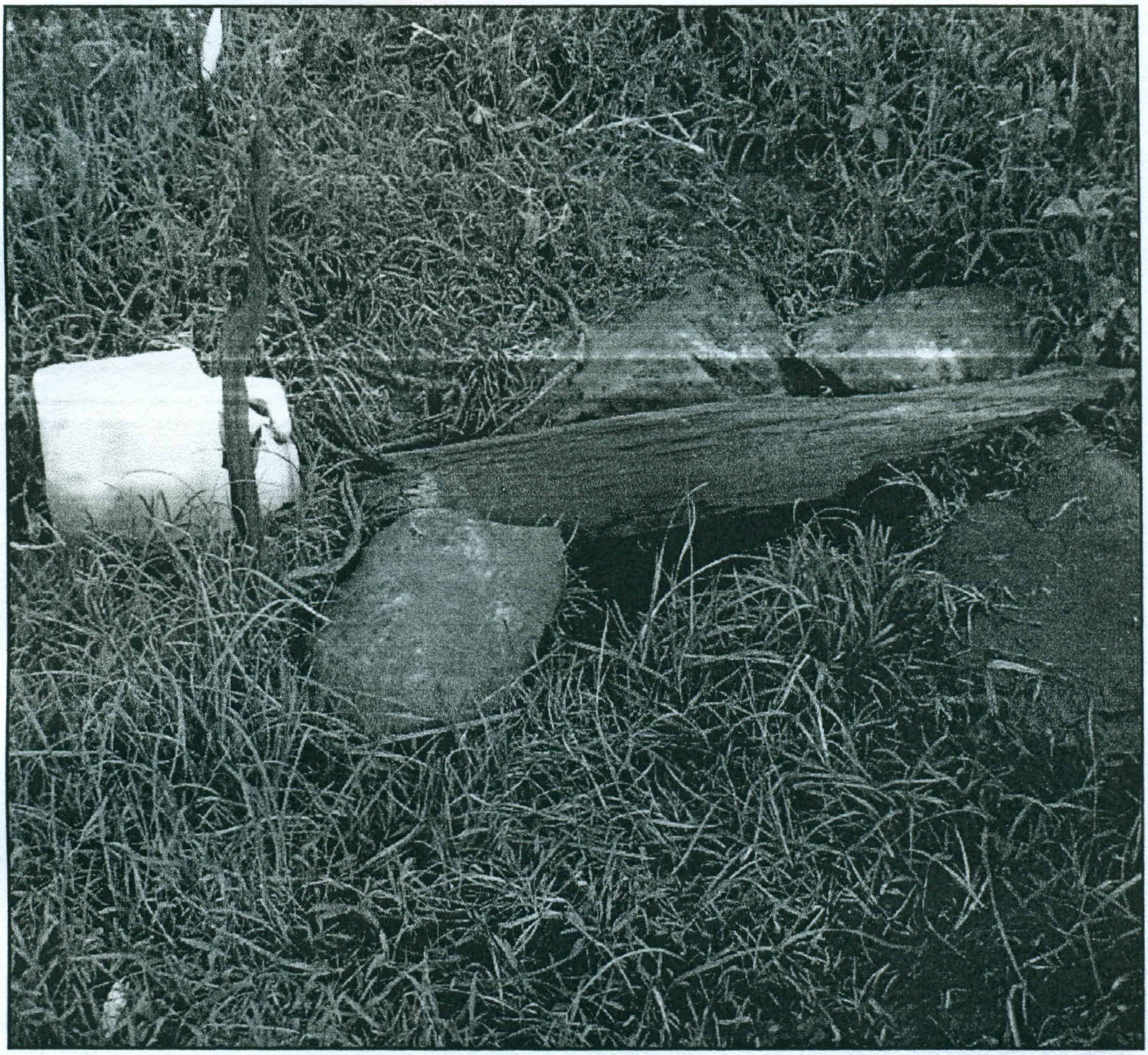
SAMPLE	TDS(mg/L)	EC(µS/cm)	Temp(oC)	PO_4(mg/L)	NO_3(mg/L)	NO_2(mg/L)	pH
SW1	38.3	79.6	14.3	0.54	7.4	0.053	5.77
SW2	55.6	123	15.5	0.97	10.9	0.069	6.50
SW3	49.6	106	11	0.56	9.1	0.071	5.93
SW4	47.8	99.3	13.6	0.77	8.1	0.033	5.98
SW5	46.8	94.6	10.9	0.81	7.9	0.073	6.02
SW6	42	84.5	19.6	0.86	9.6	0.085	6.06
SW7	43.9	86.4	19.3	0.55	7.9	0.057	6.35
SW8	44.2	88.6	13.1	0.57	6.8	0.082	6.10
SW9	38.1	79.3	14.6	0.46	6.3	0.051	6.45
SW10	35.3	77	16.3	0.77	9.5	0.084	6.11
SW11	38.6	79.8	12.5	0.09	0.05	0.004	6.55

Appendix 8: Amount of daily rainfall precipitation in mm captured by Kenya Metrological Department at Eldoret Station (ID – 8935181) as from November 2012 through to April 2013.

Day	Nov – 2012	Dec - 2012	Jan - 2013	Feb - 2013	Mar - 2013	Apr - 2013
1	0.0	0.0	0.0	3.5	0.0	7.3
2	0.0	1.6	0.0	0.0	0.0	0.0
3	0.6	0.0	0.0	0.0	0.0	42.3
4	0.0	0.0	0.0	0.0	0.0	7.6
5	7.2	1.6	0.0	0.0	0.0	14.9
6	3.8	0.0	0.0	0.0	0.0	2.3
7	2.7	0.2	0.0	0.0	2.3	3.0
8	4.7	0.0	12.7	0.0	0.0	14.4
9	1.1	0.0	0.0	0.0	0.0	18.0
10	0.0	0.0	0.0	0.0	0.4	2.3
11	0.0	0.0	0.0	0.0	0.0	7.4
12	0.0	0.0	0.0	0.0	0.0	30.2
13	0.0	0.0	0.0	0.0	0.0	15.9
14	1.2	0.0	0.0	0.0	0.0	22.0
15	0.0	0.0	2.3	0.0	0.0	0.0
16	7.8	3.4	0.0	0.0	0.0	0.0
17	0.3	1.8	0.0	0.0	0.0	0.0
18	0.0	5.0	0.0	0.0	16.5	8.1
19	0.0	0.0	0.0	0.0	0.3	0.0
20	0.0	0.0	0.0	0.0	24.4	0.0

21	0.0	3.7	0.0	0.0	0.2	4.2
22	0.0	4.3	0.0	0.0	0.0	1.5
23	0.0	0.2	0.0	0.0	0.0	3.5
24	0.0	2.3	0.0	0.0	0.0	0.0
25	0.0	0.8	0.0	0.0	0.0	13.2
26	0.0	23.7	0.0	0.0	0.0	16.5
27	0.0	0.9	0.0	0.0	17.7	15.1
28	2.5	83.0	2.0	0.0	17.8	0.0
29	0.2	20.3	27.5	0.0	17.5	6.6
30	0.0	0.0	0.8	0.0	20.9	6.6
31	0.0	0.0	13.2	0.0	4.8	0.0
Total Rainfall	32.2	152.8	58.7	3.5	122.8	262.9

Appendix 9: Shallow Wells



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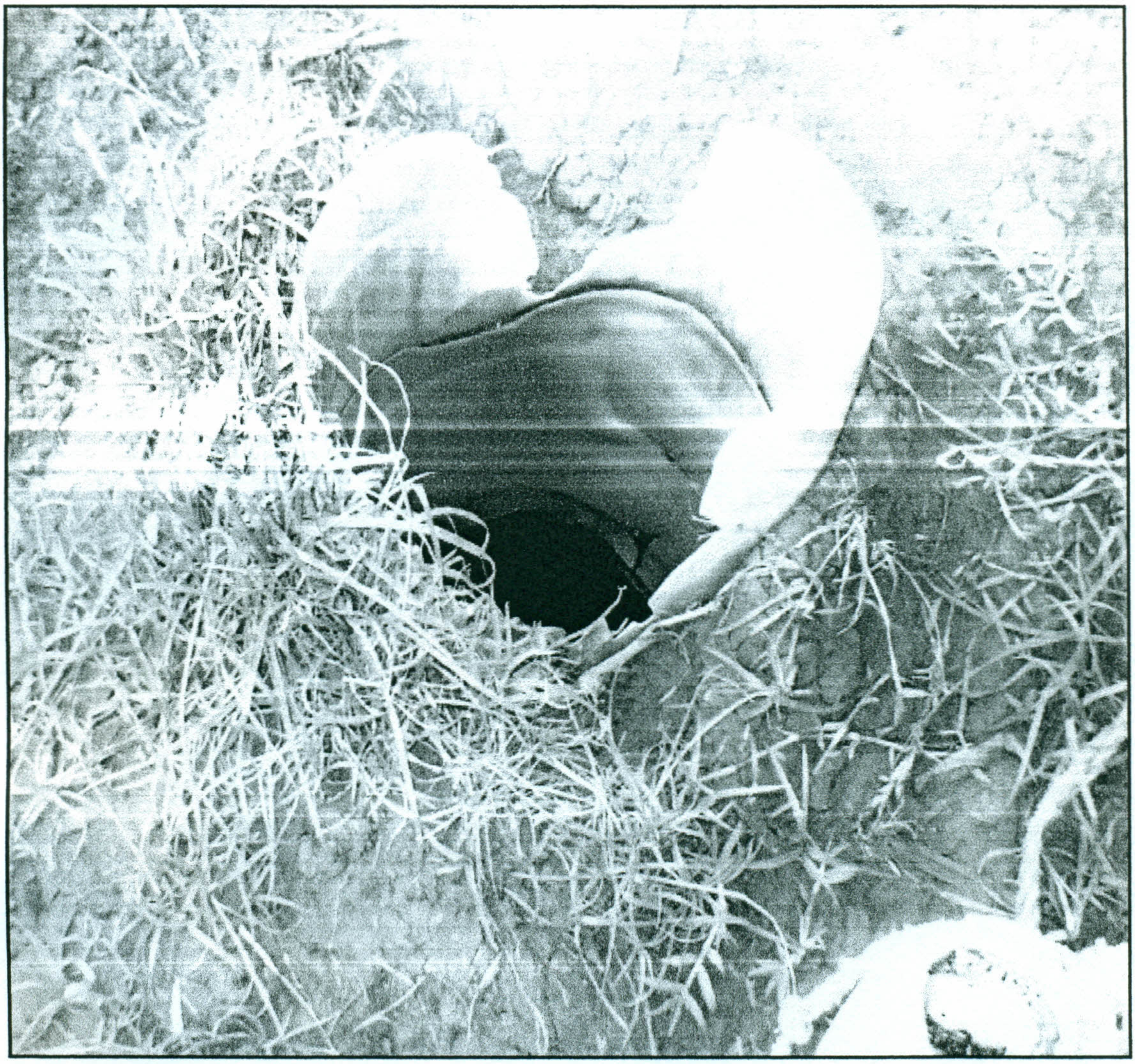


Shallow Well 2

Shallow Well 3

Shallow Well 4

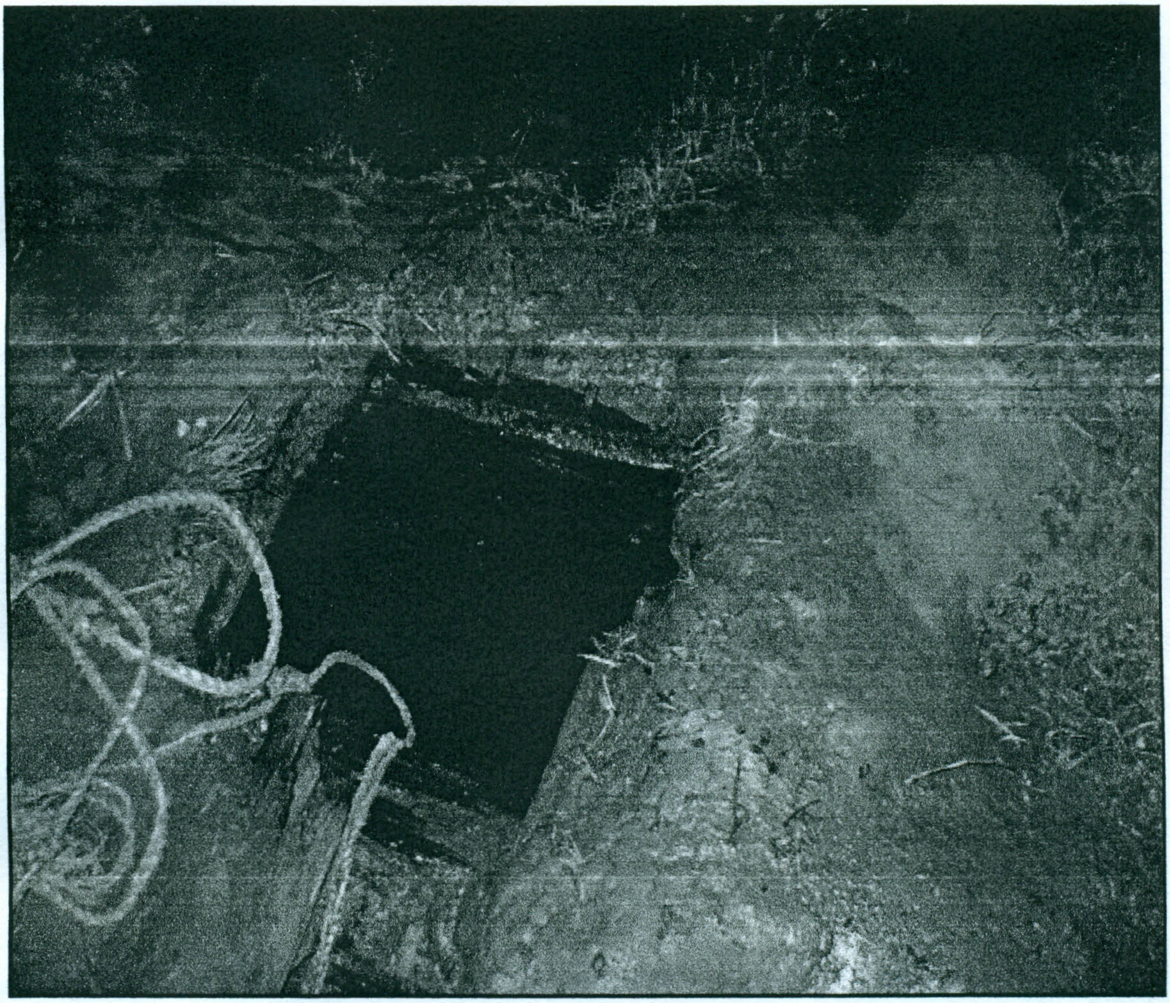
Shallow Well 5

Shallow Well 6

Shallow Well 7

Shallow Well 8

Shallow Well 9



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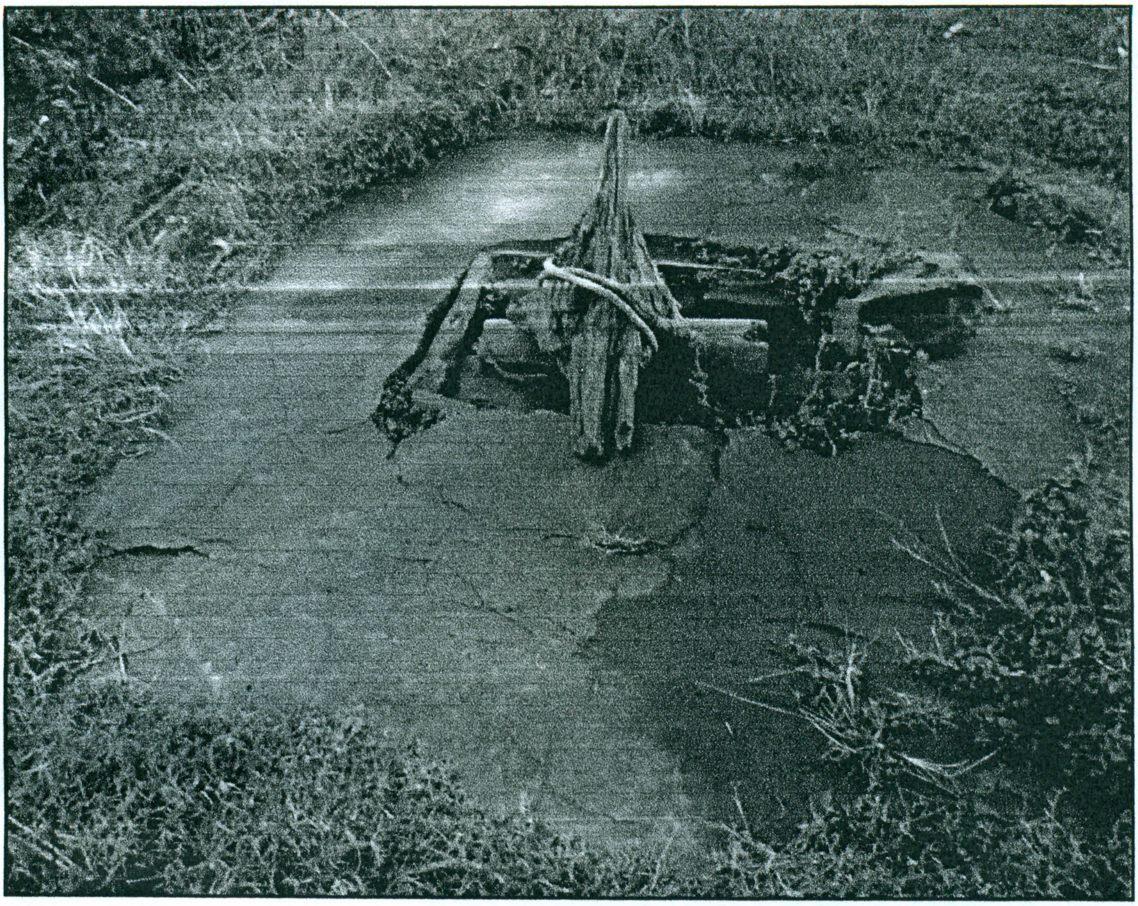

Shallow Well 11