WATER QUALITY IN SHALLOW WELLS OF GEORGE TOWNSHIP IN LUSAKA ZAMBIA AND ITS POSSIBLE HEALTH EFFECTS.

By

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DEDICATION

To the first women in my life: my late mother Medai Dia LUHANGA (1927-May 11th 2007) for introducing me to school and my darling wife Jennipher Ng'onya Phiri Mucheleng'anga for being there all the way. You made me what I am, ladies. May God remain blessed now and forever.

Plate1: Medai Dia LUHANGA 1927-2007

DECLARATION

I declare that this piece of work being submitted as a mini dissertation is a result of my own design and effort undertaken in partial fulfillment of my degree. I have made no use of materials and sources or any assistance which has not been fully acknowledged. It is therefore not in any way, a duplicate of another persons work. Any similarity to existing work is merely coincidental.

I fully understand that any breach of fair practice regulations may result in serious legal and other consequences.

Greenford Chitaku Mucheleng'anga

ABSTRACT

Lusaka sits on a limestone rock formation which makes recharge as well as pollution of groundwater very easy due to the presence of channels created by solution weathering. Informal/unplanned settlements where waste disposal facilities are non-existent, are potential groundwater contamination areas.

George Township area of Lusaka is an unplanned or informal settlement where supply of water is provided by Lusaka Water and Sewage Company through stand pipes. However, it was found that at least one percent of a sample of three hundred and fifty people interviewed in 2001 indicated that they entirely depended on shallow wells for their domestic water supply despite the availability of an ultramodern water supply infrastructure provided through a JICA grant. The quality of the water in the shallow wells has been largely unknown.

A study to monitor the quality of the water in the shallow wells in the area was instituted in April 2006 and ended in April 2007. Results obtained do indicate that the water is highly contaminated with waste materials especially human waste. The source of this contamination seems to point to the pit latrines which are the method of choice in the disposal of human excreta in the area.

With high levels of total coliforms (TC) as well as fecal coliforms (FC) and ***Escherichia coli,*** human health problems such as those related to gastro intestinal problems including diarrhoeal diseases, are a reality in the area. Further, from the preliminary results, it seems that metals such as Lead and Cadmium are also in concentrations above acceptable levels. These have serious health effects such as damage to the nervous system (Lead) as well as those related to damage of the kidneys (Cadmium). The "blue baby" syndrome in neonates arising from taking water with high nitrate concentrations such as the one in George Township area seems a real possibility.

Measures to reduce groundwater contamination from pit latrines are necessary. Those proposed range from design and construction of pit latrines to use of other types of disposal facilities as well as education of the communities. Other measures relate to treatment of water at household level to make it suitable to drink.

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LIST OF ABBREVIATIONS

AAS - Atomic Absorption Spectrophotometer
AWIRU - African Water Issues Research Unit
BOD - Biological Oxygen Demand
CEP - Copperbelt Environmental Programme
COD - Chemical Oxygen Demand
DH - Department of Health
DISS - Department of Infrastructure and Support Services
DNA - Deoxyribonucleic Acid
DPSIR - Drivers Pressures State Impacts and Responses
DWA - Department of Water Affairs
DWAF - Department of Water Affairs and Forestry
ECZ - Environmental Council of Zambia
E. coli* - *Escherichia coli
EAggEC. -Enteroaggregative *E. coli*
EHEC -Enterohaemorrhagic *E. coli*
EIEC -Enteroinvassive *E. coli*
EPEC -Enteropathogenic *E. coli*
ETEC -Enterotoxigenic *E. coli*
EC - Electrical conductivity
Eh - Redox potential
EPPCA - Environmental Protection and Pollution Control Act
FC - Fecal Coliforms
GPS - Geographical Positioning System
WARFSA - Water Research Fund for Southern Africa
WRC - Water Research Commission
JICA - Japan International Cooperation Agency
PRSP - Poverty Reduction Strategy Paper
TC - Total Coliforms
LWSC - Lusaka Water and Sewerage Company
LA - Local Authority
LCC - Lusaka City Council
MLGH - Ministry of Local Government and Housing
NISIR - National Institute for Scientific and Industrial Research
NWASCO- National Water and Sanitation Council
RNA - Ribonucleic Acid
WHO - World Health Organisation
pH - the negative $\log_{10}$ of the hydrogen ion concentration
UV - Ultra Violet light
USFDA - United States Food and Drugs Administration
HIV - Human Immunodeficiency Virus
AIDS - Acquired Immuno deficiency Syndrome
HAV - Hepatitis A Virus

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WATER QUALITY IN SHALLOW WELLS OF GEORGE TOWNSHIP IN LUSAKA ZAMBIA AND ITS POSSIBLE HEALTH EFFECTS.

CHAPTER 1: INTRODUCTION

1.1. Background

Water is one of the most important requirements for human survival. It is estimated that about one sixth of the world population does not have regular access to an adequate and affordable supply of potable water (Miller, 2005:312). Zambia is said to have vast amounts of water of generally good quality (JICA, 1995:Q-3). However, there is a general decrease in the quality of this commodity due to various anthropogenic activities (Nkhuwa, 2003:1139). According to the South African Quality of Domestic Water Supplies Volume1&2: "Assessment Guide" and "Sampling Guide" (Second and First Edition respectively), water quality is defined as "the physical, chemical and microbiological properties of water that determine its fitness for use..." (DWAF, DH, WRC, 1998:5; DWAF, DH WRC, 2000: 3). It can, therefore, be said that the chemicals dissolved or suspended as well as other materials that may be in it including microbes, determine how fit for use any quantity of water may be. Water of poor quality though may be physically available, in reality it can be said to be inaccessible and unavailable to humans as consumption of such water means exposure to diseases with catastrophic consequences.

Pollution is defined as ".the presence of substances at high enough levels in air, water, soil, or food to threaten the health, survival, or activities of humans or other organisms" (Miller, 2005:11). Polluted water would therefore have unwanted chemical and biological agents as well as suspended materials following man's actions that would render it unfit to be used (DWAF,DH,WRC, 1998:6). Groundwater is one of the major sources of water supply to many cities and towns in the world today. However there are serious threats to this source due to pollution arising from human activities. This is more evident in informal/unplanned settlements. Provision of modern infrastructure for water supply to communities may not in itself result in total abandonment of the old and contaminated supplies. The need to establish the quality of such sources of community water supply and find ways of ameliorating this problem is critical. Identification of the possible effects of consumption of such water may have on human health, is important. Further, provision of better available alternatives also becomes a necessity.

1.2. Rationale of the Study

During the period 2000-2002, a project on Adaptive Capacity, Water Demand Management and Natural Resource Reconstruction involving three SADC countries namely Botswana, South Africa and Zambia was carried out. Data gathering was done in two of these countries namely Botswana and Zambia. Anthony Richard Turton of the African Water Issues Research Unit (AWIRU) of the University of Pretoria was team leader for this project. The Water Research Fund for Southern Africa (WARFSA) supported the project. One of the findings of this project in Zambia was that as a coping strategy due to problems of access to the cleaner water supply, communities in one of the Zambian sites called George/Lilanda in Lusaka depended on shallow wells for their water supply. This was despite having an elaborate and ultra modern water supply system (Turton, A.R., Khupe, J., Mucheleng'anga C.G., 2002: 37 Appendix E2). It was also established that about all residents of this area had alternative supply in form of a shallow well (Turton *et al.,* 2002:39 Appendix E2). The shallow well therefore provided a supply of water when the clean water supply was inaccessible due to among others, inappropriate access times that is limited between 04:00-08:00hours in the morning and 15:00-17:00hours in the afternoons as well as quantity being limited to 100 litres per household.

It was also found during the same study that at least one percent of a sample of three hundred fifty (350) respondents interviewed in this area solely depended on shallow wells for their every day supply of domestic water (Turton *et al.,* 2002:39 Appendix E2). Incidentally, the modern water supply infrastructure was built to reduce the incidence of cholera outbreaks in the communities in the area. These outbreaks were associated among others, with drinking water of poor quality from shallow wells. Restrictions of accessing only a maximum of about five (5) by 20 litres containers (total 100 litres) of water each day per family were also observed (Turton *et al.,* 2002:39 Appendix E2). The operating times were also seen to be somehow awkward to most of the people especially those that had to go to work in town. In this regard water is only accessible twice a day between 04:00 and 08:00 in the mornings and between 15:00 and 17:00 in the afternoons. The problems of water borne infections in form of diarrhoeal diseases may continue to affect the communities due to the fact that shallow wells have continued to be used as a source of water despite the modern infrastructure (Turton *et al.,* 2002:39 Appendix E2). The area is one of the most affected in the now nearly-endemic cholera outbreaks in Lusaka (Nkhuwa, 2000:997).

Since the WARFSA-supported project concentrated on socio-economic issues, a look back on actual evaluation of the quality of the water of this area seemed an appropriate thing to do. To assess the quality of the water during and after the rainy season was therefore important. This was further supported by the fact that though some form of monitoring of the quality of water had been done in the past, this had been limited in scope and had never covered the George Township area. For example, Nkhuwa and team made observations on the water quality of some shallow wells in some peri-urban areas of Lusaka between 2003 and 2005 but excluded the George Township area. This exercise could also be said not to have been long term and consistent. Long term monitoring of the quality of the water in this area seems therefore not to have been done before except for ad-hoc water quality checks during disease outbreaks. The issue of monitoring quality of water regularly was also raised by the Japan International Cooperation Agency (JICA) in the National Water Resources Master Plan (JICA, 1995: Q-4, Q-28).

1.3. Problem Statement.

The 1994 Zambian National Water Policy states " ... promoting a sustainable water resources development with a view to facilitate an equitable provision of adequate quantity and quality of water for all competing groups of users at acceptable costs and ensuring security of supply under varying conditions" (MEWD, 1994:14). It further states that the amount and quality of water consumed by a community determines its standard of living (MEWD, 1994:3). It is in this regard that the Government of the Republic of Zambia embarked on the improvement of water supplies to communities in various peri-urban and rural areas of Zambia. Provision of safe and accessible drinking water in order to enhance health and productive lives of the people is an ideal that Government wants to achieve (MEWD, 1994:3). Government also aims to improve the health status of its people through among others, encouragement of lifestyles that promote health as well as creation of environments that support health (Second PRSP Implementation Progress Report July 2003-2004:41).

It has been established that there is widespread domestic use of water from shallow wells in George Township area (Turton *et al.*, 2002:39 Appendix E2). During the WARFSA project it was found that almost the entire population of George Township has a shallow well where water for various domestic activities is drawn (Turton *et al.*,2002:39 Appendix E2). Use of water of poor quality has serious effects on human health. For example domestic use of water of poor bacteriological quality may result in various diseases in the community. Some of these may be diarrhoeal in nature. In cases where some mineral elements exceed the stipulated levels, disease outbreaks may also result. For example, high Lead concentration may result in diseases that affect the nervous system while Nitrates may results in serious problems of transportation of oxygen in babies. Though only one percent (four persons) of the sample of 350 people interviewed indicated their total dependency on shallow wells, if this is extrapolated onto the entire George Township population, the figure could be in the region of 2000 individuals. This figure can not be ignored. Further, it can be said that anyone coming into contact with water of poor quality in whatever way, may also be affected. The problems of water borne infections in form of gastrointestinal ailments such as diarrhoeal diseases may continue to affect the health of the communities as shallow wells have continued to be used as a source of water (Turton *et al.*, 2002:39 Appendix E2). The area is perhaps one of the most affected in the now perennial cholera outbreaks in Lusaka (Nkhuwa, 2000:997). The lack of focus to establish the trends in the quality of the water in the area over a period of time through a consistent and long term monitoring programme propelled the need for this study.

1.4. Methodology

The project aimed at assessing the quality of the water as well as possible impacts on human health the water supply would have on the communities. It was therefore found imperative to have community consent before the work could start. In order to bring the community on board, the leadership at various levels was brought to the knowledge of the activity through written requests as well as one-to-one meetings. For example, letters were written to the Ministry of Local Government and Housing as well as the Lusaka City Council whose responsibility covers issues of water supply and sanitation (see Appendix 1). Lusaka Water and Sewerage Company was also written in similar manner to seek its support including provision of any information on among others, the issues of any past water quality observations done in the area. Department of Water Affairs (DWA) was also requested for information as well as technical support to undertake the project.

On another level, the political leadership of the area was involved long before the sampling work actually started. One-on-one meetings were held with the area councillor and other members of the communities in which sampling of water was to be carried out. Focus group discussions were also held with the community leadership as well as members of the community. Transect walks were also carried out in the area.

Initially at least twenty wells were selected at random within the Lima ward 17 of George Township area. A further sift was done to pick ten (10) wells which were subsequently sampled consistently for the period of the study. The water sampling started in April 2006 and was concluded in April 2007.

Using scoops that the communities were using to draw water at each shallow well, water was collected into sample bottles which were fully labelled (including name, date, person sampling, time of sampling). Three bottles on each site were filled with water obtained from the site: one for physical chemical, one for bacteriological while another was for heavy metal determination. These samples were then delivered to the University of Zambia Environmental Engineering Laboratory for analysis. During each sampling campaign, water depth, temperature, pH, Electrical Conductivity (EC) and Redox Potential (Eh) were determined *in situ*.

Analysis of the results was done by using the World Health Organisation (WHO,2004:Guidelines for Drinking Water quality 3rd Edition) as well as the South African Quality of Domestic Water Supplies Volume1: "Assessment Guide" on domestic water quality as guides to show whether the samples exceeded the normal permitted levels in the various parameters: physical, chemical and bacteriological. These also provided the required information on possible effects of the various materials present in the water. Other literature was also used to determine the possible health effects the water could have on the user community.

1.5. Constraints of the study

This study was undertaken under circumstances where financial resources were a major limiting factor. This made the selection of sample points not to be as extensive as would have been desired.

Therefore only ten (10) points were selected. This also implied that only one section of the George Township area could be covered for this activity. Further, the time requirements that would have been ideal if work was to be carried out for more than a year had to be done in a shorter time period. This was so in order to ensure that submission of the dissertation could not be delayed any further. The need for observations in both dry and wet seasons of the year and over a longer period of time could not be fully achieved due to the same time and cost factors. There were also technical limitations as a result of not having own equipment for the sampling campaign and these had to be hired from DWA. Only one laboratory was used for the analysis of the water samples as use of any additional laboratory for purposes of inter-comparison could not be possible due to cost. This was made worse by the fact that the NISIR Environmental Research Laboratory was at the time undergoing rehabilitation hence was not available for use.

1.6. Ethical considerations

During the sampling campaign, it was obvious especially after the initial results, that there was some serious problem especially with the bacteriological quality of the water in question. It was therefore necessary to inform the well users to take care by way of boiling the water or application of chlorine to the water that has been collected from the wells. This was important especially if such water was to be used for drinking or washing. This information had to be relayed in such a manner as not to raise any alarm. It was also necessary to inform the community that the campaign had nothing to do with the Lusaka City Council's planned closure (or burial) of the shallow wells. This was important as at the time of the start of the project, Lusaka City Council had apparently sent some people into the area to look at what was the actual situation on the ground with regard to use of shallow wells.

Any form of inducement for participation in the study could not be considered. This could also have amounted to corrupting the minds of the participants. The programme was, therefore, brought to the full attention of the leaders in the community who eventually made it easier for the community to be able to freely participate. Though one would have desired to make results available to all the users of these shallow wells after each analysis, this could not be possible as it could possibly have affected the overall results of the study. The information was however availed to the community through advice given at each subsequent visit on how to deal with the water to prevent infection. It was also found necessary not to extend to any new sampling points which communities were now freely offering for the exercise as there were no resources to do so. The community was also advised against direct application of chlorine into the wells as this could not be effective and could have affected the results as well.

It was also found prudent not to use hand gloves as well as mouth guards when sampling the water as this could have been offensive to the sensibilities and egos of the users. Use of the water drawing utensils used by the owners of the wells to draw the water during the sampling campaign, was also done so that communities did not see anything abnormal in the collection of the water. It was therefore prudent to follow the way water was collected for use by the communities. *In situ* reading of results on site had to be done in such a way that containers from communities were not used or if necessary only minimally used when it was absolutely unavoidable and done with their full permission.

CHAPTER 2: PROBLEM DESCRIPTION

2.1. Introduction

The African Water Issues Research Unit of the University of Pretoria in collaboration with National Institute for Scientific and Industrial Research (NISIR) carried out a project on Adaptive Capacity Water Demand Management and Natural Resource Reconstruction in Zambia during the period 2000-2002 (Turton, A.R., Khupe, J., Mucheleng'anga C.G., 2002). The project was supported by the Water Research Fund for Southern Africa (WARFSA). Among the findings of the project was the fact that in one of the sites covered: the George/Lilanda area, though well equipped with modern water supply infrastructure, a portion of the population entirely depended on shallow wells. This was demonstrated by the fact that of the 350 interviewed; one percent indicated that they entirely depended on shallow wells for their domestic water supply. It was also found that literally all those interviewed had an alternative water supply in form of a shallow well. Use of shallow wells as alternative sources, was found to be an extensive coping strategy in the area. Reasons for this state of affairs varied from economic to social as well as managerial ones.

When need arose for one to do a research project in a water-related aspect as a precondition for the Masters in Environmental Management Programme, a look back on the issues raised during the WARFSA study was a choice that one could not ignore. The evaluation of the quality of the water the residents depended on for the various domestic chores was such an aspect. The evaluation of the possible health effects (if any), related to use of the water in shallow wells was deemed necessary. This was for the purposes of highlighting the problem and making people aware of this problem. Further, suggestions on any mitigation measures to alleviate the problems were found necessary.

2.2. Aim of the study

The study aimed at observing the quality of the water in the shallow wells over a period of time to determine its quality on the basis of given parameters. This covered both the wet and dry seasons. Observations for any possible contamination from any sources as well as water quality variations (if any), within the area during the seasons were to be made. Elucidation on any possible health effects arising from quality of the water was also thought of. An attempt to make practical proposals on possible management strategies to improve on resource management in the area was also targeted. The shallow well in the area could be considered as "point of use" source since this water was directly used in households. It was hoped that the current quality of the water in shallow wells in George Township area may to some extent, be elucidated through this study.

Contamination of groundwater through use of unlined and unsealed pit latrines has been suggested to be a major contributing factor in the lowering of the quality of the ground water in informal/unplanned settlements. It is understood that the presence of certain substances in the water from shallow wells such as fecal coliforms may be indicative of the pollution from the pit latrines. High levels of nitrates as well as nitrites may indicate high levels of organic input into the water and the likely source may be the pit latrines. It was therefore important to look at the possible health effects of some of the physical, chemical as well as bacteriological parameters.

2.3. Study Objectives

The overall objective of the study was the determination of the quality of the water in the shallow wells in George Township area and the possible health effects it may have on the population and also to contribute towards provision of information for making sound environmental management plans. In order to mount a campaign to look at the quality of the water used by residents in shallow wells in George Township (Lima Ward 17), the study had to be able to do a number of activities which provided the base for the work. These activities included a sampling campaign in shallow wells in a selected part of George Township and analysing the data obtained from the parameters given. Another was to provide information that could serve as a basis for making sound environmental management plans as well as possible recommendations to address the problems. In this regards, the study specifically aimed to:

i. Observe the physical-chemical and microbiological quality of the water as well as the water table fluctuations in the wells in the area during the wet and dry seasons
ii. Determine the relationships (if any) and possible implications of the results of the analyses on the health of the communities

iii. Propose possible strategies that may be appropriate to the community and the Government to reduce the negative impacts on the quality of the water and health of the communities.

2.4. Extent of the problem

Lusaka lies on a limestone rock formation which is prone to solution weathering. This has led to formation of channels which allow for quick recharge of groundwater. In similar manner, pollution of the groundwater happens just as quickly. Population pressures have resulted in failure of local authorities to provide to the communities amenities such as housing, adequate sanitation and waste disposal facilities. With a lot of informal/unplanned settlements, the threat to groundwater arising from lack of appropriate waste disposal facilities has therefore become a reality.

George Township area is located in the North West part of Lusaka (see Figure 1). This township is a densely populated informal/unplanned settlement. It sits on a shallow aquifer with a lot of evidence of discharge zones. Water can be obtained within five metres of depth even during the dry season. Waste disposal in the area is far from being adequate and most residents litter their streets as well as throw wastewater into these streets which also serve as conduits for wastewater and pollutants. The area has the highest incidence of cholera in Lusaka (Nkhuwa, 2000:997) which is especially prevalent in the rainy season. The major supply of water is from the shallow wells despite the modern infrastructure due to various managerial as well as economic and sociological factors. Looking at the drivers, pressures, state, impacts and response (DPSIR) framework in environmental assessment, this could be as presented below:

2.4.1. Driving Forces (put pressures on environment)

Population increase in urban areas due to among others, the bright light syndrome has brought serious situations in these areas as there has been a huge rural-urban drift. Recent job losses due to industrial closures arising from the structural adjustment programme, have added to this density by people moving from one urban settlement to another. The local authorities have not been able to provide housing and other facilities for this population. Lack of requisite facilities such as decent housing, water supply and sanitation facilities as well as general waste disposal arrangements has beset the communities.

2.4.2. Pressures (results from the driving forces-stresses the human activities place on the environment)

The pressure on the services has resulted in the initiative by the people to construct their own facilities such as houses in any open space. These informal/unplanned settlements may be located on any space including groundwater recharge and discharge zones. Disposal of waste has become a serious problem as there are no facilities for such. Garbage collection services are non-existent. The problem is especially exacerbated in a limestone area where channels and other such conduits results into direct mixing of dirty water from the surface runoff with groundwater. Discharge of human wastes into the groundwater system through use of unlined pit latrines provides pressure on the environment.

2.4.3. State (the condition of the environment including recent trends)

Groundwater contamination results from such poor waste disposal arrangements. The poor state of the quality of the water which unfortunately is used in the various household chores has serious implications on the health of the users.

2.4.4. Impacts (consequences of the pressures on the environment)

There is a direct impact on the disease burden as the water becomes unsuitable for human consumption. Diseases resulting from use of contaminated water have had serious health and economic impacts on the population. This has been more so with frequent outbreaks of water borne diseases such as cholera. The impacts on the health care system have been overwhelming in situations where resources have to be mobilized to contain the disease outbreaks. With high morbidity and sometimes mortality being experienced during such outbreaks, the costs to the community let alone the country are very high.

2.4.5. Responses (by society on the environmental situation)

In order to reduce the problems of disease, the Government of the Republic of Zambia through financial and technical support of the Japanese Government responded by providing facilities to supply quality potable water to the communities. However, due to managerial and other problems, communities have continued to draw water from the shallow wells to supplement their clean water supply and in some cases, entirely depend on it. This apparently negative response from the communities has serious consequences. Community based organisations such as the neighbourhood health committees have also been formed within the communities to assist in monitoring the health situation of these communities.

2.5. Conclusion

The contamination of groundwater in informal/unplanned settlements especially in a limestone area is a serious problem. This is worsened in areas of higher population concentration with poor or no sanitation facilities. The incident of diseases from use of such water especially diarrhoeal diseases is a real threat. The need for measures to address the problem of groundwater pollution cannot be overemphasized. The need for information such as what this study was designed to provide so as to give an appropriate state of the situation, will assist in planning mitigations and interventions.

CHAPTER 3: LITERATURE REVIEW

3.1. Introduction

3.1.1. The water sector in Zambia

Zambia is endowed with vast amounts of both surface and groundwater resources. It is estimated that Zambia has a total surface water potential of 237 million cubic metres per day while ground water recharge is estimated to be about $57.5x10^9$ m^3 per year (MEWD, 1995). These resources are located in Zambia's rivers, lakes as well as groundwater reserves that exist in the many aquifers. However, the water sector in Zambia is faced with numerous challenges. Despite the fact that there is an apparent abundance in the resource, threats on its quality are evident. This is worsened by the fact that there is poor coverage of sanitation facilities as well as regulatory enforcements in the country thereby threatening the quality of the water resources through pollution.

Following the earlier part of the water sector reorganisation, the Ministry of Energy and Water Development which had also been involved in supply of water, has been mandated to oversee the issues related to development and management of the water resources while the responsibility to supply water is now vested in the Ministry of Local Government and Housing through the Local Authorities (LA). Formation of the Commercial Utilities by the LAs and eventual participation of the private sector for purposes of ensuring better management of the water supply has been envisaged.

3.1.2. Situation analysis of Water Supply and Sanitation in Zambia

Estimates by the National Water and Sanitation Council (NWASCO) indicate that only about 67% of the urban population and 29.5% of the rural population have access to adequate water supply. The sanitation situation is estimated at 39.2% in urban and 2.1% in rural areas having access to adequate sanitation (NWASCO, 2004:3). In the towns and cities, the most affected are the informal/unplanned settlements where water supply facilities may not be adequate while sanitation facilities may be non-existent. This implies that the large un-serviced population is prone to all possible negative health effects arising from use of contaminated water as a result of lack of water supply and sanitation facilities. It is also true that cities like Lusaka do not have adequate sewerage treatment facilities and more than 75% of its population use onsite sanitation (Nkhuwa, 2000:995; Nkhuwa, 2003:1141) which is a serious threat to groundwater. The rapid population increase and expansion of the city against the available sewage treatment capacity has meant that many areas do not have these treatment plants or if they do, then they are totally overloaded.

3.1.3. Contextualising Health Effects.

It is said that "an important requisite for good health is an adequate supply of water that is of satisfactory sanitary quality" (Salvato, 1982:173). Quality of water is determined by what the water may be carrying as it moves along in the environment. Therefore the chemicals it may dissolve, the microbes and other materials it may carry determine its quality. Presence of certain mineral elements may have positive as well as negative health effects. For example absence of certain mineral elements such as iodine may lead to deficiency diseases. Above certain levels, some of these mineral elements may become detrimental to health. In this particular case, the negative effects will be the most to be considered in this assessment. Consumption of water of poor quality has direct health effects on the consumer. These may range from short-term diseases that may last for a short while or those that may take long to manifest but with serious long-term effects. Microbial quality is important as high levels of disease causing microbes brings with it dangers to human health including death.

3.2. Legislative considerations

3.2.1. Water Resources Management Bill

The water resources management system set up in Zambia under the existing legislative framework failed to consider groundwater as part of the resources that required to be distributed to groups of users with competing demands. The result of this was that abstraction of groundwater was therefore not regulated and boreholes were sunk without any due consideration. In like manner, settlements as well as the construction of septic tanks were done without much consideration of the possible groundwater resources pollution. The old Water Act of the 1940s and 1950s is therefore antiquated and is being replaced by a new bill: the Water Resources Management Bill. The Bill among others proposes to

(d). ***provide for the equitable, reasonable and sustainable utilisation of the water resources;*** and

(e). ***provide for the management, development, conservation, protection and preservation of the water resource and its ecosystems***

Specifically Part XI Section 92 (1) states:

(a). ***encouraging the development of sustainable practices that do not degrade groundwater***

(c). ***preventing the pollution of aquifers through the regulation of toxic substances that permeate the ground; and***

(d). ***recommending to the Minister, the declaration of protected areas around groundwater recharge areas and abstraction sources.***

This piece of law-to-be is revolutionary in that groundwater is for the first time in the water law being considered as a resource that requires to be protected and regulated in its use and management. The use of the pit latrine and septic tanks would somehow be in contradiction with this legal instrument as this may be considered as part of unsustainable practices that degrade the groundwater resources. The need to prevent pollution of aquifers through regulation of substances as well as declaring certain areas protected zones to prevent pollution that may infiltrate into the groundwater is emphasized. Settlements in areas which may be considered as important recharge zones may therefore be controlled through this incoming law.

3.2.2. Environmental Protection and Pollution Control Act 1990.

The Zambian law on environmental protection and pollution control was enacted in 1990. The law states as follows:

The Environmental Protection and Pollution Control Act 1990 (EPPCA) and revised in 1999 is An Act to provide for the protection of the environment and the control of pollution; to establish the Environmental Council and to prescribe the functions and powers of the Council; and to provide for matters connected with or incidental to the foregoing.

Definition of discharge according to the Environmental Protection and Pollution Control Act is given as "spilling, leaking, pumping, emitting, emptying or dumping…"(Republic of Zambia Environmental Protection and Pollution Control Act 1990 Part IV Section 22). The definition of an aquatic environment according to this Act does include the groundwater as it says on an aquatic environment in Part IV Section 22 "….all surface and ground waters….." (Republic of Zambia EPPCA, 1990). Further, the Act prohibits discharge of any pollutant into an aquatic environment. This is presented in Part IV Section 24 and is stated as follows "…no person may discharge or apply any poisonous, toxic, erotoxic, obnoxious or obstructing matter, radiation or other pollutants or permit any person to dump or discharge such matter or pollutant into the aquatic environment in contravention of Water Pollution Control Standards established by the Council under this part" (Republic of Zambia EPPCA, 1990). This is repeated in Part VI Section 50 of the same Act where it says " no person shall discharge waste so as to cause pollution in the environment". The discharge of wastes to groundwater through use of pit latrines as method of sanitation could be said to without doubt, be against this legal provision.

3.2.3. Water Supply and Sanitation Act of 1997

The Water Supply and Sanitation Act number 28 of 1997 states:

An Act to establish the National Water and Sanitation Council and define its functions; to provide for the establishment, by local authorities, of water supply and sanitation utilities; to provide for the efficient and sustainable supply of water and sanitation services under the general regulation of the National Water Supply and Sanitation Council; and to provide for matters connected with or incidental to the foregoing.

This Act places the obligation of supply of water and sanitation services on the local authorities when it says in Part III Section 10(1) "a Local Authority shall provide water and sanitation services to the area falling under its jurisdiction....". Provision of such services to its population is therefore critical. However, with the burgeoning population and reduced financial resources to cope with such increases, there has been a general failure by the local authorities to meet this obligation. The poor sanitation facilities in George Township area could be attributed to lack of such services from the Lusaka City Council through the Lusaka Water and Sewerage Company (LWSC).
The National Water and Sanitation Council (NWASCO) is also obligated to establish and enforce standards for design and construction as well as operation and maintenance of water and sanitation facilities as stated in the above Act part II Section 4 (2) (e) (i) and (iii) of this law. Monitoring of the design quality of these water supply and sanitation facilities in George Township could therefore necessarily be looked into by NWASCO so as to ensure that the menace they cause could be minimised.

3.2.4. Public Health Act CAP 295 of the Laws of Zambia

The Public Health Act Chapter 295 of the Laws of Zambia provides necessary input in the protection of groundwater from pollution. Part IX Section 64 prohibits any individual to generate or cause nuisance that may be injurious or dangerous to health. The Local Authority is mandated to ensure that its areas of jurisdiction are kept clean and without nuisances (Section 65 of part IX). Section 67 (1) (d & e) of Part IX indicate that wells supplying domestic water of poor quality (polluted) or waste water flowing or discharged into public streets constitutes nuisance.

Prevention of pollution to water supply as well as cleaning of such water supplies in any Local Authority's jurisdiction area is the responsibility of such a Local Authority. This is contained in Part XI of the Public Health Act CAP 295 of the Laws of Zambia. In this regard Section 78 states:

> ***78. It shall be the duty of every Local Authority to take all lawful, necessary and reasonably practicable measures for:***
>
> ***(a). preventing any pollution dangers to health of any supply of water which the public within its district has a right to use and does use for drinking or***

domestic purposes(whether such supplies derived from sources within or beyond its district) and

(b). *purifying any such supply which has become so polluted; and to make measures (including if necessary, proceedings of law) against any person so polluting any such supply or polluting any stream so as to be a nuisance or danger to health.*

The seepage of materials from the pit latrines into the groundwater whether done without knowledge, is a matter that requires control by the LA and other agents as it is a public health problem.

3.2.5. Local Government Act Cap 281 of the Laws of Zambia

Functions of Councils in Zambia among others include control of developments and use of land in their areas especially in the interest of public health and public safety (Section 61 subsection 29 of the Local Government Act CAP 281 of the Laws of Zambia). Others include establishment and maintenance of public health (Section 61 subsection 40 of CAP 281). In Section 61 subsection 61, the Councils have an obligation " to take and require the taking of measures for the conservation and the prevention of the pollution of supplies of water". This therefore requires that the Council should ensure that water supply areas within its jurisdiction are maintained in a manner fit for use. Sub-section 50 of Section 61 indicates that Councils have the responsibility to provide sanitary conveniences and ablution facilities as well as ensuring that these are available and well maintained. However, due to various problems as a result of high population pressures and other related issues, the local authorities are unable to perform this function to the full. The result is informal/unplanned settlements wherever open space can be found, without authorisation and without adequate sanitation facilities. Political interference has not spared the situation either.

3.3. Other literature

Groundwater is of great importance to man. This is so because it may be easily accessible in a most cost effective way. This is specially so in situations where surface water supply becomes difficult to access (Sililo, O.T.N., Saayman, I.C., Fey, M.V., 2001:1.1). If this water has to be of use to man, knowing its quality, is therefore very important.

Quality of groundwater is usually determined by the rainfall and the geological reactions that take place in the saturated and unsaturated soil zones (Veltman, 2003:104). It is indicated that the largest cause of alteration of the natural water chemistry is through pollution from human activities. These activities include waste discharges and agriculture (Goldman and Horne, 1983:92). Urbanisation has been cited as such an element that has caused serious diffuse groundwater pollution problems today (Goldman and Horne, 1983:94) especially when unplanned.

Aquifer vulnerability is said to be a factor of accessibility of the saturated zone as well as the attenuation capacity of the ground where this aquifer occurs (Sililo *et al.*, 2001:1.1). In this regard, the more accessible the aquifer's saturated zone through penetration of mobile contaminants, the higher the vulnerability. It can also be stated that the higher the capacity to attenuate the effects of the pollutants by the subsurface soil and other materials, the less vulnerable is the aquifer (Sililo *et al.*, 2001:1.1). Limestone aquifers are said to be very vulnerable to various environmental impacts. This is due to the fact that they have a poor subsurface purification system (Veltman, 2003:104). Increased human activities in urban areas provide serious opportunities for negative impacts on groundwater quality (Sililo *et al.,* 2001:1.2). This is specially so in areas where there are inadequate facilities for sanitation and other waste disposal requirements (Sililo *et al.*, 2001:1.2). Most pollutants found in groundwater are in form of bacteria and other micro-organisms. In addition, there are inorganic ions such as nitrites and nitrates, chlorides, sulphates and trace ions such as heavy metals (Lead, Arsenic, etc) which are also important (Sililo *et al.*, 2001:2.1; Wright, 1999:1, 8; Wu *et al.*, 1999:251-256). In urban areas, it has been identified that groundwater contamination occurs from sewer leakage, sewerage effluent and sludge, urban runoff, landfill leachates, latrines and septic tanks as well as agricultural chemicals (Sililo *et al.*, 2001:2.1).

Informal/unplanned settlements are a major contributor to urban groundwater pollution. This is so because there is usually an accumulation of wastes. This accumulation of wastes is due to lack of disposal facilities (Sililo *et al.,* 2001:2.3; Wright, 1999:i). In South Africa, at least 31% of the urban population does not have adequate access to clean water and sanitation facilities (Wright, 1999:1). In China it is estimated that at least 700 million people do not have access to clean and wholesome water (Wu *et al.,* 1999:251-256). The Zambian situation is no different as at least 50% of urban dwellers have no access to adequate sanitation (NWASCO, 2004:3). Problems of space (or lack of it) do play negatively in the provision of adequate sanitation services (Wright, 1999:5). Pit latrines though the technology of choice among the communities, are perhaps one of the biggest dangers to groundwater pollution. This is so as these pit latrines discharge their contents right into the ground and near or at the water table (Nkhuwa, 2003:1141) . This is worse in areas with shallow water tables (Wright, 1999:7,8). Sanitation systems, garbage disposal sites, communal water supply points, storm water drains and informal trading areas pose a high risk of groundwater contamination. This is specially so in informal/unplanned settlements (Wright, 1999:34) where appropriate waste collection and disposal facilities are not available. However, groundwater pollution can only occur if a transport medium in form of water provided by rainfall is available (Wright, 1999:43). This could be the major reason why there is normally a raised diarrhoeal disease burden during the rainy season especially in George Township area. This may be exacerbated by the coarse texture of weathered material which allows for increased transmissivity hence probably reduced attenuation capacity and increase in transportation of pollutants to groundwater (Wright, 1999:48).

Water in dolomitic aquifers is mainly calcium-magnesium carbonate in nature in the ratio ranging 1.2 and 1.8. This water is said to be usually of recent origin (Veltman, 2003:29). This is probably so because recharge may be very active in such formations especially where there are direct channels that may quickly take water downwards. It is also said that limestone areas provide high yielding boreholes. This is attributed to the underground drainage system made up of channels, caves, canals, etc., which provides such a supply (Veltman, 2003:29). The channels are formed from the solution weathering that takes place in limestone rock along the fault lines and contact zones as well as intrusions. In this regard, the weak carbonic and/or other acids that may be formed when rainwater dissolves some gases such as carbon dioxide subsequently dissolves the rock (Goldman and Horne, 1983:95). Other such materials may come into contact with the limestone resulting in its dissolution as well (Veltman, 2003:29). Contribution of surface water bodies by limestone rock formation is very limited and usually only in form of springs and eyes (Veltman, 2003:29). Wherever dolomitic aquifers occur close to the surface there is a very high likelihood of groundwater pollution (Wright, 1999:22).

Daniel C.W. Nkhuwa in his paper titled "***Management Of Groundwater Resources In Lusaka, Zambia and Expectations For The Future***" published by A.A. Balkema/Rotterdam/Brookfield (Sililo *et al.*, 2000:993-998) indicates that a high population growth compounded by the rural-urban (as well as urban to urban) migration in search of jobs, has led to the local authority failing to meet the service demands of its citizens. This has resulted in the flourishing of informal/unplanned settlements and poor waste gathering and removal (Nkhuwa, 2000:998). It is estimated that Lusaka produces about 765 tonnes of solid wastes daily. Of this quantity, only 76.5 tonnes is actually collected and properly disposed off while the remainder is disposed off anyhow. Disposal areas include the limestone sinkholes and crevices (Nkhuwa, 2000:995). Such a situation is made worse in an area whose geology is that of dolomitic marble and limestone. This is the geology which forms the larger base of the city terrain and is highly prone to solution weathering and creation of channels and sinkholes (Nkhuwa, 2000:994; Nkhuwa, 2003:1139). Though these features provide a good groundwater infiltration and retention capacity, pollution of the groundwater is also made easy. According to Salvato, systems or facilities or activities designed to discharge waste or wastewater on land are high on the list of contributors to groundwater pollution (Salvato, 1982:176). The 1970 estimate put it that there were 16 million residential cesspools/septic tanks in the USA contributing over 4000 billion litres of sewage most of which ended polluting groundwater (salvato,1982:175). With at least three quarters ($^3/_4$) of the Lusaka population either on septic tanks or pit latrines (Nkhuwa, 2000:995; Nkhuwa 2003: 1141), pollution of groundwater is with certainty within the city's environs. This is especially worse whereby most of the informal/unplanned settlements are located in natural groundwater discharge as well as recharge zones. An increased human settlement and encroachment on the recharge zones is therefore a real hazard.

It has been observed among communities in informal/unplanned settlements that in order to prolong the time in which latrines may fill, these latrines are dug to depths of about 4 to 6 metres that are very close to the water table thereby making pollution a stark reality in these places (Nkhuwa, 2003:1141). This is made worse by the fact that these pit latrines also double as shower rooms resulting in bath water accumulating in them. The latrines are not lined and neither is their base sealed. This makes them a direct pollution hazard (JICA, 2005). It is also true that the location of some of the official dumpsites is a worrisome matter. These sites are mere excavations in the limestone rock formation. These are later filled with water during the rainy season resulting in wastes in solution form, finding their way into groundwater (Nkhuwa, 2000:995). With the advice from the Environmental Council of Zambia, some of these official dump sites have however since been closed.

It can be stated that some limited monitoring of groundwater quality has been done by the Lusaka Water and Sewerage Company: the Commercial Utility that supplies water to Lusaka residents. However, this has been done only in its water supply boreholes and lines (Nkhuwa, 2000:996). This monitoring has revealed that there are some instances when the water may not meet standards for drinking water in both physical-chemical as well as microbiological quality. It has been observed that the worst in terms of microbiological quality is water from boreholes that are located in or near the informal/unplanned settlements (Nkhuwa, 2000:996). With a population of 2 million inhabitants, the daily water requirements for Lusaka at a per-capita of 200 litres per day mean that 400 million litres are required daily. This is far above its daily supply estimated at only about 2.5×10^5 m^3 leaving a large deficit (Nkhuwa, 2000:997). This may perhaps explain the consistent rationing of water in the city. The subsequent dependence on shallow wells in some areas such as George Township (Turton *et al.,* 2002:39 Appendix E2) may perhaps find an explanation in this. The George Township area apparently records the highest cases of cholera each year (Nkhuwa, 2000:997). The area could perhaps also be said to have the highest number of shallow wells in Lusaka.

It is envisaged that with the decreasing water quality in Lusaka associated with increased human activities and accelerated decline of the quality of the environment, so would there be a decrease in the ability of the city to support human life (Nkhuwa, 2003:1139). The major sources of pollution of groundwater have been identified as the rampant (widespread) use of pit latrines and septic tanks in most of the city. The unhygienic disposal of waste as well as increased use of agrochemicals adds to this problem (Sichingabula & Nkhuwa, 1998). The unsuitable management of the waste disposal process especially in an area whose geology is such that pollution of groundwater is so easy (Sichingabula & Nkhuwa, 1998; Nkhuwa 2003: 1139), there is need for the citizenry to be made aware so that measures could be achieved to stem this downward trend in the quality of the water. Monitoring of the quality of the groundwater which has never been systematic and sustained (Nkhuwa, 2003:1142) is therefore imperative. Shallow wells whose water is likely to be consumed without appropriate and adequate treatment therefore, deserves a special programme of monitoring.

It has been stated that quality of water is usually at its lowest during the rainy season especially in areas where human fecal disposal is by pit latrine (Nkhuwa, 2003:1142). This is perhaps evident from the results obtained presented as graphs of fecal coliforms (see Figures 10,11,12,13 &14 in Chapter 6). It has been proposed that strict regulation of human activities as well as modernization of the waste disposal facilities including sewage, could assist address the problem (Nkhuwa, 2003:1141). However, it must be mentioned that regulation without appropriate public awareness and community participation would only result in discord and lack of progress in combating the problem. Consistent and appropriate generation of information with the participation of the community is critical in decision making and action on such matters of great concern. Monitoring may therefore assist to provide such requisite information and an appropriate platform for community participation towards possible resolution of their problems.

Monitored assessments based on recent physical-chemical and bacteriological data collected using commonly accepted and well documented methods have been found to be more objective. Evaluated assessments which may largely depend on professional judgement that may mainly rely and depend on extrapolation of old data are easy to carry out. However, though easy, they (Evaluated Assessments) may not be the best to use (Alabama Department of Environmental Management 2004). The observations made in these shallow wells could be said to contribute to the knowledge base on the quality of the groundwater in the George Township area of Lusaka. Observation for possible contamination of the water at the point of uptake for use (DWAF,DH,WRC, 2000:2) may provide some insight into the possible quality changes (if any) over time. Seasonal changes have been cited as one factor that may directly affect water quality in a given location apart from the geology, land use and land cover (Alabama Department of Environmental Management, 2004). The current study may probably add to this understanding. It was anticipated that the observations made during this study would cover two seasons namely the rainy as well as the dry seasons. The results from this exercise may provide an input into the management of the quality of the resource (DWAF,DH,WRC, 2000: 2) in this area.

Monitoring is said to be an important element in the successful protection regime of groundwater especially where there are human activities (Veltman, 2003:90). Water level monitoring, water quality and rainfall system flow monitoring are critical (Veltman, 2003:90). In this regard, quality and level monitoring was carried out in the study area. The information generated could perhaps be important in looking at drawdown levels, shape of the water table as well as groundwater flow directions (Veltman, 2003:90). Routine monitoring especially of the quality of the groundwater has therefore been said to be very important (Wright, 1999:53). Water quality monitoring provides an opportunity to collect information on groundwater characteristics including trends of ambient and contamination including sources of recharge as well as contamination itself. The extent of impact of contamination can also be provided by such information gathered (Veltman, 2003:90). It is this information generated that can be used to assist in building public awareness and planning upon which sustainable groundwater degradation-prevention would be based (Veltman, 2003:96).

Presence of high Nitrate levels in drinking water has serious implications on human health especially babies due to the fact that the commensal bacteria in the guts of these babies may convert Nitrates to Nitrites which causes problems of respiration as methaemoglobin forms. It is this compound (methaemoglobin) which leads to reduced oxygen carrying capacity of the blood resulting into the "blue baby" condition (Goldman and Horne, 1983:124).

Presence of high carbonate rocks such as limestone presents a situation whereby acidic water would subsequently be neutralised as the carbonate rock provides a buffering system (Goldman and Horne, 1983:147). Water in Lusaka is therefore with such a high buffering capacity.

3.4. Conclusion.

It is apparent from the literature that there is high aquifer vulnerability in the Lusaka area. Though the legal provisions to control pollution of groundwater may to some extent be available, enforcement is seen as being inadequate. Pollution of groundwater especially in the type of geology like that of Lusaka with a lot of channels from solution weathering of the limestone rock is therefore without question. This is so especially where there is failure by the local authorities to provide for its population. This has resulted in informal/unplanned settlements. These settlements are a threat to groundwater including the health of the population in these settlements and beyond due to lack of waste disposal facilities in an area of poor geology. In some cases, settlements have been established by the City Council in areas considered to be recharge zones. The threat to groundwater quality can therefore be said to be obvious to any who may care to know.

CHAPTER 4: METHODOLOGY AND STUDY AREA

4.1. Introduction

The study aimed at observing the quality of the water in the shallow wells in an informal/unplanned settlement in Lusaka over a period of time covering both wet and dry seasons. The study also addressed any possible contamination from any sources as well as water quality variations, within the area over time. Possible health effects and recommendations as an attempt to alleviate the problem, were also thought of as important outputs. Methods employed in the data gathering include those used in the preparation for sampling, sampling procedures, analysis of the water as well as analysis of the results obtained after laboratory tests.

4.2. The Study Area

The study area is located in an informal/unplanned settlement of Lusaka most of it lying in an area with a gentle South-to-North slope on the North Western fringes of the city (see Topographical Map in Figure 3). Chunga stream is the major drainage in the area. The area has a high human population. Most dwelling houses are made of concrete blocks though poorly constructed (see Plate 2 page 26).

The population is estimated at between 110,000 and 130,000 residents within an area of about 5 km^2 (Japan ODA, 1995; Japan Techno, 2005). Dense human settlements have been identified as one contributing factor to the deterioration in water quality especially in places with poor sanitation (Nkhuwa, 2000:998; DWAF, DH, WRC, 1998:6). The water table is very shallow and in some cases to about 1-2 metres below the ground surface (Satkunas *et al.*, 2001). This reduces further during the rainy season to within ten to thirty centimeters. This presents an easy access by pollutants especially in a fractured geological formation (Water Aid, 2001:3). The sanitation is almost solely through use of unlined pit latrines which have to be buried once they are full. New ones are then dug within the small space of less than 100 m^2 for each house or plot.

Plate 2: Family standing in front of their House with their well in the foreground

Shallow wells are a common feature despite the fact that a Japanese supported project has provided modern water supply infrastructure (Turton *et al.,* 2002:39 Appendix E2). There are various visible discharge zones in form of springs and streams within this heavily settled area. These are used as a source of water by the communities. The area is also located near Lusaka's heavy industrial area (i.e. west of the industrial estate). The superstructures of most pit latrines are made of any material ranging from polythene sheeting to concrete bricks (see Plates 5 &15 on pages 34 and 43). The depths of the latrines are in many cases near or even below the water table and near to the shallow wells where water used in household chores is drawn.

A distance of less than ten metres between the shallow wells and the pit latrines are common (Plates 5 &15 on pages 34 and 43). These latrines are located in a manner that does not take into account of the slope of the land. In any case, in such an area where plots are squeezed together, location of the latrine on the lowest point on one plot at the edge of the next plot usually means being on higher ground than the next well. This also means that the latrine on one plot may be much closer to the well on the next plot. The economic status of the community is generally low with a high number of individuals not in gainful employment. Petty trading (see plate 3), illegal mining/quarrying and stone-crushing are common occupations. Stone quarrying is commonly done in areas where the rock is naturally exposed or exposed through human activity such as excavations for building materials including laterite. These depressions are usually filled with water during the rainy season (Satkunas *et al*., 2001).

Plate 3: Open Air commodity vending

Evidence of underground drainage is in abundance especially in the southernmost fringes of the area (see Plate 9 page 38). Shallow wells in this place unlike elsewhere in George, are usually channels filled with water in the limestone excavations resulting from weathering by solution (Plate 9). These channels are most probably fed from the groundwater supply lines bringing the resource from the surrounding highly channelised aquifer. Digging of wells in this area is apparently difficult to achieve other than where such water is found in the rock channels of the exposed underground drainage. The major rock type that contributes to the geology of the area is mainly dolomite. Where this is not exposed, sand or lateritic concretions cover the area. Such soils may probably result into poor attenuation capacity in the area.

On the lowest part of the area, springs and surface water channels exist as discharge zones of the aquifer thereby contributing to the shallow water table in the area. The channels that form drain towards and eventually end up in the Chunga stream. Two of the wells included in the investigation were located near the main road leading into the area. These were also about the lowest points in terms of height above sea level (Table 1). These were also in the discharge zone of the sampled area. Three of the wells were located in perhaps the highest points of the area while three others in moderate locations. One well was located in a discharge zone that was much higher than the first two (Plate 11 page 40). One water point was a crevice formed by dissolution of the limestone rock formation. Water in this 'well' is probably supplied through the underground channels (Plate 9 on page 38).

Selection of the sampling points was done in such a way that both low as well as wells on high ground were captured. Other considerations included presence of certain physical features such as the main road and a natural spring or stream.

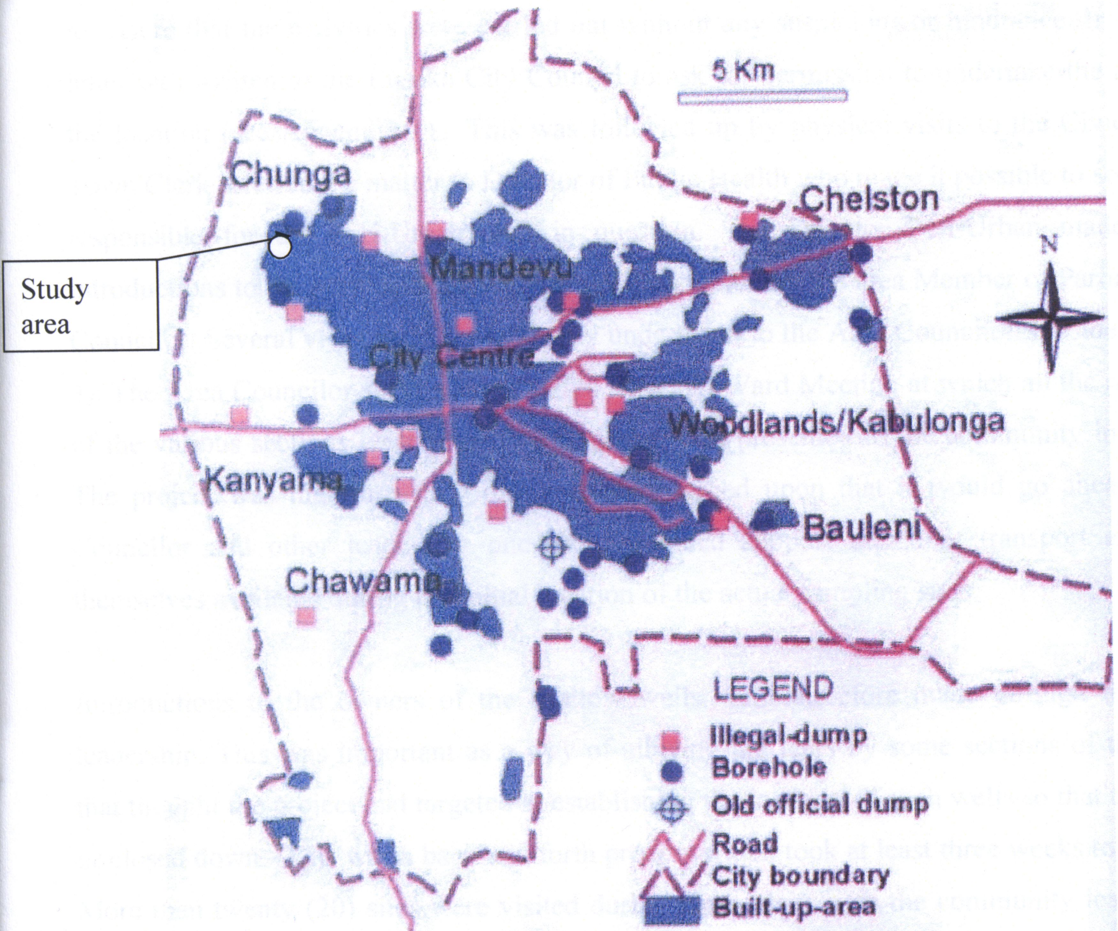

Figure 1: Map of Lusaka showing dumpsites, boreholes and the study area
Base Source: Nkhuwa, 2003.

4.3. Study Methods.

A combination of methods were employed in the research activity. Use of both sociological and scientific methods were employed in the exercise. These were reflected through the entry into the community, sampling points and their selection as well as the sampling procedures.

4.3.1. Entry into the Community.

Since the study site is located in an informal/unplanned settlement with various political interests at play, there was need to find some common ground with the political and civic leadership in the area to ensure that the activities were carried out without any suspicions or hindrance. In this regard, a letter was written to the Lusaka City Council to ask for permission to undertake the assignment in the location (see Appendix 1). This was followed up by physical visits to the Civic Centre. The Town Clerk referred the matter to Director of Public Health who made it possible to see the Director responsible for the Peri-Urban area in question. The Director Peri-Urban made preliminary introductions to the political leadership of the area including the area Member of Parliament and the Councilor. Several visits were subsequently undertaken to the Area Councilor's residence (see Plate 4). The Area Councilor subsequently called a special Ward Meeting at which all the representatives of the various sections were present. The matter was presented to the community in this meeting. The project was therefore fully discussed and agreed upon that it would go ahead. The Area Councilor and other leaders at one time provided support including transport and were also themselves available during the initial location of the actual sampling sites.

Introductions to the owners of the shallow wells were therefore made through the community leadership. This was important as a way of allaying the fears by some sections of the community that thought the project had targeted at establishing the location of such wells so that they are buried or closed down. This was a back and forth process which took at least three weeks to be completed. More than twenty (20) sites were visited during these visits with the community leadership out of which only ten (10) had to finally be selected for the study. A preliminary visit with the team involved with the sampling was also made before the actual sampling started. The first sampling was done on 19th April, second on 30th May and third on 30th June 2006. Monthly visits were subsequently done with the last one being on 30th April 2007 (see Appendix 4).

Lusaka Water and Sewerage Company, National Water and Sanitation Council (NWASCO) as well as the Department of Water Affairs (DWA) were also written to and visited to inform them about this study as well as to solicit for any information they may already have had. Ministry of Local Government and Housing's Department of Infrastructure and Support Services (DISS) who are responsible among others, for peri-urban and community water supply issues, were also written to and physical visits were also made by the proponent. Frequent contacts were made with the leadership as well as officials in the communities during and after the sampling were carried out.

Plate 4: Councilor Muchafara Marabesa (second left) with part of his team

Entry into the community was therefore through the civic and community leadership that assisted in awareness-raising as regards the study. A transect (or cross sectional) walk was also done with the area Councillor and other leaders to establish the current situation on the ground and also make selection of the possible sampling points.

4.3.2. Sampling points.

The area selected was approximately two square kilometers within the George Township. Wells that were finally selected to be sampled were grid-referenced (see Table 1 and Figures 2 and 3 on page 33) and names of the owners as well as height above sea level and house numbers were also noted. This data and other details were entered into a note book used for field work. Some of these wells are as shown in Table 1. One deep well or borehole (Borehole #4) for Lusaka Water and Sewerage Company (LWSC) was also sampled once and historical data was also used to provide the background water quality for the area.

Table 1: Sampling points and their location

WELL NUMBER	HOUSE NUMBER	NAME OF OWNER	ELEVATION (METRES ASL)	GPS REFERENCE Deg ' " Deg ' "
1	192/19	Amake Mirriam	1260	S15 22 54.5 E 28 14 25.9
2	194/5	Aibaki Lungu	1256	S 15 22 54.7 E 28 14 23.3
3	303/19	Peter Mwiinga	1264	S15 23 05.3 E 28 14 25.1
4	217/23	Everson Phiri	1268	S15 23 12.4 E 28 14 19.7
5	560/22	Amake Elina Phiri	1269	S15 23 16.7 E 28 14 10.7
6	17/05	Makwaya Andrew	1262	S15 23 01.4 E 28 13 58.9
7	175/3	Joyce Mbewe	1257	S 15 22 43.2 E 28 14 09.2
8	176/8	Felix Tembo	1257	S15 22 43.7 E 28 14 26.7
9	184/22	Redson Matabula	1249	S15 22 43.3 E 28 14 36.8
10	255/12	Ndumo Titus	1231	S15 37 91.6 E 28 24 55.8

There were also specially designed data sheets that were used to record information of similar nature to provide a back up (see Appendix 2). Additional information recorded included weather conditions, sample treatment as well as the general conditions that existed around the well at the time of the visit. Photographs of the sites were also taken during some of the visits to record the site conditions at that particular time as well. These points are shown in an aerial photo from Quick Bird Satellite Image as red dots in the aerial photo as well as the topographical map shown as blue dots (Figures 2 and 3).

Figure 2: Quick Bird Satellite Aerial Image showing location of the shallow wells used in the study shown as red dots

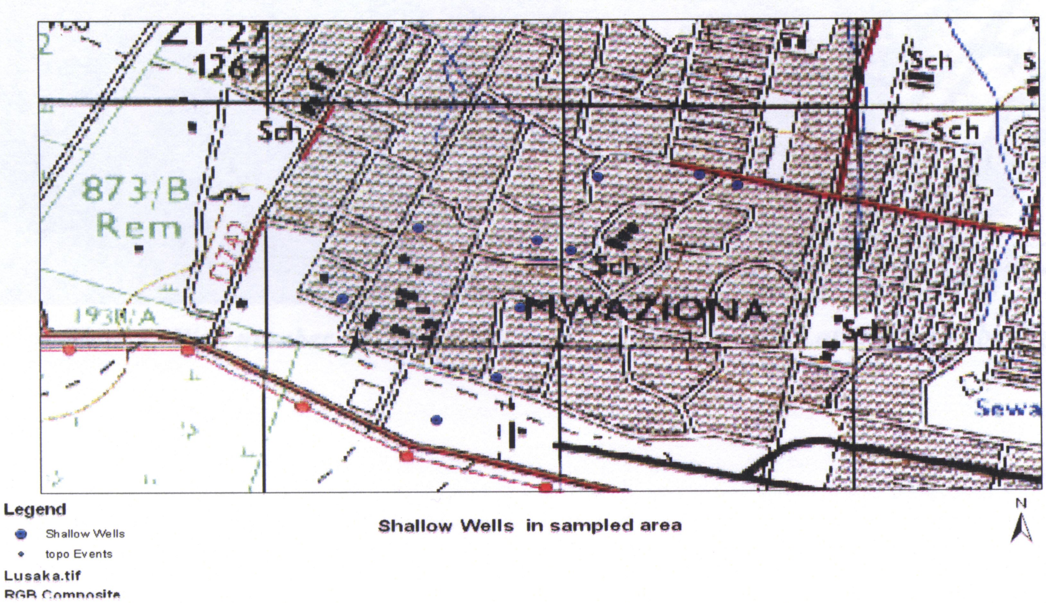

Figure 3: Topographical map showing Distribution of Shallow wells for the Study shown as blue dots

Well Number 1: Amake Mirriam (House number 192/19).

This well is one of the most used. Water is always spilled on the ground very close to the mouth of the well (see Plate 5). The mouth of this well is at about ground level. The people drawing water most times come with their flip flops to draw water using a specially fashioned scoop made from a plastic container that is lowered into the well using a rope tied to it (Plate 5). The pit latrine is about six metres west of the well (see plate 5).

Plate 5. Well number 1 (Amake Mirriam's well) with a Pit Latrine in the background

Well Number 2: Mr. Aibaki Lungu (House number 194/5).

Mr. Lungu's well is located right in the foot path which also acts as a water channel whenever there is a downpour. The mouth of the well is also at ground level (see Plate 6). A lot of debris is usually found floating in the water. Most of the material is brought into the well by running water during the rainy season. The pit latrine is about ten metres west of the well. The well is also frequently used by Mr. Lungu and his family as well as others in the neighborhood. Washing of clothes around the well was a common feature during each of the visits.

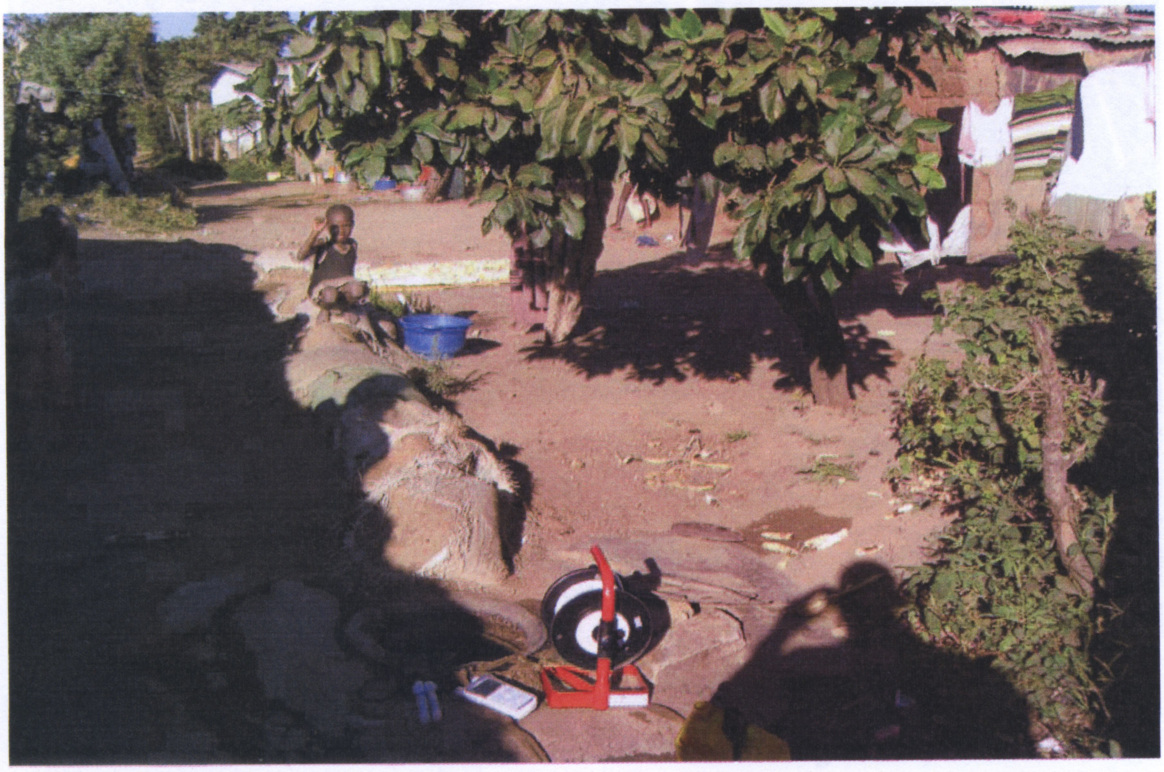

Plate 6: Well Number 2 (Mr. Aibaki Lungu's well) with sandbags used as protection against running water. Some of the equipment used during the study for** in situ **analysis Left to right- Multifunction Horiba meter and Water level Meter (on a reel)

Well Number 3: Mr. Peter Mwiinga (House number 303/19).

Mr. Mwiinga has his well located in a fenced off area with only his immediate family accessing it. An old car rim provides protection to the well opening (see Plate 7). He has provided another well for the public to use outside his yard. The well is on raised ground to the rest of the area and is located about fifteen metres away and South of the pit latrine.

Plate 7: Well Number 3 (Mr. Peter Mwiinga's well)

Well Number 4:Mr. Everson Phiri (House number 217/23).

Mr. Everson Phiri's well is located at about ground level except for the metal ring that protrudes about ten centimetres above ground (Plate 8). This well also serves many families that come to draw water hence the ground was always wet around the well on each subsequent visit. The pit latrine is also about six to eight metres west of the well.

Plate 8: Well Number 4 (Mr. Everson Phiri's well)4 Young women drawing water at the well

Well Number 5: Amake Elina Phiri (House number 560/22).

This water point is a well formed from a hole left behind by solution weathering of the calcified rock in the area (Plate 9). This is apparently an open well with water possibly coming from the underground drainage system. A Pit latrine has been built about two metres from this water point. This latrine is apparently constructed on higher ground than the water well. However, the sides seem to be made of concrete blocks while the bottom is apparently formed by the bed rock. This point was selected due to the fact that the area does not have dug wells mainly due to the apparent rocky geology. Further, the point never runs out of water throughout the year. Exposed rock is very common in this section of the area. People have set on this rock to quarry for aggregate as well as flat stone which they dig/crush and sell.

Plate 9: Well Number 5 (Amake Elina Phiri's well)

Well Number 6: Mr. Andrew Makwaya (House number 17/05).

Mr. Makwaya's well has a raised brick wall which guards the opening (Plate 10). A pit latrine is located about ten metres west of the well. This well is always in use throughout the year. Like most wells in the area, it never runs dry.

Plate 10: Well Number 6 (Mr. Andrew Makwaya's well).

Well Number 7: Mrs Joyce Mbewe (House number 175/3).

Mrs Mbewe's well is located about twenty metres West of the pit latrine. Being another of the heavily used facilities, the area around the well is always wet as people continue to flock to draw water for their use (Plate 11). This well is also located in an apparent discharge zone. Washing of clothes like on other sites is common (see plate 12.)

Plate 11: Well Number 7 (Mrs. Joyce Mbewe's well)

Plate 12: Children washing clothes at Well Number 7.

Well Number 8:Mr. Felix Tembo (House number 176/8).

Mr. Tembo's shallow well serves a lot of people including those with minibuses who come to wash their vehicles at the start and close of business. The surroundings just like all the other wells, is always wet from the water that is drawn very often (Plate 13). The well is merely two metres from a busy dust road. A pit latrine is also within a vicinity of about fifteen metres east of the well.

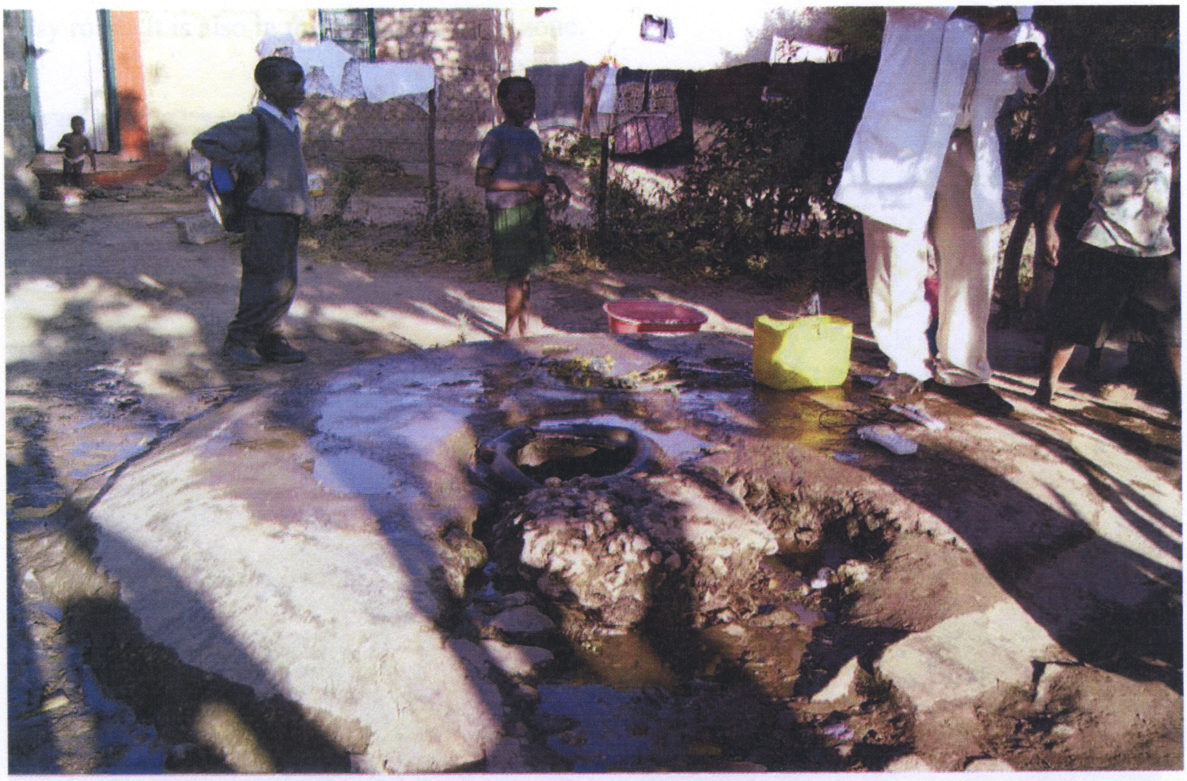

Plate 13: Well Number 8 (Mr. Felix Tembo's well).

Well Number 9: Mr. Redsom Matabula (House number 184/22).

Mr. Matabula's well is about five metres from the main tarred road. It is covered by a rubber tyre which forms the well inlet (Plate 14). The distance from the nearest pit latrine is about fifteen metres. As usual, drawing of water by the family and other users is very frequent. There are fruit trees growing nearby. Some flowers and shrubs grow near the well. The well is located near a very busy road. It is also in the main discharge zone.

Plate 14: Well Number 9 (Mr. Redsom Matabula's well).

Well Number 10:Mr. Titus Ndumo (House number 255/12).

Mr. Ndumo's well is located about ten metres from the main road. A pit latrine is about ten metres from it while the shower room is within five metres. This well is located at a place which is the lowest point on the sampling circuit in terms of its elevation. The well is located in the discharge zone hence the surrounding is always damp (Plate 15 and table 1). This is the apparent main discharge zone of the area under consideration.

Plate 15: Well Number 10 (Mr. Titus Ndumo's well) located in an apparent discharge zone with a shower room covered in plastic sheeting in the background

4.3.3. Sampling.

Water samples were collected from the shallow wells at each of the visits that were done on a monthly basis. It was however, difficult to maintain the exact one month duration between the sampling campaigns due to various logistical problems. The more than twelve (12) months which should have been done to cover more than one of the wet and the dry seasons could not be fully achieved due to problems of logistics as financial and other resources could not be fully provided and measures could only be instituted in April and not February 2006 as earlier planned. The community entry that required full awareness and participation of the community leadership also took some time to achieve. However, the frequency was at least a month on average. These visits were carried out on 19th April, 30th May, 30th June and 21st July and subsequently on a monthly basis until December 2006. The sampling was resumed in January and continued until April 2007.

Sampling was done using an already existing scoop at each well. This was important in order to replicate the conditions that existed at the site rather than using other scoops that could have been brought to the site by the team. By so doing it was considered appropriate that the water collected was representative of what was being used by the communities. A scoop usually made from a plastic container cut out into shape and attached to a rope for the purpose (see plate 5), was used to draw the water. The scoop was lowered down into the water and was made to go down below the surface by lifting it and dropping it down until it was totally immersed in the water to about ten to twenty centimeters below the surface. The scoop was then lifted up and out of the well and water samples were then put into three (3) bottles: two made of plastic each of 500 and 1000 millilitres respectively. The third bottle made of glass with a volume of 500 mililitres was used to collect a sample for microbiological examination. The bottle for bacteriological or microbiological examination was specially prepared at the laboratory through autoclaving at temperatures of at least 90^0 Celsius. Special foil was put around the lid of this bottle and was only removed at the time of putting in the water sample and then the bottle was carefully placed in a specially designed carrier case supplied by specialized suppliers to avoid spillage as well as contamination and deterioration of the sample.

The small plastic bottle of volume of 500 ml had Nitric acid added to it earlier as a preservative to ensure that the collected sample did not deteriorate before it was analysed for heavy metals. The bigger one (1000 ml) did not have any chemical or preservatives added but was tightly closed. The samples were then rushed to the laboratory for analysis except the first time when the monitoring started. These samples were left overnight in a fridge and rushed to the laboratory the next morning.

The subsequent samplings were always done in such a way that the samples were delivered to the laboratory immediately after sampling.

In order to measure the water level, a water level meter was used (see Plate 10). The probe end of the meter was lowered down into the well and continued to be wound down until a sound and light was heard and seen. This was adjusted accordingly to ensure that the correct reading was obtained. The depth was therefore read off the tape that constituted the mechanism for lowering of the probe into the well. After the reading was taken, the probe was lowered further into the water and the temperature reading was also obtained and recorded. A sample of water was taken and used to measure the pH, Eh (Redox potential) and EC (electrical conductivity) as well. A Horiba multifunction meter (see Plate 6) was used to take these readings (EC, pH and Eh). Other values also recorded included the time and date of the sampling and name of the sampler. The biological oxygen demand (BOD) and chemical oxygen demand (COD) were not measured as these cannot be measured in the field. It was also felt that these parameters were more important in running river water. The water was also noted for odour and other physical characteristics including appearance. The general weather conditions at the time of sampling were also noted and recorded.

The sampling team was made up of the investigator and two officers from the Department of Water Affairs. These were experienced officers in water sampling and this kind of work was within their full understanding. They had earlier been briefed as regards the reason for the sampling campaign as required (Bartram & Ballance, 1996). This briefing was done long before the commencement of the exercise. A driver was also a team member on these sampling missions which lasted a year.

As stated earlier, onsite determination was done for pH, electrical conductivity (EC) and Redox Potential (Eh) using a Horiba pH/Conductivity meter. Temperature was read using the water level meter that has both the function for water level measurements as well as temperature. The water level meter was found more suitable for temperature reading as it was lowered down the well. This reading was considered to be more representative of the water in the well than that which had been taken out to do the readings for pH, Electrical Conductivity (EC) and Redox potential (Eh).

Preservation of the samples for heavy metal analysis was done using Nitric acid that was put in the 500 ml bottles before going into the field. Water samples for bacteriological/microbiological quality was collected and placed in a special box which had been provided by the suppliers for the purpose. These bottles were put in a separate cool box at all times and then taken to the laboratory for analysis within six to twelve hours. If this was not possible then, the samples were kept in a fridge (without being frozen) and later submitted to the laboratory but within the stipulated maximum twenty-four hour period. This was only done once as samples were always submitted immediately after they were collected. The date, time of sampling and other details and conditions that existed at the time of sampling were also recorded.

Laboratory analysis of the water samples was done by the Environmental Engineering Laboratory of the University of Zambia. Various methods were used to analyse for various parameters. For example, colorimetric method was used to analyse for Manganese, Phosporous Nitrites and Nitrates as well as Sulphates, Iron and Ammonia using an Ultra Visible Spectrophotopmeter (UV Spectrophotometer). In this particular case, a Cecil 1000 Model CE 1010 system was used. In the case of heavy metals such as Lead, Arsenic, etc, an Atomic Absorption Spectrophotometer (AAS) was used. For turbidity, electrometric method was used using a Hach 2100N Turbidimeter while titrimetric methods were used to analyse for Magnesium, Calcium and total hardness. Gravimetric method was used to analyse for total dissolved solids whereby weighing of the sample before and after evaporation to dryness, was done.

Membrane filtration whereby the sample is filtered and the filtrate cultured and counted thereafter was used in the bacteriological examination of the water samples. One millilitre of solution was used in the dilution process.

In order to quality-control the analysis of the water samples by the laboratory, distilled water was put in labeled bottles with the same labeling sequence. Blanks (distilled water) and duplicate samples were therefore submitted and labeled in similar manner to assist in the laboratory quality control. This helped in ensuring that the laboratory maintained the quality of its results. These were placed among the collected samples and submitted to the laboratory for analysis without raising any alarm.

The equipment and materials used during the sampling campaign included among others, sample bottles (both glass and plastic) for collection of water samples for bacteriological, physical and chemical analyses. A water level meter was also used to measure the level of the water table at each of the sampling points. A Global Positioning System (GPS) provided the geo-referenced position of each of the sampling sites. Other tools included cool boxes to carry water samples in and transport for the field team and equipment. Laboratory analytical facilities for physical and chemical as well as bacteriological analyses of the water samples were provided by the University of Zambia Environmental Engineering Laboratory. A camera to record some interesting feature at the sampling sites was used in the exercise as information captured was found useful during the exercise including analysis of the results.

The major parameters considered for observation in the water quality included physical, chemical as well as microbiological (bacteriological). The full list of parameters considered is Appendix 3.

Since the water was analysed for among others, trace metals such as Zinc, etc. metal tops on the sample bottles were totally avoided (DWAF,DH,WRC, 2000:16). This was done so as to avoid possible contamination from the metal that could probably dissolve into the water sample thereby negatively affecting the results of the analysis. Appropriate preservation measures were put in place during and after the field work in order to preserve the integrity of the water samples collected before they were analysed (DWAF,DH,WRC, 2000:18; DWAF,DH,WRC, 2001:4). Use of sterile bottles to collect and store water for microbiological examination was strictly adhered to.

A small gap was left in each bottle to ensure that there was thorough and appropriate mixing when the water was being analysed by the laboratory staff. As stated before, for pH, temperature, electrical conductivity (EC) and Redox Potential (Eh) measurements, a field combination meter with pH and other readings was used and the results recorded in the field note book and on specially designed data sheets which were kept by the study proponent and principal investigator. The geo-references for each sampling point were also recorded (see Table 1).

4.4. Analysis of data.

The World Healthy Organization (WHO) as well as the South African water quality guideline documents to assess the quality of the water and also its possible health effects were used. The Zambia Bureau of Standards drinking water standards were also referred to.

The "assessment of fitness for use" (DWAF,DH,WRC, 2000:8) was carried out using well known instruments in the field of water quality assessment. The World Health Organization (WHO) Guidelines for Drinking Water Quality as well as the South African Water Quality Assessment Guide were therefore used as the basis for comparing the results of the water for its quality as well as its possible effects on health through use or consumption of such water. Other documents were also used in the analysis of the data.

4.5. Conclusion.

Use of well documented and standardized methods for the field work, laboratory analysis as well as general assessments was critical as the need to get a reasonable output was essential. Community involvement in order to ensure that there was no friction was ensured through use of appropriate community leadership and other such channels to access the sampling points and other such requisite facilities.

CHAPTER 5: RESULTS

5.1 Introduction

After many months of sampling and analysis of the water samples from the shallow wells, results were obtained against predetermined parameters. These were then averaged to find the values for each site during the period of the exercise which lasted at least one full year. However, as for the results for pH as well as microbiological quality, the lowest and highest respectively, were picked as representing these parameters for the period in question (DWAF, DH, WRC, 1998:24, 25). It may also suffice to mention that even when averaged results were used for bacteriological contamination, the problems of contamination were not masked in any way as there was consistent presence of fecal coliforms as well as ***E. coli.***

In all ten sampling sites, it was found that the bacteriological quality of the water was far below the acceptable standards for drinking or cooking water as the Total Coliforms count was higher that the recommended maximum of 10 counts per 100 ml. It was in fact higher than 1000 counts per 100 ml and in some cases the counts were above 10,000. This was the case even when averages were taken over the whole period of time. This was also the case with Fecal Coliforms as well as ***Escherichia coli,*** which were also in maximum concentration values of greater than 1000 counts per 100 ml from the recommend zero. This put the water into the class 4 (or purple i.e. unacceptable) classification as regards the bacteriological quality. Turbidity was another parameter that was of great concern as it was generally in class 2 (or yellow) classification of the water in this regard and so was the Lead content. Cadmium concentration also provided another element of concern in the water samples. The Nitrates concentration was also another parameter of serious concern However, comparing these results to the bench mark (LWSC bore hole), though these were not ideal either, it is apparent that the LWSC bore hole was a better supply than the shallow wells.

5.2 Site by site findings and results

Well 1:Amake Mirriam/Ms.Ennie (House number 192/19).

This well was one of the most used as it was usually very busy each time we carried out the sampling. Water was always found spilled on the ground around the well very close to the mouth of the well (Plate 5). The mouth of this well was at ground level during most of the period of the sampling exercise. However, the mouth was raised by about fifteen centimeters towards the end of the year.

Table 2: Water Quality at Well 1:Amake Mirriam/Ms. Ennie's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1571	1395	Yellow 2	1500/70	Blue 0
Eh(Mv)	38	-6.7 5			
pH*	6.46	6.46	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	2082	1022	Yellow 2	450	Yellow 2
Turbidity (NTU)	5.01	1.71	Yellow 2	5	Yellow 2
Sodium (mg/l)	99.20	63.26	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.033	0.017	Red 3	0.003	Red 3
Fluoride (mg/l)	0.21	0.162	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$ /l)	1700	611.09	Red 3		Red 3
Potassium (mg/l)	18.75	10.49	Blue 0	25	Blue 0
Iron (mg/l)	3.20	0.91	Yellow 2	0.5	Yellow 2
Ammonia (as NH_4^-N mg/l)	2.32	0.78		None	
Zinc (mg/l)	0.023	0.0168	Blue 0	3.0	Blue 0
Chlorides (mg/l)	180	127.09	Green 1	250	Green 1
Nitrites (as NO_2^-N mg/l)	0.658	0.210	Blue 0	3	Blue 0
Nitrates(as NO_3^-N mg/l)	40.80	21.94	Purple 4	6	Purple 4
Lead (mg/l)	2.40	0.42	Red 3	0.01	Red 3
Total Phosphates (mg/l)	5.68	1.67		None	
Magnesium(mg/l)	295	65.24	Blue 0	200	Green 1
Calcium (mg/l)	188.0	123.11	Green 1	200	Green 1
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	10000	3036	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	6200	1536	Purple 4	0	Purple 4
E coli/100ml**	3100	616	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

The people drawing water most times come with their flip flops to draw water using a specially fashioned scoop made from a plastic container that is lowered into the well using a rope tied to it. The pit latrine is about six metres west of the well (Plate 5).

At this site, the average Total Coliforms count per 100 ml was at 3,036 while Fecal Coliforms count was at 1,536 and ***E .coli*** at 616 (see table 2 above). All these values were above the recommended 0-10 for Total Coliforms, and zero counts for Fecal Coliforms and ***E. coli*** per 100 ml giving it purple classification (class 4). Total Hardness was also found to average at above 600 mg/l a level that put the water in the class 3 (or red) classification while Total Dissolved Solids at 1022 mg/l put it in class 2 (or yellow). Turbidity was at an average of about 2 NTU thereby putting the water into class 2 (or yellow). Cadmium and Lead at an average of 0.017mg/l and 0.4 mg/l respectively could have classified the water into yellow (class 2). However, due to the fact that the maximum concentration values for Cadmium of 0.033mg/l and Lead of 2.40 mg/l, the classification moved to red (class 3) in both cases. Nitrates averaging at 21.94 mg/l could put the water into the red category (class 3) but with a maximum of 40.80 mg/l, the class moved to purple (class 4) and unacceptable for human consumption. Iron (0.91mg/l), would give a green or class 1 classification. However, with the maximum concentration at 3.20 mg/l, the class moved to yellow (class 2). Chlorides (127.09 mg/l) and calcium (123.11mg/l) put the water in class 1 (green) category. The rest of the parameters were in the blue category.

According to the South African Quality of Domestic Water Supplies Volume 1: Assessment Guide, water is classified under five colour codes namely blue, green, yellow, red, and purple (DWAF,DH,WRC, 1998:22). The blue or class 0 represents the ideal water quality which presents no health effects and suitable over long periods of time (DWAF,DH,WRC,1998:22). The water is said to have no effects in all its uses and is pleasant to drink (DWAF,DH,WRC,1998:22). The green or class 1 is water of good quality which is suitable for various uses with rare instances of negative health and other effects (DWAF,DH,WRC,1998:22). This water may have some slight effects on bath fixtures and when using it for bathing as well as laundry (DWAF,DH,WRC, 1998:22). Yellow or class 2 water is marginal water in terms of its quality (DWAF,DH,WRC,1998:22). Such water may be drank by many people but those that may be in the sensitive group may suffer from various ailments upon use of such water (DWAF, DH, WRC, 1998:22). The water would have poor taste as well as appearance and may cause some slight effects when using it for bathing and laundry as well as on bath and laundry fixtures (DWAF, DH,WRC,1998:22). However, this water may be used for preparing food for the majority of people (DWAF,DH,WRC,1998:22). Water of red colour (or class 3) classification denotes poor quality water (DWAF,DH,WRC,1998:22). The water is a risk to human health and cannot be drank without chronic health effects arising especially in sensitive groups such as babies and the elderly (DWAF,DH,WRC,1998:22). The water has bad taste and appearance and would pose serious problems if used in food preparations especially among the children and the aged (DWAF,DH,WRC,1998:22). Class 4 or purple water is unacceptable water quality (DWAF,DH,WRC,1998:22). This water poses serious and acute health effects when used for drinking as well as food preparation (DWAF,DH,WRC,1998:22). The water is also not good for bathing and laundry as it will cause serious effects on the body and laundry as well as the fixtures (DWAF,DH,WRC,1998:22).

From the results above, it was observed that some parameters were in class 0 or blue and green (class 1). However due to the fact that one of the critical parameters-the bacteriological quality of the water as well as Nitrates was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 2: Mr. Aibaki Lungu (House number 194/5).

Mr. Lungu's well is located on a foot path which also acts as a water channel whenever there is waste water from washing of clothes by neighbours or when there is a downpour. The mouth of the well is also at ground level. Mr. Lungu uses sandbags to protect the well against surface flow during the rainy season (see Plate 6). The well was frequently in use during the period of the sampling. Washing of clothes around the well was a common feature during each of the sampling visits.

Table 3: Water Quality at Well number 2: Mr. Aibaki Lungu's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1362	1145	Blue 0	1500 <70	Blue 0
Eh(mV)	16	-18.83			
pH*	6.62	6.62	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1121	761.64	Yellow 2	450	Yellow 2
Turbidity (NTU)	37.6	5.13	Red 3	5	Red 3
Sodium (mg/l)	118.45	61.97	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.026	0.013	Red 3	0.003	Red 3
Fluoride (mg/l)	0.40	0.19	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	612.0	436.73	Red 3		Red 3
Potassium (mg/l)	33.04	16.30	Green 1	25	Green 1
Iron (Mg/l)	4.25	0.863	Green 1	0.5	Green 1
Ammonia (as NH_4-N mg/l)	1.98	0.53		None	
Zinc (mg/l)	0.021	0.0146	Blue 0	3.0	Blue 0
Chlorides (mg/l)	220.0	119.273	Yellow 2	250	Yellow 2
Nitrites (as NO_2-N mg/l)	1.065	0.321	Blue 0	3	Blue 0
Nitrates(as NO_3-N mg/l)	32.85	20.25	Red 3	6	Red 3
Lead (mg/l)	2.90	0.485	Red 3	0.01	Red 3
Total Phosphates (mg/l)	5.10	1.41		None	
Magnesium(mg/l)	67.20	39.45	Blue 0	200	Blue 0
Calcium (mg/l)	156.0	98.04	Yellow 2	200	Yellow 2
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	9400	3845	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	7700	2255	Purple 4	0	Purple 4
E coli/100ml**	7600	1192	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Findings on this location indicate that the averagê Total Coliforms count per 100 ml was 3,845 while Fecal Coliforms count was at 2,255 and ***E .coli*** at 1,192 (see table 3 above). All these values were above the recommended zero counts per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms thereby classifying the water as purple (class 4). Total Hardness was also found to average at above 400 mg/l a level that put the water in the class 2 (or yellow) classification. However, with the maximum concentration value of 612 mg/l, the water is classified as red (class 3).

Total Dissolved Solids at an average of 761 mg/l could put it in class 1 (or green) but a maximum of 1121 mg/l puts it into class 2 or yellow category. Turbidity was at an average of about 5.13 NTU thereby putting the water into class 2 (or yellow) but the maximum of 37 NTU moved it to red or class 3. Cadmium and Lead at an average of 0.013 mg/l and 0.485 mg/l respectively could have classified the water into yellow (class 2). However, the maximum values (0.26 mg/l Cadmium and 2.90 mg/l Lead) put the class of the water for both of these elements to red (class 3). Nitrates averaging at 20.25mg/l put the water into the red category (class 3). Iron (0.863 mg/l) put the water in class 1 (green) category. Chlorides (119.273 mg/l) and calcium (98.04 mg/l) could have given the water a green (class 1) rating but the maximum values of 220 mg/l and 156.0 mg/l respectively moved the class to yellow (class 2). The rest of the parameters were mostly in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 3: Mr. Peter Mwiinga (House number 303/19).

Mr. Mwiinga has his well located in a fenced off area with only his immediate family accessing it (plate 7). He has provided another well for the public to use outside his yard. The well is on raised ground to the rest of the area and is located about fifteen metres away and South of the pit latrine.

Table 4: Water Quality at Well Number 3: Mr. Peter Mwiinga's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1301	983.45	Blue 0	1500 /<70	Blue 0
Eh(mV)	25	-15.82			
pH*	6.50	6.50	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1956	724.54	Yellow 2	450	Yellow 2
Turbidity (NTU)	8.16	1.83	Yellow 2	5	Yellow 2
Sodium (mg/l)	78.05	45.84	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.034	0.013	Red 3	0.003	Red 3
Fluoride (mg/l)	0.55	0.180	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	1390	495.64	Red 3		Red
Potassium (mg/l)	11.65	5.93	Blue 0	25	Blue 0
Iron (mg/l)	6.99	2.36	Red 3	0.5	Red 3
Ammonia (as NH_4^-N mg/l)	1.96	0.45		None	
Zinc (mg/l)	0.019	0.011	Blue 0	3.0	Blue 0
Chlorides (mg/l)	130	81.45	Green 1	100	Green
Nitrites (as NO_2^-N mg/l)	0.290	0.072	Blue 0	3	Blue 0
Nitrates(as NO_3^-N mg/l)	27.85	12.51	Red 3	6	Red 3
Lead (mg/l)	2.70	0.44	Red 3	0.01	Red 3
Total Phosphates (mg/l)	1.89	1.06		None	
Magnesium(mg/l)	67.20	52.45	Blue 0	200	Blue 0
Calcium (mg/l)	168.0	98.71	Yellow 2	200	Yellow
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	8200	2691	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	6400	1691	Purple 4	0	Purple 4
E coli/100ml**	1400	517	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Water analysis on this location indicate that the average Total Coliforms count per 100 ml was 2,691 while Fecal Coliforms count was at 1,691 and ***E. coli*** at 517 (see Table 4 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms bringing the water to purple classification (class 4). Total Hardness was also found to average at above 490 mg/l a level that could have put the water in the class 2 (or yellow) classification but moved to class 3 (red) due to the high maximum value of 1390 mg/l. Total

Dissolved Solids at 724.54 mg/l could have put it in class 1 (or green) but with a maximum concentration of 1956 mg/l, the class became yellow (class 2). Turbidity was at an average of 1.83 NTU thereby putting the water into class 2 (or yellow). Cadmium and Lead at an average of 0.013 mg/l and 0.44 mg/l respectively could have classified the water into yellow (class 2) as well but with maximas of 0.034 mg/l and 2.70 mg/l respectively, the class moved to red (class 3) in both cases. Nitrates averaging at 12.51 mg/l should have put the water into the yellow category (class 2). However, with the maximum at 27.85 mg/l, the class for the water moved to red (class 3) considering the concentration of Nitrates. Iron at concentration of 2.36 mg/l, should have been in the yellow (class 2) category but moved to red (class 3) due to the maximum value of 6.99 mg/l. Calcium (98.71 mg/l average) could have put the water in class 1 (green) category but the maximum of 168 mg/l shifts the class to yellow (class 2). The rest of the parameters were in the blue category except Chlorides that gave the water a green category due to the maximum concentration value of 130 mg/l.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 4: Mr. Everson Phiri (House number 217/23).

The mouth of Mr. Everson Phiri's well is located at about ground level (plate 8). However, there is a metal ring that protrudes about ten centimetres above ground. This well also serves many families that come to draw water. The surroundings of the well were always wet on each of the visits. The pit latrine is also about eight metres west of the well.

Table 5: Water Quality at Well Number 4: Mr. Everson Phiri's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	863	753.18	Blue 0	1500/<70	Blue 0
Eh(mV)	19	-23.20			
pH*	6.78	6.78	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	640.0	513.10	Green 1	450	Green 1
Turbidity (NTU)	7.73	2.78	Yellow 2	5	Yellow 2
Sodium (mg/l)	55.99	31.33	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.030	0.013	Red 3	0.003	Red 3
Fluoride (mg/l)	0.30	0.175	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	560	346.73	Yellow 2		Yellow 2
Potassium (mg/l)	10.45	5.80	Blue 0	25	Blue 0
Iron (Mg/l)	3.66	1.31	Yellow 2	0.5	Yellow 2
Ammonia (as NH_4^-N mg/l)	0.06	0.039		None	
Zinc (mg/l)	0.02	0.012	Blue 0	3.0	Blue 0
Chlorides (mg/l)	80.0	45.0	Blue 0	250	Blue 0
Nitrites (as NO_2^-N mg/l)	0.038	0.017	Blue 0	3	Blue 0
Nitrates(as NO_3^-N mg/l)	27.00	7.96	Yellow 2	6	Yellow 2
Lead (mg/l)	2.50	0.473	Red 3	0.01	Red 3
Total Phosphates (mg/l)	4.11	1.43		None	
Magnesium(mg/l)	70.08	29.67	Green 1	200	Green 1
Calcium (mg/l)	116.0	70.58	Green 1	200	Green 1
Manganese (mg/l)	0.04	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	9400	3445	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	6500	1855	Purple 4	0	Purple 4
E coli/100ml**	1100	304	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Upon laboratory analysis of the water samples from Mr. Everson Phiri's well over the period of time, it was found that the average Total Coliforms count per 100 ml was 3,445 while Fecal Coliforms count was at 1,855 and ***E. coli*** at 304 (see Table 4 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms thereby giving the water a class 4 or purple classification. Total Hardness was also found to average at above 340 mg/l a level that put the water in the class 2 (or yellow) classification while Total Dissolved Solids at 513.10 mg/l put it in class 1 (or green). Turbidity was at an average of 2.78 NTU thereby putting the water into class 2 (or yellow). Cadmium and Lead at an average of 0.013 mg/l and 0.473 mg/l respectively could have given the water a yellow (class 2) classification but due to the high maximum values for both (0.030 mg/l and 2.50 mg/l respectively), the classification moved to red (class 3) in both cases. Iron at 1.31 mg/l classified the water into yellow (class 2) as well. Nitrates averaging at 7.96 mg/l should have put the water into the green category (class 1) but with a maximum value of 27.0 mg/l, the yellow (class 2) was assigned to it. Calcium at 70.58 mg/l was in the green category (class 1) as well. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4). For seasonal variations see Chapter 6 (discussion).

Well 5: Amake Elina Phiri (House number 560/22).

Solution weathering has left space occupied by water in the calcified rock formation which is being used as a well- a feature very common in this part of George Township area. This is an open well with water possibly coming from the underground drainage system (plate 9). A Pit Latrine has been built about two metres from this water point. This latrine is apparently constructed on higher ground than the water well. This point was selected due to the fact that in this specific location, there are no dug wells due mainly to the rocky geology. A lot of quarrying in this area has also left behind holes some of which are being used as water supply points.

Table 6: Water Quality at Well Number 5: Amake Elina Phiri's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES (class 1/0)	SUBSTANCE CLASS
EC(uS/cm)/mS/m	655	548.45	Blue 0	1500/<70	Blue 0
Eh(mV)	16	-38.32			
pH*	6.54	6.94	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1420	482	Yellow 2	450	Yellow 2
Turbidity (NTU)	23.10	7.9	Red 3	5	Red 3
Sodium (mg/l)	40.04	24.76	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.025	0.018	Red 3	0.003	Red 3
Fluoride (mg/l)	0.27	0.165	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	650.0	317.27	Red 3		Red 3
Potassium (mg/l)	7.0	3.37	Blue 0	25	Blue 0
Iron (mg/l)	0.20	0.096	Blue 0	0.5	Blue 0
Ammonia (as NH_4-N mg/l)	0.13	0.114		None	
Zinc (mg/l)	0.016	0.013	Blue 0	3.0	Blue 0
Chlorides (mg/l)	55	31.91	Blue 0	250	Blue 0
Nitrites (as NO_2-N mg/l)	0.089	0.541	Blue 0	3	Blue 0
Nitrates(as NO_3-N mg/l)	25.10	12.11	Red 3	6	Red 3
Lead (mg/l)	2.10	0.40	Red 3	0.01	Red 3
Total Phosphates (mg/l)	1.41	1.071		None	
Magnesium(mg/l)	108.0	39.43	Green 1	200	Green 1
Calcium (mg/l)	84.0	56.67	Blue 0	200	Blue 0
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	9300	4464	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	7400	2855	Purple 4	0	Purple 4
E coli/100ml**	1600	417	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Following laboratory analysis on the water samples from Amake Elina Phiri's well over the period of time, it was found that the average Total Coliforms count per 100ml was 4,464 while Fecal Coliforms count was at 2,855 and ***E. coli*** at 417 (see Table 5 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms giving a purple or class 4 classification. Total Hardness was also found to average at above 317 mg/l, a level that could have put the water in the class 2 (or yellow) classification but the maximum value of 650 mg/l moved it to red (class 3). Total Dissolved Solids at 482 mg/l could have meant class 1 (or green) for this water but the maximum value of 1420 mg/l shifted it to yellow (class 2). Turbidity was at an average of about 7.9 NTU which could have put the water into class 2 (or yellow) but the fact that the maximum value was 23.10 NTU, moved the water to red (class 3) category. Cadmium and Lead at an average of 0.018 mg/l and 0.40 mg/l respectively could have classified the water into yellow (class 2) but the maximum values of 0.025 mg/l and 2.10 mg/l respectively gave it class 3 or red. Nitrates averaging at 12.11 mg/l should have put the water into the yellow category (class 2). However, the maximum concentration of 25 mg/l put it in red (class 3) as well. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 6: Mr. Andrew Makwaya (House number 17/05).

Mr. Makwaya's well has a raised brick wall of about fifteen centimeters which guards the opening (plate 10). A pit latrine is located about ten metres west of the well. Trees are also growing around this well which is under shed throughout the year.

Table 7: Water Quality at Well Number 6: Mr. Andrew Makwaya's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	775	688.45	Blue 0	1500/<70	Blue 0
Eh(mV)	16	-27.79			
pH*	6.68	6.68	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1760	656.54	Yellow 2	450	Yellow 2
Turbidity (NTU)	10.5	1.85	Yellow 2	5	Yellow 2
Sodium (mg/l)	59.91	32.56	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.007	0.0053	Yellow 2	0.003	Yellow 2
Fluoride (mg/l)	0.42	0.23	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	1000	399.45	Red 3		Red 3
Potassium (mg/l)	3.0	1.32	Blue 0	25	Blue 0
Iron (Mg/l)	0.18	0.122	Blue 0	0.5	Blue 0
Ammonia (as NH_4-N mg/l)	0.13	0.047		None	
Zinc (mg/l)	0.17	0.0122	Blue 0	3.0	Blue 0
Chlorides (mg/l)	138	52.18	Green 1	250	Green 1
Nitrites (as NO_2-N mg/l)	0.010	0.005	Blue 0	3	Blue0
Nitrates(as NO_3-N mg/l)	19.91	5.54	Yellow 2	6	Yellow 2
Lead (mg/l)	3.20	0.50	Red 3	0.01	Red 3
Total Phosphates (mg/l)	3.38	1.24		None	
Magnesium(mg/l)	63.36	44.80	Blue 0	200	Blue 0
Calcium (mg/l)	108.0	76.18	Green 1	200	Green 1
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	9000	2718	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	7000	1909	Purple 4	0	Purple 4
E coli/100ml**	2100	331	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Laboratory results following analysis of the water samples from Mr. Makwaya's well over the period of time, showed that the average Total Coliforms count per 100 ml was 2,718 while Fecal Coliforms count was at 1,909 and ***E. coli*** at 331 (see Table 6 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms. Following this result purple or class 4 was assigned to the water. Total Hardness was also found to average at above 390 mg/l a level that could have put the water in the class 2 (or yellow) classification but the maximum concentration value of 1000 mg/l moved it to class 3 (red). Total Dissolved Solids at 656.54 mg/l should have given the water a class 1 (or green) rating but this moved to yellow (class 2) since the maximum concentration value was 1760 mg/l. Turbidity was at an average of about 1.85 NTU thereby putting the water into class 2 (or yellow). Cadmium at an average of 0.007 mg/l classified the water into yellow (class 2). Lead at an average of 0.50 mg/l could have given the water a yellow (class 2) rating but this moved up to red (class 3) due to the maximum concentration value of 3.20 mg/l. Nitrates averaging at 5.54 mg/l should have put the water into the blue category (class 0) but the maximum value of 19.91 mg/l pushed it to class 2 (yellow) category. This was the only sampling point with such a low average result for Nitrates. However, the maximum recorded (19.91 mg/l) was well above the limit hence the classification. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4). In comparison to other wells, this was probably the best. Washing of clothes at this well was also very common.

Well 7: Mrs. Joyce Mbewe (House number 175/3).

Mrs Mbewe's well is located about twenty metres West of the pit latrine. Being another of the heavily used facilities, the area around the well is always wet with the drains filled with waste water as people continue to flock to draw water as well as to wash their cooking utensils and clothes. This well is apparently another one in a discharge zone (Plate 11 and 12).

Table 8: Water Quality at Well number 7:Mrs. Joyce Mbewe's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1369	1345	Blue 0	1500/<70	Blue 0
Eh(mV)	45	-3.6			
pH*	6.68	6.68	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1038	944.54	Yellow 2	450	Yellow 2
Turbidity (NTU)	1.54	0.69	Yellow 2	5	Yellow 2
Sodium (mg/l)	94.41	54.79	Blue 0	200/<100	Blue 0
Cadmium (mg/l)	0.013	0.0093	Yellow 2	0.003	Yellow 2
Fluoride (mg/l)	0.28	0.19	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	1400	571.0	Red 3		Red 3
Potassium (mg/l)	15.27	7.22	Blue 0	25	Blue 0
Iron (mg/l)	0.53	0.285	Green 1	0.5	Green 1
Ammonia (as NH_4^-N mg/l)	0.18	0.111		None	
Zinc (mg/l)	0.074	0.022	Blue 0	3.0	Blue 0
Chlorides (mg/l)	190.0	118.81	Green 1	250	Green 1
Nitrites (as NO_2^-N mg/l)	0.120	0.07	Blue 0	3	Blue 0
Nitrates(as NO_3^-N mg/l)	41.60	21.14	Purple 4	6	Purple 4
Lead (mg/l)	2.60	0.45	Red 3	0.01	Red 3
Total Phosphates (mg/l)	5.04	1.92		None	
Magnesium(mg/l)	257	61.02	Yellow 2	200	Yellow 2
Calcium (mg/l)	180.0	116	Yellow 2	200	Yellow 2
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	8800	3873	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	7900	2182	Purple 4	0	Purple 4
E coli/100ml**	1000	424	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Laboratory results show that water samples from Mrs. Joyce Mbewe's well over the period of time had average Total Coliforms count per 100 ml at 3,873 while Fecal Coliforms count at 2,182 and ***E. coli*** at 424 (see Table 7 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms. This places the water into class 4 or purple category. Total Hardness was also found to average at above 571 mg/l, a level that should have put the water in the class 2 (or yellow) classification. However, with a maximum concentration of 1400 mg/l, the class was raised to red (class 3). Total Dissolved Solids at 944.54

mg/l could have put it in class 1 (or green) but the maximum concentration value of 1038 mg/l put it into class 2 or yellow category. Turbidity at an average of about 0.69 NTU could have given the water a class 1 (or green) rating but the maximum of 1.54 NTU gave it a yellow (class 2) rating. Cadmium at an average of 0.0093 mg/l classified the water into yellow (class 2). Lead at 0.45mg/l could have given the water a yellow (class 2) rating but for the maximum concentration value of 2.60 mg/l, the class was red (class 3). Chlorides (118.81 mg/l) and Calcium (116 mg/l) gave the water a green (class 1) rating in both cases. Nitrates averaging at 21.14 mg/l should have put the water into the red category (class 3) but for the maximum concentration of 41.60 mg/l, the class went up to purple (class 4). Calcium and Magnesium made the water to be classified as yellow (class 2) due to the high maximas of 180 mg/l and 257 mg/l each despite their averages being 116 mg/l and 61.02 mg/l respectively. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water as well as that of Nitrates was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 8: Mr. Felix Tembo (House number 176/8).

Mr. Tembo's shallow well is a facility accessible to a lot of users including car washers. The surroundings just like all the other wells, is always wet (plate 13). It is just about two or so metres from a busy dust road. A pit latrine is located about fifteen metres East of the well.

Table 9: Water Quality at Well number 8: Mr. Felix Tembo's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1840	1528	Blue 0	1500/<70	Blue 0
Eh(mV)	41	-4.06			
pH*	6.43	6.43	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1338	997	Yellow 2	450	Yellow 2
Turbidity (NTU)	4.08	1.12	Yellow 2	5	Yellow 2
Sodium (mg/l)	118	70.25	Green 1	200/<100	Green 1
Cadmium (mg/l)	0.110	0.04	Red 3	0.003	Red 3
Fluoride (mg/l)	0.41	0.21	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	870	555	Red 3		Red 3
Potassium (mg/l)	47.10	26.34	Green 1	25	Green 1
Iron (mg/l)	2.50	0.63	Yellow 2	0.5	Yellow 2
Ammonia (as NH_4^-N mg/l)	2.23	1.4		None	
Zinc (mg/l)	0.067	0.025	Blue 0	3.0	Blue 0
Chlorides (mg/l)	273	152.27	Yellow 2	250	Yellow 2
Nitrites (as NO_2^-N mg/l)	0.395	0.124	Blue 0	3	Blue 0
Nitrates(as NO_3^-N mg/l)	43.20	21.76	Purple 4	6	Purple 4
Lead (mg/l)	3.40	0.48	Red 3	0.01	Red 3
Total Phosphates (mg/l)	5.04	1.66		None	
Magnesium(mg/l)	96.48	50.92	Green 1	200	Green 1
Calcium (mg/l)	228.0	123.33	Yellow	200	Yellow 2
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	9000	3473	Purple 4	0-10	Purple 4
Faecal coliforms/100ml**	7000	2009	Purple 4	0	Purple 4
E coli/100ml**	2000	669	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Laboratory results show that water samples from Mr.Felix Tembo's well over the period of time, had average Total Coliforms count per 100 ml at 3,473 while Fecal Coliforms count at 2,009 and ***E. coli*** at 669 (see Table 8 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms. Purple (class 4) was the classification given to the water at this well. Total Hardness was also found to average at above 555 mg/l, a level that should have put the water in the class 2 (or yellow) classification. However, due to the maximum concentration value of 870 mg/l, the class was raised to red (class 3). Total Dissolved

Solids at 997 mg/l should also have put the water in class 1 (or green) but was raised to yellow (class 2) due to the maximum concentration value of 1338 mg/l. Turbidity was at an average of 1.12 NTU thereby putting the water into class 2 (or yellow). Cadmium concentration of 0.04 mg/l put it in class 3 (red category). Lead at an average of 0.48mg/l should have classified the water into yellow (class 2) but with a maximum concentration value at 3.40 mg/l, this raised the class to 3 (red). Nitrates averaging at 21.76 mg/l should have put the water into the red category (class 3). However, the maximum value of 43.20 mg/l shifted this classification to purple (class 4). Chlorides at 152.27 mg/l should have classified the water as green (class 1) but the maximum values of 273 mg/l and Calcium 228 mg/l (against average of 123.33 mg/l) while Iron at 2.50 mg/l (against average of 0.63 mg/l) gave the water a yellow (class 2) classification. Potassium (26.34 mg/l) gave the water a green (class 1) rating. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water as well as Nitrates was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 9: Mr. Redsom Matabula (House number 184/22).

Mr. Matabula's well is about five metres from a tarred road that is heavily used. It is covered by a rubber tyre which forms the well inlet. The distance from the nearest pit latrine is about fifteen metres. It is also located in the main discharge zone (Plate 14).

Table 10: Water Quality at Well Number 9: Mr. Redson Matabula's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	1870	1,110.1	Blue 0	1500/<70	Blue 0
Eh(mV)	21	-16.0			
pH*	6.56	6.56	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1620	870	Yellow 2	450	Yellow 2
Turbidity (NTU)	128	17.43	Red 3	5	Red 3
Sodium (mg/l)	153.86	66.96	Green 1	200/<100	Green 1
Cadmium (mg/l)	0.113	0.02	Red 3	0.003	Red 3
Fluoride (mg/l)	0.42	0.17	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	1052	484	Red 3		Red 3
Potassium (mg/l)	63.96	29.50	Yellow 2	25	Yellow 2
Iron (mg/l)	0.81	0.34	Green 1	0.5	Green 1
Ammonia (as NH_4-N mg/l)	0.22	0.095		None	
Zinc (mg/l)	0.038	0.015	Blue 0	3.0	Blue 0
Chlorides (mg/l)	358	130.18	Yellow 2	250	Yellow 2
Nitrites (as $NO2_2$-N mg/l)	0.287	0.11	Blue 0	3	Blue 0
Nitrates(as $NO3_3$-N mg/l)	38.50	18.77	Red 3	6	Red 3
Lead (mg/l)	1.50	0.35	Red 3	0.01	Red 3
Total Phosphates (mg/l)	4.80	1.57		None	
Magnesium(mg/l)	70.08	37.39	Green 1	200	Green 1
Calcium (mg/l)	280	102.84	Yellow 2	200	Yellow 2
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	12000	3827	Purple 4	1-10	Purple 4
Faecal coliforms/100ml**	12000	3236	Purple 4	0	Purple 4
E coli/100ml**	2100	677	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Laboratory results show that water samples from Mr. Redson Matabula's well over the period of time, had average Total Coliforms count per 100 ml at 3,827 and Fecal Coliforms count at 3,236 while ***E. coli*** at 677 (see Table 9 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms putting the water into class 4 (purple) category. Total Hardness was also found to average at above 484 mg/l, a level that could put the water in the class 2 (or yellow) but moved to red (class 3) classification due to the maximum concentration of 1052 mg/l while Total Dissolved Solids at 870 mg/l could have put it in class 1 (or green) but this was raised to yellow (class 2) due to the maximum concentration value of 1620 mg/l. Turbidity at an average of 17.43 NTU could have put the water into class 2 (or yellow) but the maximum value of 128 NTU raised it to red (class 3). Cadmium concentration of 0.02 mg/l put it in class 3 (red category). Lead at an average of 0.35 mg/l should have classified the water into yellow (class 2). However, with maximum concentration of 1.50 mg/l, this raised the classification to red (class 3). Nitrates averaging at 18.77 mg/l should have put the water into the yellow category (class 2) but moved to red (class 3) due to the maximum concentration value of 38.50 mg/l. Chlorides (130.18 mg/l), Calcium (102.84 mg/l), Potassium (29.50 mg/l) should have given the water a green (class 1) rating but was raised to yellow (class 2) in all these cases due to the maximum values of 358 mg/l, 280 mg/l and 63.96 mg/l respectively. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

Well 10: Mr. Titus Ndumo (House number 255/12).

Mr. Ndumo's well is also located along the main road. A pit latrine is about ten metres from the well. This well is located at a place which is the lowest point on the sampling circuit in terms of its elevation. It is also in the main discharge zone of the area (See Table 1).

Table 11: Water Quality at Well Number 10: Mr. Titus Ndumo's well

PARAMETER	Maximum	Average	CLASS	WHO/SA GUIDELINES Class 1/0	SUBSTANCE CLASS
EC(uS/cm)/mS/m	2090	1402	Blue 0	1500/<70	Blue 0
Eh(mV)	41	0.49			
pH*	6.55	6.55	Blue 0	6.5-8.5	Blue 0
Arsenic (mg/l)	<0.001	<0.001	Blue 0	0.01	Blue 0
Total Dissolved Solids (mg/l)	1510	1442	Yellow 2	450	Yellow 2
Turbidity (NTU)	4.48	1.91	Yellow 2	5	Yellow 2
Sodium (mg/l)	129.77	98.02	Green 1	200/<100	Green 1
Cadmium (mg/l)	0.015	0.012	Yellow 2	0.003	Yellow 2
Fluoride (mg/l)	0.51	0.195	Blue 0	1.5	Blue 0
Total Hardness (as mg $CaCO_3$/l)	890	748.25	Red 3		Red 3
Potassium (mg/l)	50.42	32.48	Yellow 2	25	Yellow 2
Iron (mg/l)	0.31	0.19	Blue 0	0.5	Blue 0
Ammonia (as NH_4N mg/l)	3.66	1.48		None	
Zinc (mg/l)	0.027	0.019	Blue 0	3.0	Blue 0
Chlorides (mg/l)	250	212.18	Yellow 2	250	Yellow 2
Nitrites (as NO_2N mg/l)	0.434	0.23	Blue 0	3	Blue 0
Nitrates(as NO_3N mg/l)	39.95	23.47	Red 3	6	Red 3
Lead (mg/l)	2.10	0.45	Red 3	0.01	Red 3
Total Phosphates (mg/l)	6.56	2.31		None	
Magnesium(mg/l)	96.0	52.52	Green 1	200	Green 1
Calcium (mg/l)	212	143.63	Yellow 2	200	Yellow 2
Manganese (mg/l)	<0.01	<0.01	Blue 0	0.1-0.4	Blue 0
Bacteriological					
Total coliforms/100ml**	10500	5745	Purple 4	1-10	Purple 4
Faecal coliforms/100ml**	10000	3173	Purple 4	0	Purple 4
E coli/100ml**	3000	869	Purple 4	0	Purple 4
OVERALL WATER CLASS					Purple 4

* for pH minimum is used ** for bacteriological maximum is used

Laboratory results show that water samples from Mr. Titus Ndumo's well over the period of time, had average Total Coliforms count per 100 ml at 5,745 and Fecal Coliforms count at 3,173 while ***E. coli*** at 869 (see Table 10 above). All these values were above the recommended zero per 100 ml for Fecal Coliforms and ***E. coli*** and 0-10 for Total Coliforms giving it a purple (class 4) category. Total Hardness was also found to average at above 748 mg/l-a level that put the water in the class 3 (or red) classification while Total Dissolved Solids at 1442 mg/l put it in class 2 (or yellow). Turbidity was at an average of about 1.91NTU thereby putting the water into class 2 (or yellow). Cadmium concentration of 0.012 mg/l put it in class 2 (yellow) category. Lead at an average of 0.45 mg/l could have classified the water into yellow (class 2) but this was raised to red (class 3) due to the maximum value which was at 2.10 mg/l. Nitrates averaging at 23.47 mg/l put the water into the red category (class 3). This could be said to have been the worst average in the sampling circuit. Chlorides (212.18 mg/l) were in yellow category (class 2). Calcium (143.63 mg/l) and Potassium (32.48 mg/l) should have given the water a green (class 1) rating in both these cases but this was raised to yellow (class 2) due to the maximum concentration values of 212 mg/l and 50.42 mg/l respectively. The rest of the parameters were in the blue category.

It was observed that some parameters were in the blue (class 0) as well as green (class 1) category. However due to the fact that one of the critical parameters-the bacteriological quality of the water was class 4 (purple), the over all class for the water at this sampling point was therefore purple (class 4).

5.3. Health and Safety

The health and safety of the water especially for direct domestic use, is a serious threat to community health as it is apparently poor and of unacceptable quality. This statement arises from the fact that the microbiological/bacteriological quality of the water is far below the barest minimum. It is said that water with more than 1000 counts of ***E. coli*** per 100 ml is grossly polluted and needs to be treated or abandoned altogether (Feachem *et al.*,1977:87). The maximum value of the ***E. coli*** concentration presents such a picture. The metal elements of major concern include Cadmium (Cd) and Lead (Pb). Turbidity of the water in some cases is also below the recommended values.

A look at the Nitrate concentration reveals that there is an elevated level of concentration of this substance in all the wells in this regard. This has serious health implications especially to the babies. The seasonal variations in the quality of the water was also very evident whereby it was comparatively better during the dry season and worse during the rainy season as shown by the differences in the fecal coliforms concentration per 100 ml during the said seasons (see Figures 10,11,12,13 & 14 in Chapter 6-discussion).

5.4. Conclusion

The results seem to suggest that the water in all the sampling points has an overall very poor or unacceptable quality i.e. purple classification (class 4) rating. This water is of an unacceptable quality. This water is apparently a serious health hazard if it were to be used especially for purposes of drinking and cooking without treatment. The bacteriological quality is the poorest (purple or class 4) and provides the greatest health concern. Other concerns are on the levels of elements such as Cadmium and Lead which apparently seem to appear higher than the recommended levels; if these results are anything to go by. High Nitrate levels imply a direct heath hazard especially to the new members of society (babies). The bench mark provided by the supply from LWSC Borehole number 4, is slightly better that the water from shallow wells. It can also be stated that the water from the Lusaka Water and Sewerage Company boreholes unlike that from shallow wells, undergoes some form of treatment including chlorination before being supplied to the residents. However it may be said that the type of treatment may not be able to deal with the issue of high Nitrates in the water.

CHAPTER 6: DISCUSSION

6.1. Introduction

It is estimated that about 2.2 million people in the world die from diarrhoeal diseases every year (WHO, 2001). Most of these cases are certainly related to poor quality water. Water quality alludes to the description of the microbiological as well as physical-chemical properties of water that determine its fitness for use. Domestic use of water includes among others, the utilization of water for drinking and cooking purposes and other such uses around the home including washing kitchen utensils, clothes, bathing, etc. Taking into consideration of all quality factors such as microbiological, physical and chemical parameters, the quality of the water in George Township area can, according to the South African Quality of Domestic Water Supplies Volume 1: Assessment Guide, generally be classified as class 4 or purple. In this class, water is believed to be of very poor (or unacceptable) quality (DWAF,DH,WRC, 1998: 22). This normally does take account of the group A substances which are the major indicators of water quality. These include Electrical conductivity (EC), Fecal Coliforms (FC), pH value and Turbidity. Selecting just these parameters the water is classified into the lowest quality class 4-purple. However, the need for baseline information through monitoring activities is required. Ineffective regulation and enforcement of laws seem to hold sway. Therefore this has increased the potential health hazards and risks associated with consumption of poor quality water. This is so especially when the microbiological quality is considered whereby the water is in the poorest state (unacceptable class 4 or purple). It is said that water with more than 1000 counts of ***E. coli*** per 100 ml is grossly polluted and needs to be treated or abandoned all together (Feachem, *et al.,* 1977:87). This was the case with basically all the water in George Township's shallow wells if maximum values were considered.

6.2. Lack of Baseline Information

There has generally been no water quality monitoring programme especially for the shallow wells in Lusaka and in the study area. Lack of a consistent monitoring programme has resulted in an inadequacy as regards information on the quality of groundwater especially in informal/unplanned settlements. This therefore implies that at the beginning of the project, there was no baseline data except for some coming from ad-hoc sampling of the deep wells by the Lusaka Water and Sewerage Company done once in a while for purposes of monitoring their supply system. The data obtained from the exercise could most likely contribute to some baseline information on the quality of the water in the George Township area being made available.

6.3. Ineffective Regulation & Enforcement

It has clearly been seen that the various laws such as the Environmental Protection and Pollution Control Act, the Public Health Act, Local Government Act, the Water Resources Management Bill, etc., all do allude to the issues of the need to control pollution of water especially ground water. Part IX Section 67 (1) (d) and (e) of the Public Health Act says that wells supplying water of poor quality are classified as a danger to health and the LA has power to act against such facilities. Part XI Section 78 (a) of the same Act assigns the responsibility of pollution prevention to the LA including LCC. Further, Section 61 subsection 61 of the Local Government Act, conservation and prevention of pollution of water supplies is an assigned responsibility to the LAs. However, this does not seem to be the case in Lusaka perhaps due to the fact that the LA has failed to provide for its inhabitants hence the apparent "let sleeping dogs lie" attitude.

NWASCO is obligated by the National Water Supply and Sanitation Act Part II Section 4(2) (e) (i) to monitor design quality of water supply and sanitation infrastructure. This apparently is not done especially in George Township area and other informal/unplanned settlements. However, despite these legal provisions, groundwater continues to be polluted especially in the various parts of Lusaka. This is made worse in a situation where there is currently no law to govern use and management of groundwater. Until the Water Resources Management Bill becomes law, use of groundwater will remain unregulated in terms of its abstraction and use. However, the available provisions in the EPPCA, Local Government Act, Public Health Act, Water Supply and Sanitation Act, etc are adequate to deal with the issues of groundwater pollution though the major drawback is enforcement of these laws which has remained pathetic. However, the communities most of the time boil the water obtained from shallow wells or apply chlorine when they can afford.

6.4. Potential Health Hazards & Risks

Health effects of water according to the South African Quality of Domestic Water Supplies Volume 1: Assessment Guide, may be classified either as ***acute*** or ***chronic***. Acute effects are those which may manifest themselves within a very short time upon exposure to such water while chronic ones may show after long time of exposure. These effects may be serious and long lasting or of no significance and temporal. Depending on the concentrations of the various substances, these may provide acute or chronic health effects. Under normal circumstances, the maximum and the average values of the concentration of a substance may be used to assess the acute as well as the chronic effects of the water to the user, respectively. Most bacteriological effects may be acute while most metals may be chronic. There are however some exceptions.

The potential hazards from use of such water in the George Township area for drinking and cooking is associated with the very poor microbiological quality. Solution channels in limestone are said to be a factor that assists microbiological pollutants traveling longer distances (Salvato, 1982:177). The George Township area situation may not be far from this. Other hazards come from turbidity and elements such as Lead, Cadmium, and other such which are in concentrations above the limits set by either the World Health Organization or the South African/Zambian Governments. Nitrates are another parameter of concern as these seem to be higher than the recommended levels. High Nitrate levels further confirm that there has been contamination of the groundwater from human wastes (DWAF,DH,WRC, 1998:86).

The high level of Total Coliforms (Figure 4) especially presence of Fecal Coliforms (Figure 5), does confirm the fact that there has been recent contamination of the water from fecal matter (DWAF,DH,WRC, 1998:50). This is further put beyond doubt with the presence of ***Escherichia coli*** a bacterium associated with guts of homeotherms or warm blooded animals such as man (Figure 6). With very few such animals including dogs in the area, the source of such indicator organisms once again points to the presence of pit latrines where human fecal matter could be polluting the water.

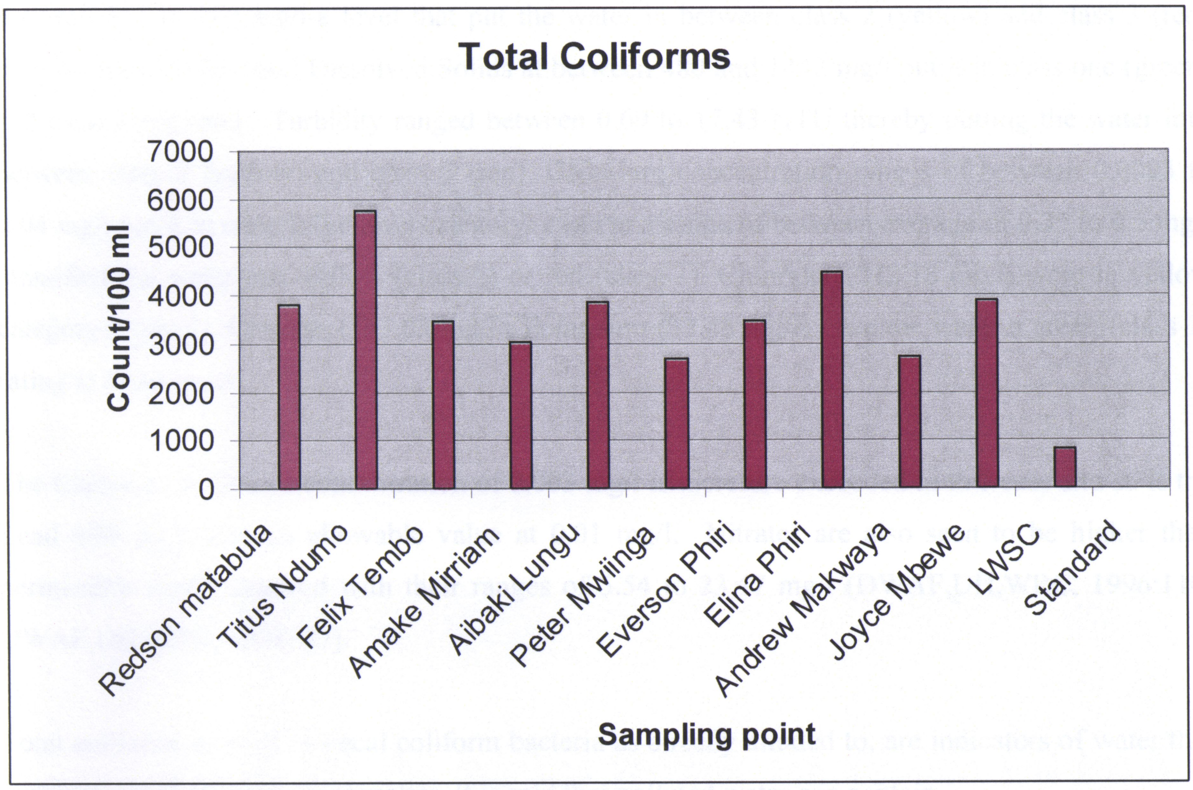

Figure 4: Bar Graph showing Total coliforms (averages) concentrations in water samples at different sampling points (standard equal to 10 counts/100 ml)

The source of such pollution could therefore with some certainty, point to the pit latrines which are within very short distances from the wells.

Other parameters of concern include total hardness, total dissolved solids, turbidity, Cadmium, Lead, Nitrates, Calcium, Chlorides and in some cases Potassium. On the whole, of major concern would generally be bacteriological as well as Cadmium, Lead and Nitrates.

Laboratory results show that water samples from George Township area shallow wells over the period of time, had maximum Total Coliforms count per 100 ml at between 8200 to 12,000 and maximum Fecal Coliforms count between 6200 to 12000 while *E. coli* between 1000 to 3,100. All these values were above the recommended zero per 100 ml for Fecal Coliforms and *E. coli* and 0-10 for Total Coliforms giving it a purple (class 4) rating . Total Hardness was also found to range between 317 to 740 mg/l-a level that put the water in between class 2 (yellow) and class 3 (red) classification while Total Dissolved Solids at between 480 and 1442 mg/l put it in class one (green) and class 2 (yellow). Turbidity ranged between 0.69 to 17.43 NTU thereby putting the water into between class 2 (yellow) and class 3 (red). Cadmium concentration ranges of between 0.0093 to 0.04 mg/l put it in class 2 (yellow) category. Lead at a range of between average of 0.35 to 0.5 mg/l classified the water into yellow (class 2) or red (class 3). Chlorides (212.18 mg/l) were in yellow category (class 2). Calcium (143.63 mg/l), Potassium (32.48 mg/l) gave the water a green (class 1) rating in these cases.

The Cadmium minimum concentration of 0.003 mg/l is therefore exceeded in this case and so is the Lead with its minimum allowable value at 0.01 mg/l. Nitrates are also seen to be higher than permissible levels required with their ranges of 5.54 to 23.47 mg/l (DWAF,DH,WRC, 1996:110; DWAF,DH,WRC, 1998: 87).

Total coliforms as well as Fecal coliform bacteria as already alluded to, are indicators of water that is recently polluted with fecal matter. It is said that polluted water can contain

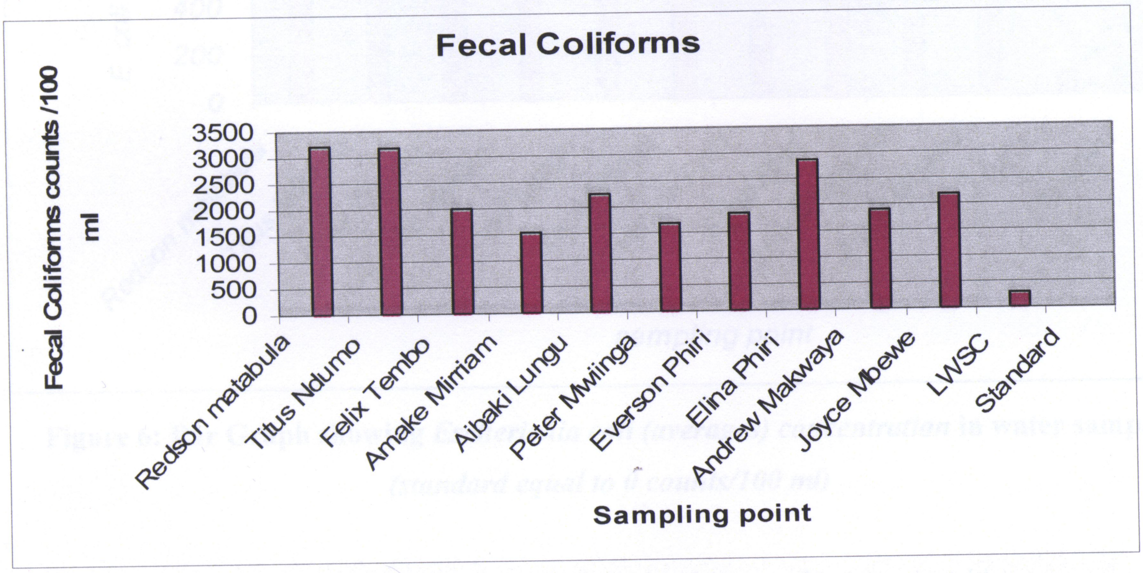

Figure 5: Bar Graph showing Fecal coliforms (averages) concentration in sampled water (standard equal to 0 counts/100 ml)

fecal coliform counts in the range between 10-1,000,000 per 100 ml of water (DWAF,DH,WRC, 1998:50). From the information provided by the water analysis results, water wells in George

Township area therefore present water that is polluted by fecal matter. The presence of the fecal coliforms presents the fact that there are other disease-causing microorganisms such as other bacteria, viruses and parasites which may cause gastro-intestinal diseases manifesting themselves in form of diarrhea and other complications. The high levels of fecal coliforms (Figure 5) are indeed a source of worry. However, it can also be noted that using the LWSC borehole which is much deeper than the shallow wells as the background, it may be said that there is a clear contrast with the LWSC showing a reduced level of contamination by all the three bacteriological parameters namely Total Coliforms, Fecal Coliforms as well as ***Escherichia coli.*** The isolation provided by the depth of the deep well may somehow account for this reduction in the counts (see Figures 4, 5, & 6).

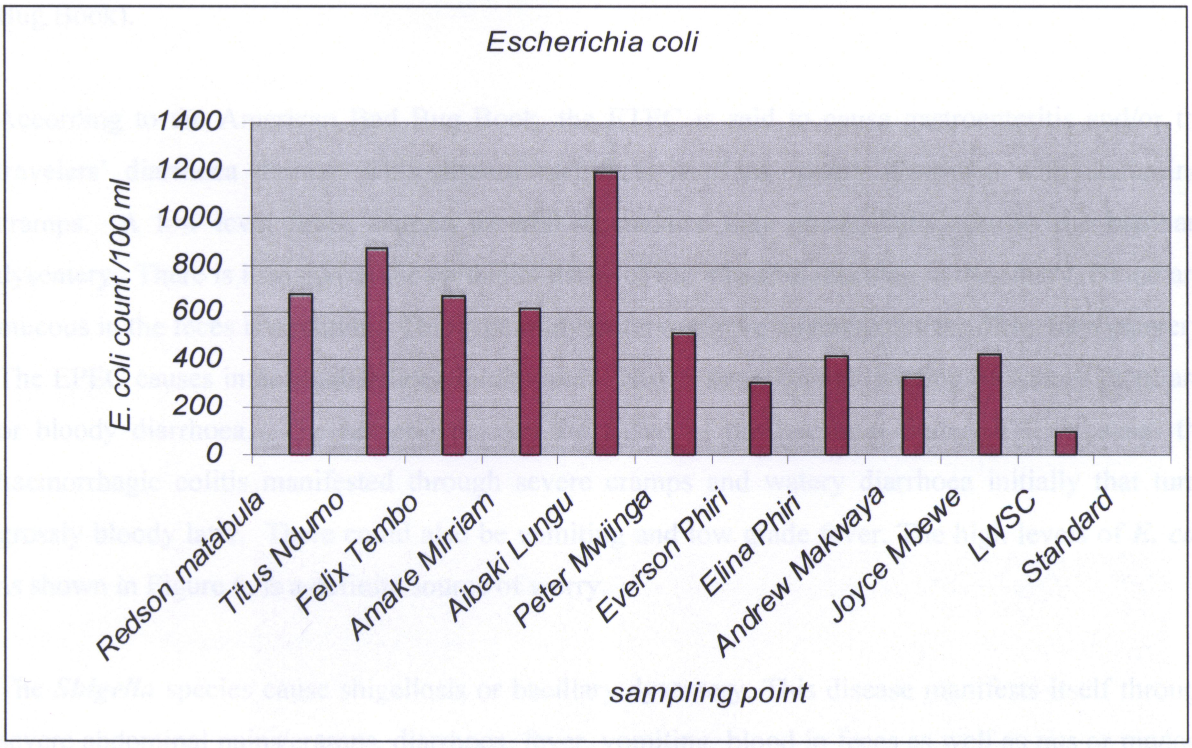

Figure 6: Bar Graph showing *Escherichia coli (averages) concentration* in water samples *(standard equal to 0 counts/100 ml)*

Escherichia coli is a bacterium that normally inhabits the gut of mammals without any problems. However, the virulent types that evolve may cause various diseases especially gastro-intestinal diseases. According to Todar (Todar's Online Textbook of Bacteriology 2002) some strains of ***E. coli*** can cause apart from intestinal diseases (gastroenteritis), a number of diseases such as urinary tract infections (UTIs) and Neonatal meningitis. Ingestion of food or water containing the virulent types of ***E. coli*** will result in disease (Evans & Evans, 2004). The disease that results is usually acute as its onset is within a short period of time and its severity very high. The common diarrhoea may be as a result of an infection with this organism. Others types of ***E. coli*** may cause dysentery-like diarrhoeal disease in which a patient passes blood in the feces apart from the great pain suffered. Haemorrhagic colitis is an acute disease caused by one type of ***E. Coli*** (USFDA Bad Bug Book; Nataro & Kaper, 1998). There are at least five known virulent strains of ***E. coli*** namely Enterotoxigenic (ETEC), Enteroinvasive (EIEC), Enteropathogenic (EPEC), Enteroaggregative (EAggEC) and the Enterohaemorrhagic (EHEC) causing various diseases in man (US FDA Bad Bug Book).

According to the American Bad Bug Book, the ETEC is said to cause gastroenteritis and/or the travelers' diarrhoea disease. This disease manifests itself as watery diarrhoea with abdominal cramps. A low level fever, nausea as well as malaise may occur. EIEC causes the bacillary dysentery. There is invasion of the epithelial tissue of the intestine resulting in dysentery. Blood and mucous in the feces is common. This type of dysentery may be mistaken for the ***Shigella*** dysentery. The EPEC causes infantile diarrhoea in children. This is seen through passing of watery feces and or bloody diarrhoea. The bacteria destroy the tissue of the intestinal lining. EHEC causes the haemorrhagic colitis manifested through severe cramps and watery diarrhoea initially that turns grossly bloody later. There could also be vomiting and low grade fever. The high levels of ***E. coli*** as shown in Figure 6, is a definite source of worry.

The ***Shigella*** species cause shigellosis or bacillary dysentery. This disease manifests itself through severe abdominal pains/cramps, diarrhoea, fever, vomiting, blood in feces as well as pus or mucous in the stool. The high likelihood of having ***shigella*** species in the water from shallow wells in George Township can not be ignored. It is recorded that ***Shigella*** species can survive in water for between one month to two years (Salvato, 1982:25). This implies that water with such microorganisms will remain infective over a long period of time.

Water of poor bacteriological quality as the case is, may apart from bacteria carry other disease-causing microbes such as protozoa and viruses (WHO Guidelines for drinking Water Quality, 2004:122). For example, ***Entamoeba histolytica***, a type of amoeba, is known to cause diarrhoeal diseases such as dysentery. Amoebiasis presents itself in form of dysentery with blood and mucous in the feces. However, complications may result in ulceration and abscess pain apart from intestinal blockage. Severe pain coupled with blood in the feces is therefore associated with amoebic dysentery. People with low immunity would most likely suffer from this disease. With turbidity being a parameter of concern especially with high microbial loads found in the water, the amoebae group would certainly be found in such water. These protozoa may therefore probably be found in water sampled in George Township shallow wells though it was not included in the analysis of the water. ***Entamoeba histolytica*** is also said to survive in water for at least one month (Salvato, 1982:25) thereby providing a good pool of infection during that time.

The ***Vibrio cholerae*** which has been ravaging the community every year with the now endemic cholera outbreaks, which was not specifically identified but pointers as regards its possible presence are there to that effect hence to some level of certainty, could be said to be very present. ***Vibrio cholerae*** is estimated to survive for at least five to sixteen days in water (Salvato, 1982:250 during which the disease burden will continue to be high. The suffering including deaths that have occurred in past cholera outbreaks are well known in George Township area. The possibility of typhoid-causing ***Salmonella enterica typhi*** bacteria being present in the water is also very high. Typhoid is another debilitating disease which apart from systemic and sustained fever and painful diarrhoea, severe headache, nausea and constipation, may also result in death (Pollack, 2003). Survival of ***Salmonella typhi*** in water is estimated as being between one day and two months (Salvato, 1982:25). This is long enough time for a lot of infections to occur among communities consuming such water.

The loss of water and electrolytes ($Na^+Cl^-K^+$) is the major cause of death in most cases of diarrhoeal diseases such as cholera. Sensitive groups such as infants, the aged and HIV positive persons as well as those on certain treatments which may affect their immunity such as those on cancer drugs, would definitely suffer from various life threatening diarrhoeal ailments through use of such water found in the shallow wells of George Township. With a high HIV/AIDS prevalence at 16% that Zambia experiences while Lusaka Province stands at 20.1 %(National AIDS Council, 2005:22), the use of water from shallow wells by the George Township community is a serious potential health problem. This is so because immuno-compromised individuals apart from children under five years of age as well as the elderly are the most vulnerable (WHO, 2004: 124).

Viruses such as Hepatitis A and E that may cause various human ailments are also known to be found in water of poor quality (WHO, 2004: 122). It is also stated that disease-causing pathogens transmitted through the fecal-oral route may also apart from drinking water, be taken up through contaminated food, hands, utensils and clothing (WHO, 2004: 125). Washing of hands, clothes, utensils using water from the shallow wells which is so common in the area could to some extent, contribute to the diseases transmission. Hepatitis A Virus (HAV) that causes Infectious Hepatitis (WHO, 2004: 125) that can be found in water, is a virus that needs some attention in public health arrangements especially in situations where poor quality water may come into contact with communities. The potential of infection of the people from this virus through use of water from shallow wells in George Township area is apparently very high.

Presence of other parasites in water from shallow wells in George such as flat or round worms may also affect the health of the water users. For example, stages of ***Ascaris lumbricoides*** as well as tapeworm (***Taenia*** species) may be present in the highly turbid water. Infection from this parasite may result in serious health problems arising from among others, loss of digested food as the digested food would continue to be absorbed by these parasites (Feachem *et al.,* 1977:15). Pneumonitis or ascaroid pneumonia, a condition arising from the effect of the movement of ascaris by burrowing from the blood stream into the lungs and later coughed out and into the alimentary canal, is a serious disease especially in children (USFDA Bad Bug Book). Blockage of the alimentary canal may also result from ascaris infection with disastrous effects (Feachem *et al.,* 1977:15). Eggs of Ascaris can survive up to seven years in the wet soil (Salvato, 1982:24).

It may also be possible to find some stages of hook worm parasites in this turbid water. This type of parasite may suck blood from the alimentary canal thereby causing anemia and other health complications (Feachem, *et al.,* 1977:15).

Cryptosporidiosis caused by ***Cryptosporidium parvus*** may be another disease that may arise out of use of the water from George Township shallow wells. There are three types of cryptosporidiosis namely intestinal, tracheal and/or pulmonary form of disease (USFDA Bad Bug Book). The intestinal disease is associated with severe watery diarrhoea while coughing, low grade fever as well as severe intestinal distress may characterize pulmonary cryptosporidiosis. Large scale outbreaks have usually been associated with use of contaminated water (USFDA Bad Bug Book).

Chemical quality.

Total Hardness was also found to have an average peak at about 748 mg/l a level that put the water in the class 3 (or red) classification. This is said to have chronic effects in sensitive groups. These include people with kidney or gall bladder stones as well as infants that may be sensitive to Magnesium if this is the major contributor to the hardness of the water. Diarrhoea may result due to Magnesium sensitivity in children taking hard water with this mineral component being high. The health effects though in some cases may be positive, could be negative in the sensitive groups. However, one may not be in a position to indicate how large this group could be-people with kidney/gall bladder stones that may be most vulnerable to hard water. There may also be a dry skin effect on individuals using such water for their bath apart from poor soap lathering.

The high concentration of Total Dissolved Solids (TDS) peaking at an average of about 1,442 mg/l put the water in class 2 (or yellow). This level of Total Dissolved Solids concentration may provide some slight possibility of salt overload in sensitive groups such as those with heart conditions as well as children less than one year of age. Increase in hypertensive reactions among sensitive groups especially those with heart conditions may have negative health effects (DWAF,DH,WRC, 1998:58).

Turbidity in itself does not confer poor water quality status. However, its association with microbiological contamination and growth brings the concerns to the fore. In this particular case, turbidity was in certain cases, above recommended levels thereby putting the water into class 2 (or yellow). The acceptable level of turbidity is about <1NTU (DWAF,DH,WRC, 1998:63). Values of <0.1 NTU are the most ideal with no effects on the quality of the water as well as to the consumer. However, values of 0.1-1 NTU provide some slight risk of potential health effects and any level above 1 NTU have high possibility of secondary health effects. This is so because high turbidities are also associated with possibilities of microbiological contamination. Infants below the age of two years as well as those adults with problems of suppressed immunity will likely have some serious health problems from drinking this water. Diarrhoeal diseases outbreaks would likely be associated with consumption of such water.

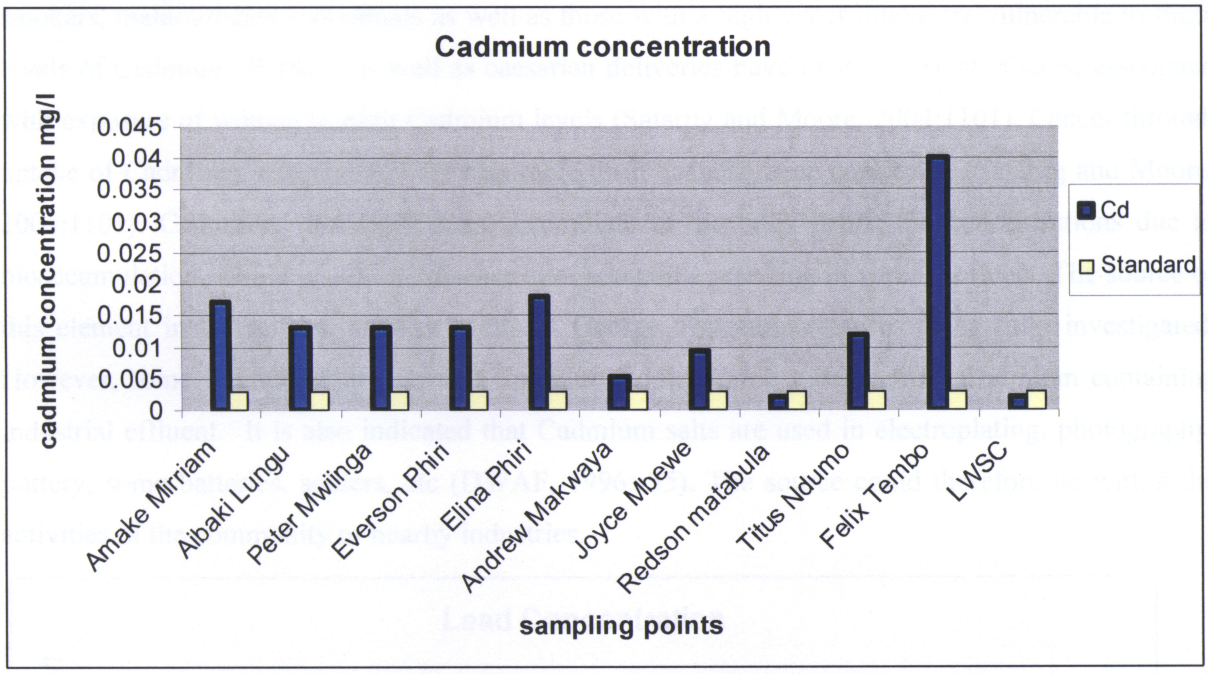

Figure 7: Bar graph showing Cadmium (average) concentration (mg/l) in sampled water from shallow wells for class 0 (0.003 mg/l)

Presented in Figure 7 above are the observed levels of the element Cadmium found in the water sampled from the various shallow wells over the period of the research. It is clear that these concentrations are above permissible standards though it is said to be within acceptable levels from the LWSC borehole. Above acceptable levels of Cadmium concentration put the water in class 2 (yellow) category. It may also be noted that the maximum concentrations of 0.003 mg/l refer to class 0 water while that for class 1 is 0.005 mg/l and class 2 at 0.01 mg/l. It is stated that acute health effects of cadmium give food poisoning symptoms such as nausea, vomiting and diarrhoea. Acute gastroenteritis that may mimic that caused by microorganisms may result from Cadmium poisoning (DWAF, 1996:36). Cadmium is said to be nephrotoxic. This means that it becomes toxic to the nephrones in the kidneys. Kidney damage as well as pain in the bones characteristic of the Japanese itai-itai disease (DWAF,DH,WRC, 1998:68) are some of the chronic effects on human health of high levels of Cadmium. Chronic effects such as renal failure have serious health effects (Satarug and Moore, 2004:1100). It is also understood that Cadmium may lead to skeletal demineralization leading to bone fragility through excretion of Calcium in the presence of high cadmium levels (Satarug and Moore, 2004:1100). Cadmium is also understood to have a direct causal effect on hypertension in humans (Klevay and Combs, 2004:93). Sensitive individuals such as heavy smokers, malnourished individuals as well as those with a high water intake are vulnerable to these levels of Cadmium. Preterm as well as caesarian deliveries have to some extent, also be associated with exposure of women to high Cadmium levels (Satarug and Moore, 2004:1101). Cancer through uptake of Cadmium, especially in its respirable form has also been confirmed (Satarug and Moore, 2004:1101). Cadmium, like Lead does accumulate in the body hence the concentrations due to bioaccumulation, would result into disease after sometime resulting in chronic effects. The source of this element in water from shallow wells of George Township requires to be fully investigated. However, some literature suggests that Cadmium could possibly come from Cadmium containing industrial effluent. It is also indicated that Cadmium salts are used in electroplating, photography, pottery, some batteries, solders, etc (DWAF, 1996: 35). The source could therefore be within the activities of the community or nearby industries.

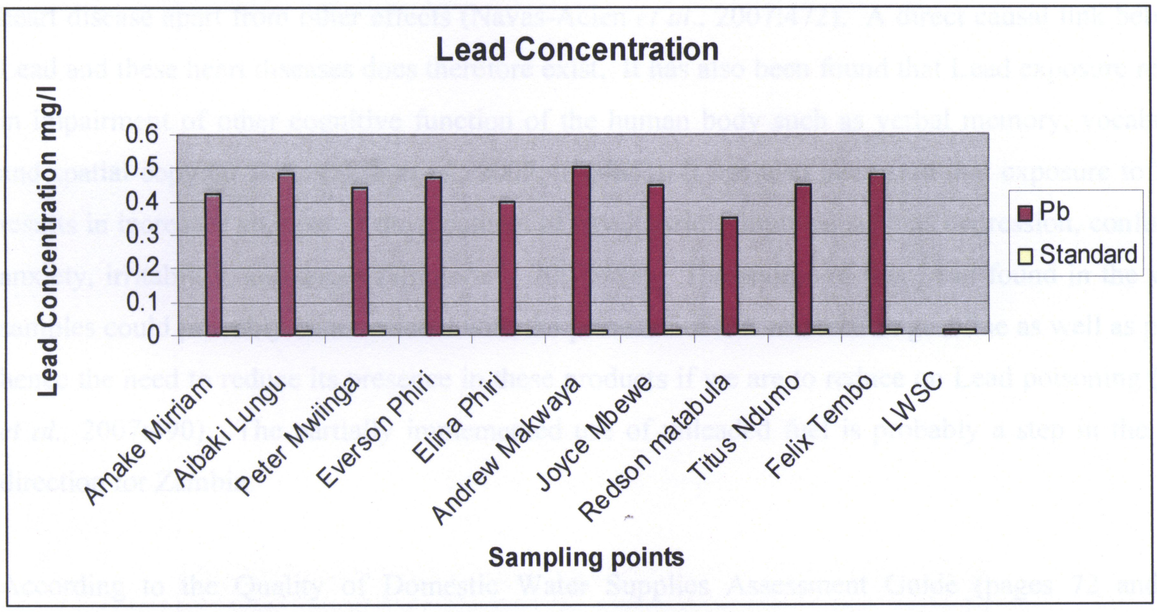

Figure 8: Bar graph showing Lead (average) concentration (mg/l) in sampled wells against standard for class 0 (0.01 mg/l).

The bar graph presented above (Figure 8) shows the average concentration of the Lead in the water sampled from the ten (10) shallow wells during the period of time. Compared to the permissible levels shown as the standard, it is clear that the levels found were way beyond the acceptable one. The level from the LWSC borehole is at 0.01 mg/l which is about the limit. Unacceptable Lead levels at a range of between 0.35 to 0.5 mg/l have been observed in these water samples from the area. This has classified the water into a poor or very poor or red/purple (class 3or 4). Under normal circumstances, Lead levels in the water need to be at a minimum of 0.01mg/l. However, it is apparent that the average concentration level at 0.45 mg/l is well above the stipulated limit (0.01mg/l). Lead is known to be harmful to the Central Nervous System of humans especially to the structure as well as neurochemistry (Shih *et al.*, 2007:490). It is understood to reduce brain circuitry capacity which results in lowered baseline cognitive functions (Shih *et al.*, 2007:490). Serious chronic effects could arise from use of this water especially drinking and cooking. It has been observed that continuous exposure to Lead can lead to neurological impairment in fetuses and young children resulting in serious behavioural changes and impaired performance in intelligence quotient tests (DWAF, 1996:94). Lead intake in adults has been associated with anemia and a disease known as Lead colic whereby the patient suffers severe abdominal pains. Lead has been identified as a contributor to life threatening cardiovascular disorders such as high blood pressure and coronary heart disease apart from other effects (Navas-Acien *et al.*, 2007:472). A direct causal link between Lead and these heart diseases does therefore exist. It has also been found that Lead exposure results in impairment of other cognitive function of the human body such as verbal memory, vocabulary and spatial copying skills (Shih *et al.*, 2007:483,485). It has also been said that exposure to Lead results in increased chances of development of psychiatric symptoms such as depression, confusion, anxiety, irritability, and anger (Shih *et al.*, 2007:488). The source of this Lead found in the water samples could probably be associated with the presence of this material in gasoline as well as paints hence the need to reduce its presence in these products if we are to reduce on Lead poisoning (Shih *et al.*, 2007:490). The partially implemented use of unleaded fuel is probably a step in the right direction for Zambia.

According to the Quality of Domestic Water Supplies Assessment Guide (pages 72 and 73) concentrations of Chlorides in some cases (212.18 mg/l) placed the water into yellow category (class 2) with an increasing health risk to sensitive groups such as some infants of less than one year old as well as individuals with congestive heart diseases including hypertension who may be on a salt-restricted diet.

Observed concentrations of Calcium in some instances at 143.63 mg/l or below would not pose any serious effects. However at elevated levels of above150 mg/l, there could be increased possibility of kidney stones especially in sensitive groups such as those already with Kidney/gall bladder stone problems as well as those that take a lot of water.

Generally, concentration of Potassium in some cases of about 32.48 mg/l or less gave the water a green (class 1) rating in all cases. It is said that sudden exposure to high levels of Potassium could disrupt heart as well as muscular function (DWAF,DH,WRC, 1996: 88). It may also irritate mucous membranes and cause nausea and vomiting (DWAF,DH,WRC, 1998:88). People with kidney diseases and infants below two years are the most vulnerable.

Another definite concern is the apparently high Nitrate levels which are above the limits (DWAF, DH,WRC, 1998:87). This provides an area of serious worry especially in babies. It was observed that though there was one case where the threshold Nitrate levels of 6 mg/l were not exceeded, it was apparent that in eight of the ten sampling points, a red classification was achieved. If the maximum values were considered (DWAF,DH,WRC, 1998: 87) all sampling points could not meet the minimum required Nitrate levels. The average values were between 5.54 mg/l and 23.47 mg/l with most of them being above 10 mg/l (Bar Graph 6). The maximum values ranged between 27.0 mg/l to 43.20 mg/l. However, using the South African water quality system (DWAF,DH,WRC, 1996:110), all the values presented in all sampling points can be said to be above the threshold which is given as 6 mg/l.

It is said that Nitrate concentration values of between 0-6 mg/l have no adverse health effects. However, those of above 6 mg/l become a danger to children (DWAF, 1996: 110). It is presented that Nitrate concentration values of between 6-10 gives rare instances of methaemoglobinaemia in infants without any effects in adults. However, Nitrate concentration values of between 10-20 mg/l provide definite problems in infants while Nitrate values beyond 20 mg/l also affects mucous membranes in adults apart from the methaemoglobinaemia in infants. At least four or so of the samples (Amake Mirriam, Mrs. Joyce Mbewe, Mr. Felix Tembo, Mr. Titus Ndumo) apparently could be a problem even to the adults (Fig.9).

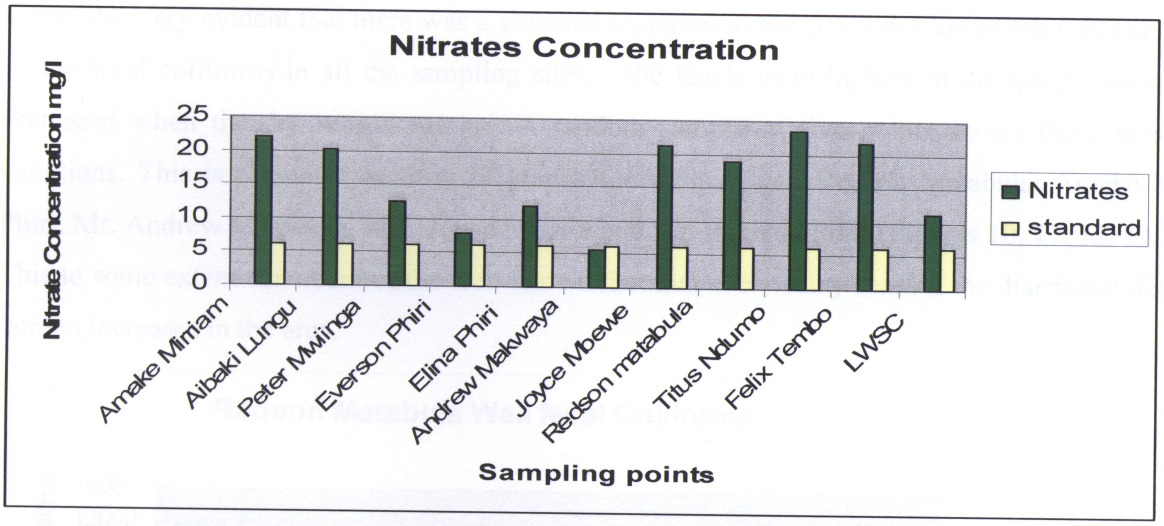

Figure 9: Bar Graph showing Nitrate (average) concentration (mg/l) in the shallow wells of George Township (against the standard of 6 mg/l)

Methaemoglobinaemia is a disease in babies resulting in most cases, from intake of water with high levels of Nitrates. In this regard, the comensal bacteria in the guts of babies convert the Nitrates to Nitrites which in turn convert normal haemoglobin to methaemoglobin. It is understood that methaemoglobin is formed when iron in the haem molecule in the blood is changed from the iron 2/ferrous state (Fe^{2+}) to the iron 3 or ferric state (Fe^{3+}) (Van Heijst, *1995)*. Methaemoglobin is not able to carry oxygen (DWAF, 1996: 109; Van Heijst, *1995*). The purple colour of the blood thereby making the skin look blue, a condition termed cyanosis (Van Heijst 1995*)* may have serious effects. This condition makes babies appear bluish due to lack of oxygen and is especially acute in babies under three months of age (DWAF, 1996: 109). This is exacerbated in conditions where there is less intake of vitamin C by the infants (DWAF, 1996: 109). From the results in Figure 9, even the LWSC sample does not seem to be completely exempt from the problem of Nitrates

Iron which was in some cases found to be above recommended levels gives water a bad colour as well as taste. It may also stain clothes as well as kitchen utensils. In extreme cases of high Iron concentrations acute poisoning in infants and young children may occur (DWAF,DH,WRC, 1998:78). Chronic poisoning or haemochromatosis may result from intake of Iron over long periods of time (DWAF,DH,WRC, 1998:78).

It was also very evident that there was a seasonal variation in the concentration of microbes as seen by the fecal coliforms in all the sampling sites. The levels were highest in the rainy season and decreased when the dry season set in. A random sample of five points shows these seasonal variations. This is presented in form of graphs for wells of Mr. Redson Matabula, Amake Elina Phiri, Mr. Andrew Makwaya, Mrs. Joyce Mbewe and Mr. Everson Phiri (Figures 10, 11, 12, 13, 14). This to some extent corroborates the well known fact that every rainy season, the diarrhoeal disease burden increases in the area.

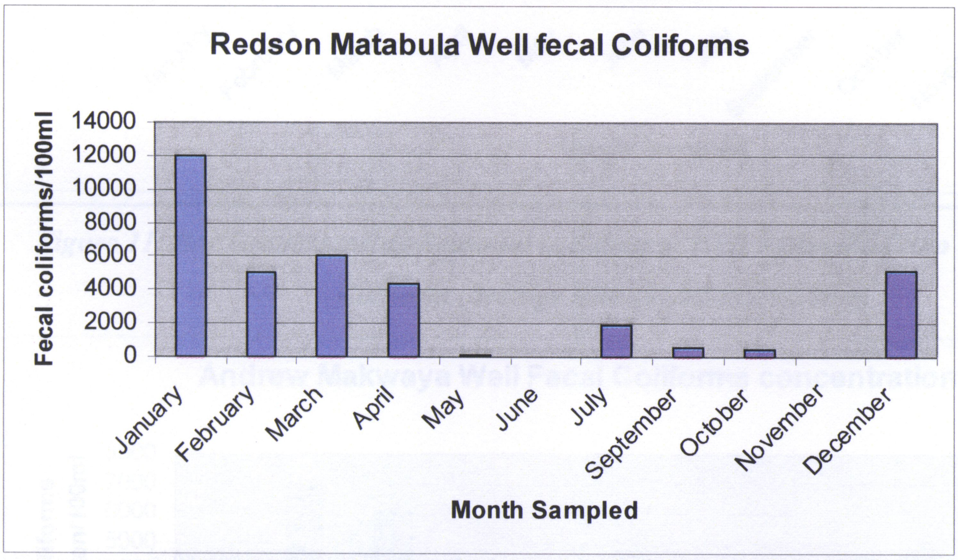

Figure 10: Bar Graph showing Seasonal variation at Well 9 (Redson Matabula's) for Fecal Coliforms (average concentration) #/100ml

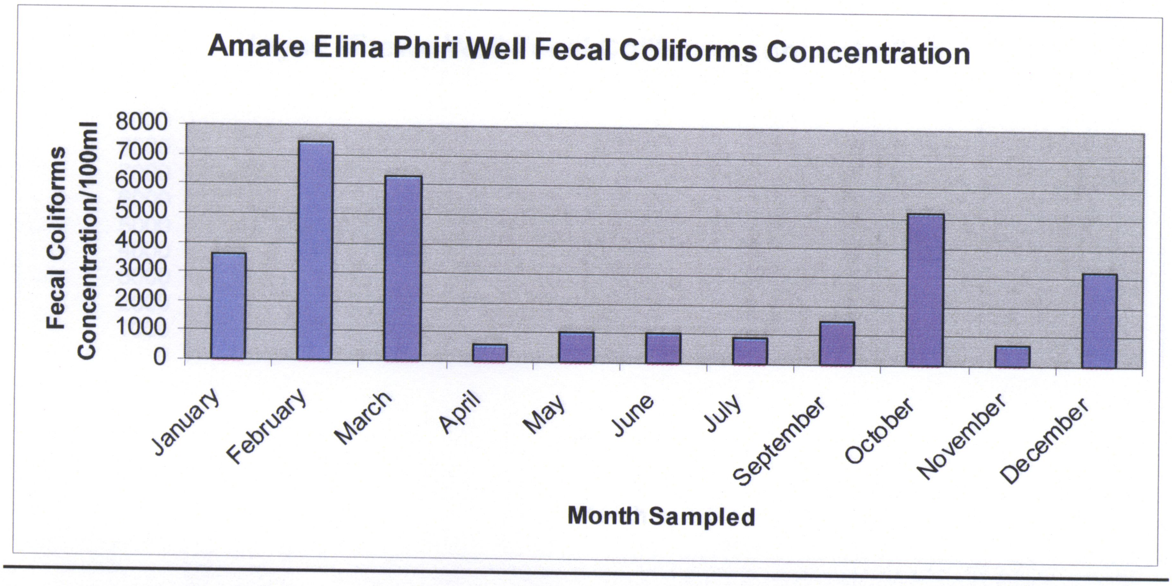

Figure 11: Bar Graphshowing Seasonal variation at Well 5 (Amake Elina Phiri's) for Fecal Coliform (average concentration) #/100ml

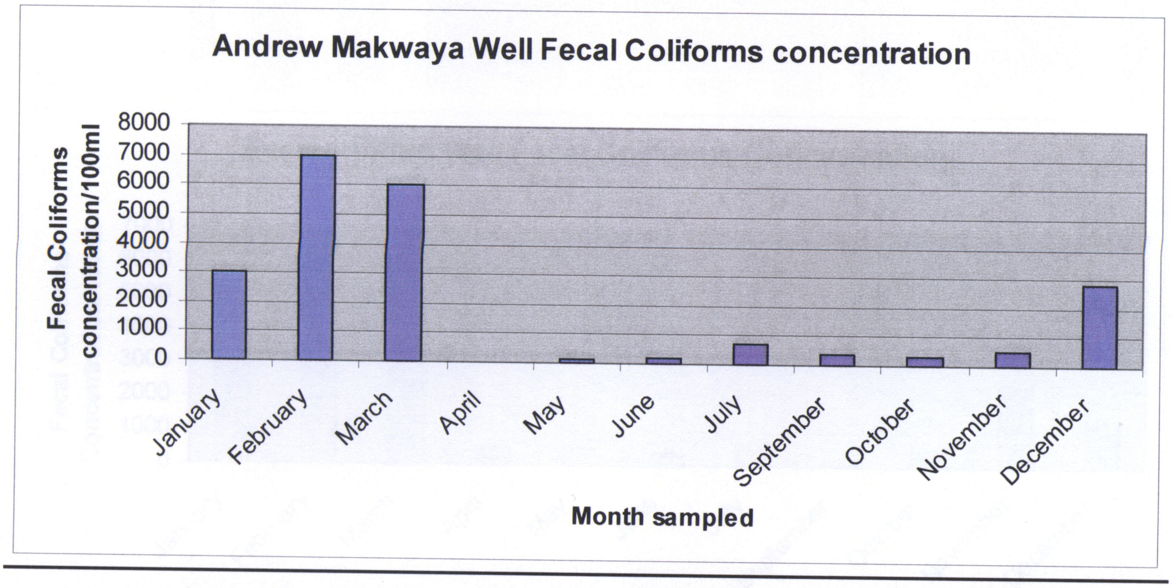

Figure 12: Bar graph showing Seasonal variation at Well 6 (Andrew Makwaya's) for Fecal Coliforms (average concentration) #/100ml

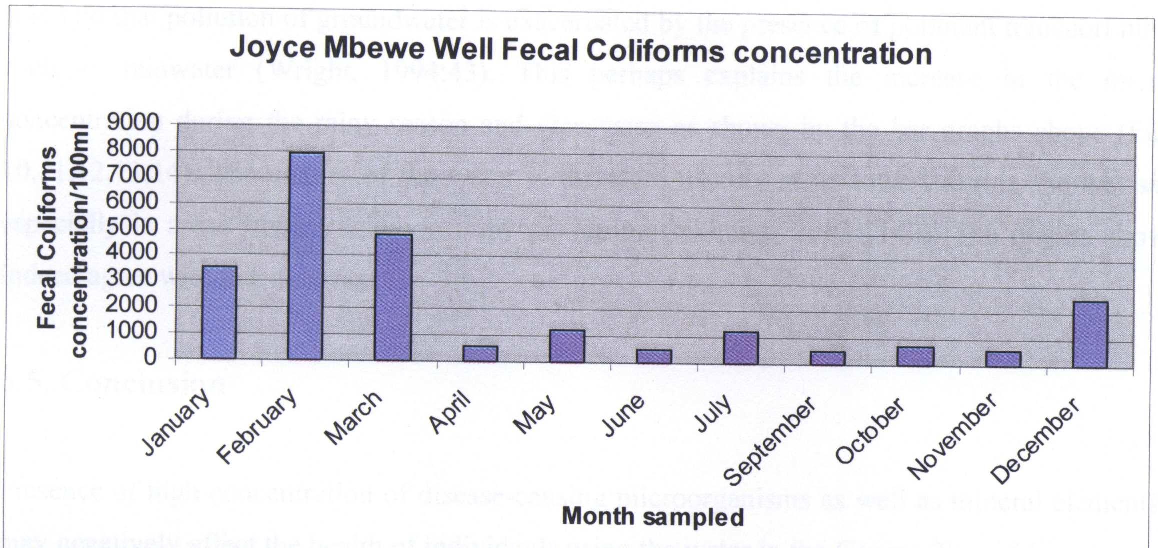

Figure 13: Bar graph showing Seasonal variation at Well 7(Joyce Mbewe's) for Fecal Coliforms (average concentration) #/100ml

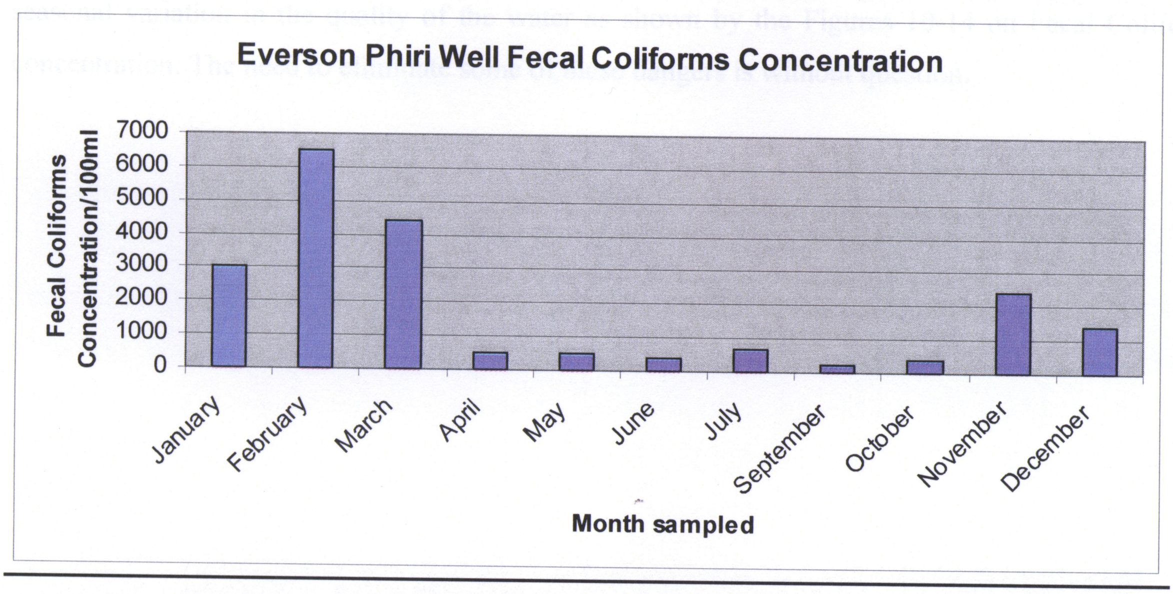

Figure 14: Bar Graph showing Seasonal variation at Well 4 (Everson Phiri's) for Fecal Coliforms #/100ml (average concentration #/100 ml).

It is said that pollution of groundwater is exacerbated by the presence of pollutant transport medium such as rainwater (Wright, 1994:43). This perhaps explains the increase in the microbial concentration during the rainy season and vice versa as shown by the bar graphs above (Figures 10,11,12,13,14). The quality of the water is therefore usually at its lowest during the wet season especially in areas where sanitation is by pit latrine (Nkhuwa, 2003:1142). The graphs above do indeed agree with this assertion.

6.5. Conclusion

Presence of high concentration of disease-causing microorganisms as well as mineral elements that may negatively affect the health of individuals using the water in the George Township area, poses a serious challenge to the community as well as government. The need to alleviate these problems cannot be overemphasized. The population in George Township is therefore at great risk of disease outbreaks especially related to the poor microbiological quality of the water. Other diseases would be those related to Cadmium, Lead as well as Nitrates concentration. There is also an observed seasonal variation in the quality of the water as shown by the Figures 10-14 on Fecal Coliforms concentration. The need to eliminate some of these dangers is without question.

CHAPTER 7: CONCLUSIONS & GENERAL RECOMMENDATIONS

7.1. Introduction.

The study area is very rich in groundwater resources which are found very close to the surface. The deepest level for the water table observed during the sampling exercise was at less than five metres during the driest time of the period. Digging to access this resource does not require a lot of effort and cost. The ease with access to groundwater as well as other factors related to the restrictive supply of the good quality water may be at the centre of influencing the communities into increased use of such methods to obtain water supply whether safe or not. The presence of water near the surface also provides an increased access by pollutants from wastes dumped on the ground surface as well as from other waste disposal facilities like pit latrines which are the major method in the disposal of human excreta in the area. The use of shallow wells as a source of water has therefore been on going for a long time. However, despite the new and modern infrastructure built to assist in reducing the diarrhoeal disease burden which has been experienced for a long time now, this source continues to be the most reliable and important supply due to various reasons. If the findings from the above study are anything to go by, the danger of disease outbreaks is real and not imaginary.

7.2. Observations.

The more than one percent of a sample of 350 persons interviewed during 2001 (WARFSA supported research project) that were seen to be entirely depended on water from shallow wells are people at greatest risk. Those that may use such water for bathing and washing could also be at risk of picking up some of these health hazards. This by implication means that about 99% or more of the people in George Township area are at risk one way or the other as there is rampant use of water from shallow wells in domestic applications such as washing of clothes, washing of utensils, etc. as a fall back strategy. This is despite the fact that communities are aware of the dangers associated with use of such water. Some of the reasons advanced by the communities include the payment of the fees slapped on supply as well as the rationing of supply of the commodity that is apparently being implemented in the area. There are clear indications that there is definite contamination of groundwater from the pit latrines which are the major method of disposal of fecal matter. This is seen by the high levels of coliform bacteria including ***Escherichia coli (E. coli)*** which usually inhabits guts of mammals. Fecal contamination is a reality. The bacteriological quality of the water apparently changed with seasons as shown by the higher Fecal Colifoms count per 100 ml during the wet season and a reduced level during the dry season (see Figures 10-14). The disease burden due to poor quality water (bacteriological) could be apparently high. This is exacerbated by the apparent high Cadmium, Lead and Nitrate concentrations which may result in various health problems. The need to re-look at the water from the wells in this area to confirm some of these findings especially with regard to heavy metal contamination is necessary.

7.3. Recommendations.

With an apparently very high bacteriological contamination of the water, it is clear that there are serious health implications on the people as they continue to use the water from the shallow wells in George Township if this is used without being treated. Further, there is need to ensure that the resource is also protected. It is in this regard that some recommendations on treatment of water at household level as well as those related to resource protection are being presented.

7.3.1. Treatment options at household level

There are various options to treat water with bacteriological contamination at household level and make it safe to drink. For example, water could be treated by adding two teaspoonfuls of a bleach such as Jik to a 20 litre bucket of water and letting it remain for thirty minutes before being utilised (DWAF,DH,WRC, 1998:50). However, with high turbidity levels observed in the water from shallow wells in George Township, addition of bleach or chlorine would prove less effective and the microorganisms would therefore survive the treatment (DWAF,DH,WRC, 1998:50). Reduction in the turbidity of this water would therefore be an essential step before addition of the bleach. Use of plant material such as powder from the ***Moringa oleifera*** Lam seeds which has been proved effective as a coagulant would go a long way in reducing the turbidity of the water from the shallow wells. It has been proved beyond any reasonable doubt that powder from ***Moringa oleifera*** Lam seed can replace the Aluminium sulphate or alum-a chemical very essential in water treatment (Sutherland *et al.*, 1994:297; NISIR Annual Report 2006). In experiments conducted at water works in Thyolo Southern Malawi, it was found that ***Moringa oleifera*** Lam seed powder was able to reduce turbidities of about 400 NTUs to below 4 NTUs (Sutherland *et al*., 1994:298). In the same study, it was observed that 75 mg/l of ***Moringa oleifera*** seed powder (***see plates 16, 17, 18***) was able to perform equal to 50 mg/l of alum (Sutherland *et al*., 1994:298).

Plate 16: Fresh and dry *Moringa oleifera* pods

In laboratory experiments in Zambia, ***Moringa oleifera*** was able to reduce turbidities as well as bacteriological concentration by about 98 percent (NISIR Annual Report 2006).

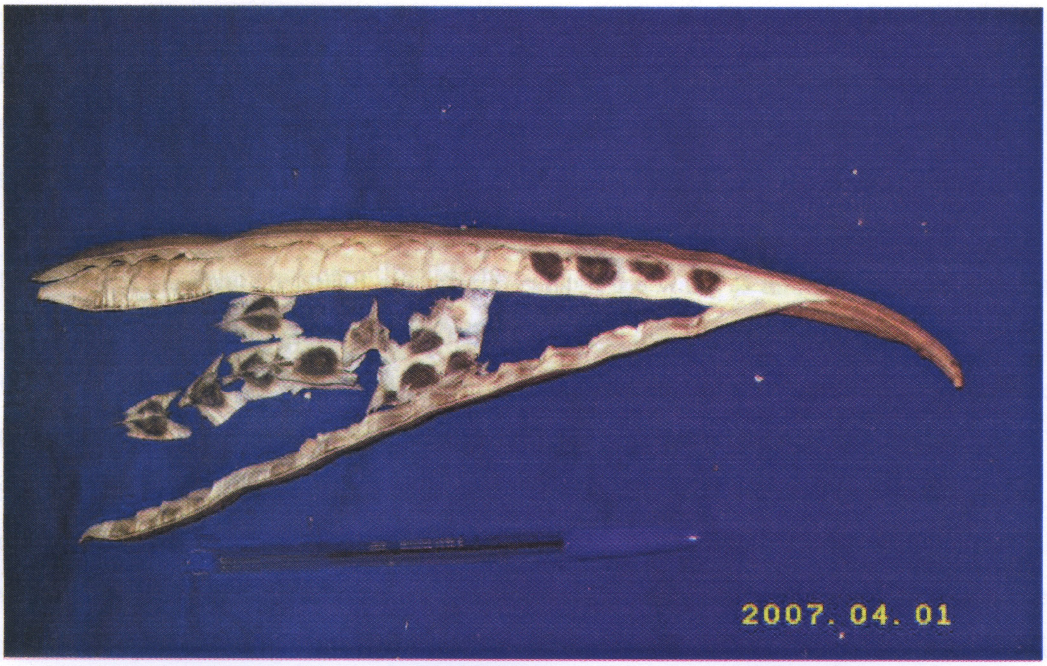

Plate 17: Split Moringa pod with seeds showing

This was when two teaspoonfuls of powder was mixed with 20 litres of water and allowed to settle for about two hours and the water later decanted.

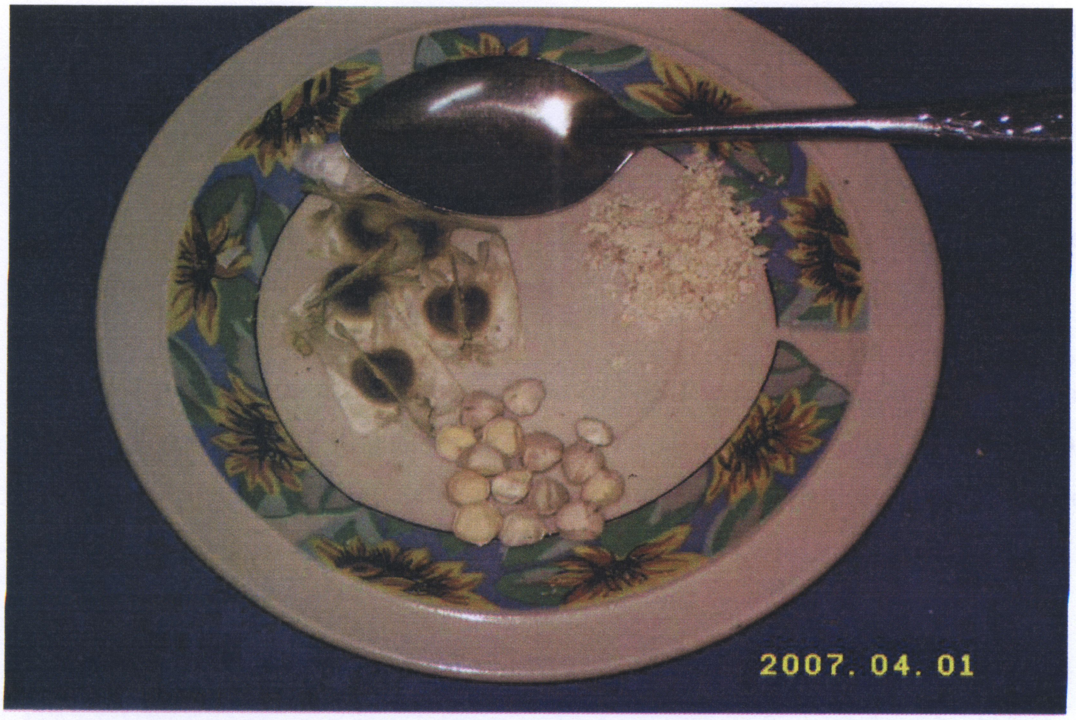

Plate 18: Moringa oleifera unshelled and shelled seeds as well as powder

It can therefore be suggested that ***Moringa oleifera*** seed powder would be mixed with water at the levels described and allowed to settle for about two hours and later decanted before bleach is added to the water. This would to some extent, ensure elimination of microorganisms from the water thereby making it safer to drink.

Use of ceramic filters to strain out microbes from the water is another method that could be used to provide wholesome potable water to the George Township community. Ceramic filters are made from various ceramic materials including clay. Fine pores in the ceramic body are used as channels through which water passes thereby leaving larger particles strained out. These filters have different shapes and sizes. Some filters are long columns through which water passes and the filtrate is collected at the bottom. Others may be in form of pots in which raw water is put and filtered through with the filtrate being collected at the bottom. It has been estimated that some ceramic filters produced by the Potters for Peace are able to remove 99.88% of most water borne disease causing microorganisms (**http://www.potpaz.org/pfpfilters.htm**). NISIR has also been involved in the development and production of ceramic water filters from local clays. The filter is in form of a candle with a hollow middle but closed at one end (***plate 19 page 96***). Water passes through the tiny pores of the filter candle thereby straining the bacteria and other microorganisms together with the suspended materials. At a throughput of 1.5 litres/hour, for each filter candle and bacteriological removal efficiency of about 98%, there would be enough good quality water for a family using such an assembly of filter candles (***Plates 19 & 20 page 96***) produced by NISIR (NISIR Annual Report 1996). This could also be supplemented with the use of bleach or chlorine to complete the process of disinfection.

In 1996, forty (40) filter assemblies produced by NISIR were tested in the Development Aid from People to People (DAPP) Malambanyama Children's Town in Zambia's Chibombo District North East of Lusaka and proved effective in dealing with issues of improvement in the quality of the water supplied to the communities (NISIR Annual Report 1996).

Plate 19: Ceramic water filter candle produced by NISIR

Ceramic water filters coated with silver are said to perform even better in the straining of bacteria and other microorganisms as well as suspended solids from water. Silver is said to act as a bacteriostasis medium (**www.who.int/household_water**) hence its increased efficiency in removal of these microbes.

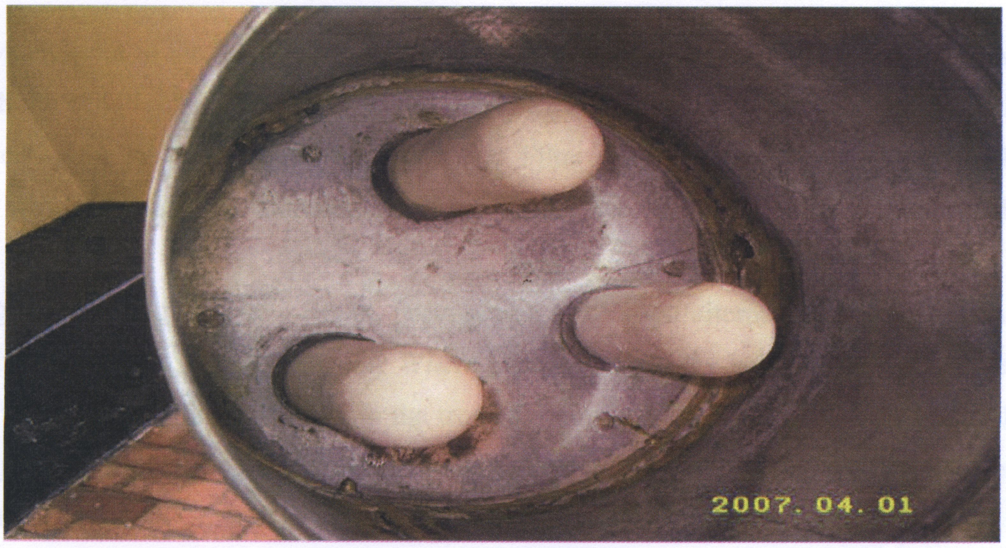

Plate 20: Ceramic Water filter candles fitted in an assembly mounted in the top container

However, there is need to frequently clean the filters to unclog them as well as to ensure that there is no bacterial growth in order to ensure their continued performance and efficiency (**www.who.int/household_water**). This proven technology could be a great asset to the community of George Township.

Plate 21: Left to right complete filter systems from local artisans to commercial products

Raw water is put in the top container fitted with the filter candles (***Plate 20***) and is allowed to seep through the candles and is collected in the container below. Clean water is then drawn through the tap fitted on the lower container (***see Plate 21)***. Filter candles could also be packed with activated carbon which can act as an additional purifier medium thereby making the water safer to drink.

Boiling of water may to some extent, provide one of the best alternatives to rid drinking water of most disease-causing microorganisms. Where a source of energy is not a problem, water could be boiled using various means. Being in the tropics, Zambia is endowed with a lot of sunshine (Rijal and Fujioka, 2001:155). Use of solar radiation has been found to be effective in the lowering of the numbers of fecal coliforms, ***E coli,*** and other such bacteria (Rijal and Fujioka, 2001:155). In George Township, use of solar water pasteurization systems would be ideal as most people may not afford the cost of fuel to boil their water. A Solar Water Pasteurisation System developed by Professor Eugene Cloete and his students at University of Pretoria has been tried at NISIR in Zambia and found very effective in treating water by way of destroying bacteria through heating. The pasteuriser is made up of a receiver tank and solar panels made of a metal tray and a system of PVC tubing painted back for maximum solar absorption (Plate 22). Raw water is placed into the tank and is allowed to flow through the PVC piping and gets heated as it passes through the tubing. The treated water rises to a storage reservoir where it is drawn through a tap. The water is heated to a temperature of at least 60 degrees Celsius which is adequate to kill most of the bacteria.

Other heating devices may include solar cookers that may be used to boil the water to kill the bacteria. Some of these devices are made of mirrors or silver paper arranged in a parabolic fashion which is used to trap the solar radiation and concentrate it to a point. A pot put in an area with the maximum concentration of the radiation will be heated to the critical temperature of 60 degrees Celsius or higher which may result in about 99% efficiency in the inactivation of fecal coliforms within 2 to 5 hours of exposure (Rijal and Fujioka, 2001:155). Water put into such a pot will be boiled thereby killing most of the bacteria.

Boiling may not be completely effective against some bacteria including spores of ***cryptosporidium*** species (Rijal and Fujioka, 2001:158). It has been established that Ultra Violet (UV) radiation can be used to kill bacteria. This is especially true of UV-B and UV- C with the range of wavelengths of between 200 to 310nm (LeChavellier and Au, 2004:58). It is said that the thymine bases on the DNA and RNA react with the UV light to form dimers thereby inhibiting transcription as well as replication of the bacteria (LeChavellier and Au, 2004:58). This may be done without necessarily having to raise the water temperature to the 60 degrees Celsius critical point (Rijal and Fujioka, 2001:156). Use of Ultraviolet (UV) light may therefore also be another method for disinfection of the water in George Township. It is said that UV light inactivates microorganisms as a result of reactions with the nucleic acids of the microbes (LeChavellier and Au, 2004:58). ***Cryptosporidium*** is one such group of microorganism that UV light is reported to be very effective against (LeChavellier and Au, 2004:59). In this regard, UV light could be fitted in a room and water could be exposed to the light for a period of time to have it sterilised. Exposure to normal sunlight could also be done especially if the water is put in clear plastic bottles and left in the sun. The UV radiation from the sun may thus treat the water. However, a combination of heat and UV treatment is found to be more efficient and effective against bacteria (Rijal and Fujioka, 2001:161) However, there may be need to reduce the turbidity of the water so as to make the disinfection using UV radiation more effective (LeChavellier and Au, 2004:61) and ***Moringa oleifera*** Lam could be the answer.

Plate 22: A Solar Water Pasteuriser Panel

In order to assist alleviate possible problems of methaemoglobinaemia in infants due to the high Nitrate concentration in drinking water , provision of Vitamin C supplementation apart from vitamin C rich diets, may prevent the problem occurring in children (DWAF, 1996: 109)

7.3.2. Options for resource conservation and improvement

Finding ways of reducing groundwater contamination would go a long way in reducing this problem. One such a way is through ensuring that all pit latrines being constructed in the area are fully lined and have their bases completely sealed to avoid leakage of human wastes and with it nutrients and dangerous microbes into groundwater. The need to construct latrines in accessible places so that vacuum tankers can easily reach them when required to take away the wastes when these latrines are filled, cannot be overemphasized. This would also reduce in the continuous digging of latrines in the limited land space which leads to reuse of the spaces which can also result in exposure to hazardous materials including eggs of parasitic flat and round worms which may survive over long periods of time. Use of hand drawn tankers for the purposes of removal of liquid wastes from the latrines in these overcrowded areas could also be considered.

Another possibility is the use of portable latrines that can be carried away once filled and their contents disposed off in a more sanitary manner. This could be another way of fecal disposal that could be implemented by the communities in the area. These latrines may be secured by individuals or family groups that could either hire them or outright purchase such which would then be cleaned every now and then whenever they are filled up. However, problems of acceptance of such technology may need to be considered before its introduction.

The use of the ecological sanitation systems may also be considered as an ideal arrangement in the area. Material recovery and recycling is an important aspect that is involved the principles of ecological sanitation system. This is one recommended method for waste reduction after it has been generated (Feachem *et al.,* 1977:68). The issue involves closing the loop whereby waste is reused for other purposes (Esrey *et al*., 1998:4). For example, use of the urine diversion toilets which separates urine from fecal matter would go a long way in ensuring that the material does not get into the water system. In this regard, the fecal matter would be composted without getting wet with urine. The smell nuisance is therefore minimised through this separation. The urine which is rich in phosphorus is a good source of this plant nutrient (P). After a period of one year or more, the fecal matter could be used as manure (Esrey *et al*., 1998:5). The urine would be used directly in irrigating vegetables or other crops and plants including flowers around the homes immediately after being collected. The dry fecal matter would with certainty, be easier to dispose off without much impact on the groundwater system. The material as earlier indicated would however be used as manure for the gardens upon complete decomposition and most microbes would then have been eliminated from it. Acceptance of such technologies would require investigation and thorough evaluation coupled with a consistent education campaign. Working with the Water Supply and Sanitation Council (NWASCO) to look at the changes in the design of sanitation facilities as well as monitoring the quality of the water especially in informal/unplanned settlements could go a long way to ensure that progress is made to reduce pollution of groundwater.

Consideration could also be given to the lowering of the water table to depths where latrine leakages cannot reach. This could be through pumping out of the water from the area thereby dropping the level to keep it at depths of at least twenty (20) metres at all times. The water so pumped could be used for irrigation in the Kasupe area farming block not far away from the area. This water may also be treated and then supplied to other places within the city including George itself where inadequate supply is experienced. However, this needs careful assessment in order to avoid any ecological/environmental disturbances that may arise from such an action.

Education for the communities as regards waste disposal especially fecal matter would go a long way in ensuring that sustainable solutions are found, applied and acceptable to all. For example, the ecological sanitation processes require such an input as communities need to be fully educated on such matters to avoid failure.

Location of settlements in any open spaces whether legally or otherwise needs careful assessment based on informed actions. The need for a hydro-geologist in the city's planning teams seems a reasonable proposition.

Continued and extended water quality monitoring programme in George Township as well as other parts of the city especially in informal/unplanned settlements could be necessary to determine the extent of the pollution in the groundwater regime in Lusaka. This programme could also be extended to other parts of the country.

Salvato says "data of high quality is needed to support enforcement action or to support a health effects strategy" (Salvato, 1982:185). The need to verify some of these findings especially on the Lead and Cadmium concentrations in the water can therefore not be overemphasized. If this is confirmed, then the source(s) of these contaminants may need to be identified and measures to minimize or curb the contamination put in place. There could also be need to monitor metal concentrations in blood samples in the George Township population.

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APPENDICES.
1. Letter to LCC.

10th February 2006

The Town Clerk
Lusaka City Council
Civic Centre
LUSAKA

Dear Sir,

RE: WATER QUALITY ASSESSMENT OF SHALLOW WELLS IN GEORGE AREA

The National Institute for Scientific and Industrial Research would like to carry out a small project on water quality assessment of shallow wells in the George-Lilanda area as a student project. The assessment will be carried out over a period of six or so months in which both physical-chemical and microbiological sampling and analysis of the water will be done.

As an important partner and stakeholder in this regard, we write to ask for your participation in the exercise which we consider could add to the available information on this subject matter. Provision of information on previous work that was done in the said area could also go a long way in assisting this exercise.

Thanking you in anticipation.

Yours faithfully

NATIONAL INSTITUTE FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Chitaku G. Mucheleng'anga
FOR/EXECUTIVE DIRECTOR

2. FIELD DATA SHEET

Well NO.	Well name	Sample Id.
…………	……………….	…………….
Latitude: dd/mm/ss	Longitudes dd/mm/ss	Air temperature
S… ^{0}…… '……"	E … ^{0}…… '……"	………………..

Date of sampling …………Time of sampling……… Sampled by…………………

Time	Water Table depth	Water Temp(^{0}C)	EC (µS/cm)	pH	Eh (mV)	O_2 (mg/l)	O_2 (% mg/l)

On site observations

Odour Present ☐
Absent ☐

Normal ☐
Abnormal ☐

Appearance of the water…………………………..

Preservative added……….Yes ☐ No ☐

Name of Preservative added………………………………
Rainfall figures (if available)……………………

Weather………Sun ☐ Rain ☐ Clouds ☐ Wind ☐

General Notes/other observations……………………………………………………..
……………………………………………………………………………………………

3. Parameters Observed

PARAMETER
Water table depth
Temperature (^0C)
EC(uS/cm)
Eh(mV)
pH
Arsenic (Mg/l)
Total Dissolved Solids (Mg/l)
Turbidity (NTU)
Sodium (Mg/l)
Cadmium (Mg/l)
Fluoride (Mg/l)
Total Hardness (as Mg $CaCO_3$/l)
Potassium (Mg/l)
Iron (Mg/l)
Ammonia (as NH_4^-NMg/l)
Zinc (mg/l)
Chlorides (mg/l)
Nitrites (as NO_2^-Nmg/l)
Nitrates(as NO_3^-Nmg/l)
Lead (mg/l)
Total Phosphates (mg/l)
Magnesium(mg/l)
Calcium (mg/l)
Manganese (mg/l)
Bacteriological
Total coliforms
Faecal coliforms
E coli

4. COMPILED SITE BY SITE LABORATORY RESULTS.

WATER QUALITY OBSERVATIONS IN SHALLOW WELLS

SITE NAME: REDSON MATABULA

HOUSE NUMBER: 184/22
GPS LOCATION: S 15 22 43.3 E 28 14 36.8

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	1.56	1.54	1.60	1.59		2.13	2.48	2.05	2.53	2.03	1.73	1.82	
Temperature (^{0}C)	23.5	21.8	20.5	21.2		21.2	24.3	25.1	25.10	24.3	23.7	24.1	
EC(uS/cm)	1367	1870	825	1304		1632	1472	294	399	1229	1029	790	
Eh(mV)	-24	-18	-39	-29		-30	16.5	-24	-40	-22	21	13	
pH	7.02	6.56	7.5	7.34		7.3	7.11	7.5	7.88	7.85	7.47	8.02	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	1,620	1,220	490	1,170		1,054	1,155	409	436	729	735	552	
Turbidity (NTU)	1.00	0.53	0.94	0.47		13.2	43.10	2.02	128	0.68	0.65	1.16	
Sodium (mg/l)	153.86	137	49.39	103		53.16	69.7	19.31	18.1	38.60	50.87	43.59	
Cadmium (mg/l)	0.013	<0.002	<0.002	0.004		0.008	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.11	0.06	0.14	0.33		0.16	0.11	0.12	0.14	0.09	0.18	0.42	
Total Hardness (as mg $CaCO_3$/l)	1,052	750	348	800		488	296	230	376	290	344	350	
Potassium (mg/l)	63.96	40.35	23.59	32.72		34.16	28.5	33.66	25.0	18.61	12.22	11.86	
Iron (mg/l)	<0.01	<0.01	0.81	<0.01		<0.01	0.44	<0.01	0.07	<0.01	0.08	0.29	
Ammonia (as NH_4^-Nmg/l)	0.04	0.22	0.07	<0.01		0.08	0.15	0.07	<0.01	0.05	0.13	0.05	
Zinc (mg/l)	0.021	0.015	<0.001	0.038		0.006	0.006	<0.001	0.008	<0.001	<0.001	<0.001	
Chlorides (mg/l)	358	290	45.0	130		167	132	38	32	100.0	90	50	
Nitrites (as NO_2^- N mg/l)	0.139	0.145	0.054	0.126		0.050	0.109	0.003	0.136	0.078	0.287	0.050	
Nitrates(as NO_3^- N mg/l)	4.11	26.25	38.50	21.04		12.38	16.68	7.48	4.42	36.70	20.20	18.71	
Lead (mg/l)	0.08	0.064	0.422	0.333		*	0.036	0.09	1.50	<0.01	0.10	<0.01	
Total Phosphates (mg/l)	1.23	1.72	1.80	1.78		4.80	1.24	0.09	1.75	0.38	0.84	1.68	
Magnesium (mg/l)	70.08	51.36	23.52	24.00		51.84	30.24	27.84	55.60	15.84	29.79	31.2	
Calcium (mg/l)			100.0	280		108.8	68.0	45.60	57.6	89.6	88.0	88	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	5,200	700	1,300	3,200		1,400	700	300	12,000	1800	5500	10,000	
Faecal coliforms (#/100 ml)	4,400	100	0	1,900		600	400	0	5,200	12000 *	5000	6000	
E coli (#/100ml)	1,200	40	0	620		3	8	0	1,300	180	2100	2000	

SITE NAME: TITUS NDUMO

HOUSE NUMBER:255/12
GPS LOCATION: S 15 37 91.6 E 28 24 55.8

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	0.28	0.30	0.46	0.38		0.80	1.31	1.45	1.36	0.4	0.37	0.48	
Temperature (^0C)	25	20.8	19.4	19.4		20.2	23.6	24.5	24.4	24	23.4	24.0	
EC(uS/cm)	2010	1830	212	1103		1800	1897	203	195	2090	2060	2030	
Eh(mV)	-29	-17	-18	-16		-19	-12.3	-4	-7.0	-10	41	36	
pH	7.09	6.55	7.14	7.13		7.16	7.04	7.03	7.26	7.64	7.12	7.63	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001*	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	1,510	1,340	1,291*	2,200		1,253	1,490	1,300	1,291	1256	1485	1450	
Turbidity (NTU)	1.73	3.99	0.66	0.62		1.09	4.48	2.97	1.8	0.65	2.05	0.96	
Sodium (mg/l)	98.32	136	109.85	131		62.06	82.8	20.82	89.0	129.77	108.58	109.97	
Cadmium (mg/l)	0.013	<0.002	0.015	0.007		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.13	0.12	0.21	0.18		0.14	0.13	0.18	0.17	0.16	0.21`	0.51	
Total Hardness (as mg $CaCO_3$/l)	808	890	768.0	1,990		624	354	608	780	492	808	710	
Potassium (mg/l)	47.96	27.15	27.15	30.12		32.36	30.3	50.42	49.0	28.12	16.62	18.07	
Iron (mg/l)	<0.01	<0.01	0.18	0.31		<0.01	0.03	<0.01	<0.01	<0.01	0.21	0.21	
Ammonia (as NH_4-N mg/l)	0.04	<0.01	0.21	2.30		1.34	1.92	3.66	1.70	1.25	1.38	0.99	
Zinc (mg/l)	0.03	0.022	<0.001	0.027		0.008	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	250	242	225.0	250		192	170	240	190	210.0	135	230	
Nitrites (as NO_2^- N mg/l)	0.184	0.177	0.195	0.243		0.158	0.266	0.231	0.434	0.156	0.130	0.401	
Nitrates(as NO_3^- N mg/l)	7.12	34.50	42.50	18.12		6.36	14.38	20.98	32.80	39.95	18.18	23.28	
Lead (mg/l)	0.06	0.001	0.753	0.385		*	0.055	0.10	2.10	<0.01	0.17	<0.01	
Total Phosphates (mg/l)	2.86	1.44	3.08	3.88		6.56	1.29	0.56	1.45	0.48	1.09	2.74	
Magnesium(mg/l)	44.16	7440	62.40	334		34.56	27.36	74.40	68.16	19.68	96.00	43.2	
Calcium (mg/l)			203.2	240		192.0	96.0	119.20	198.4	156.0	163.2	212	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	6,500	2,800	9.600	3,000		6,400	500	2,700	9,300	2100	9800	10500	
Faecal coliforms (#/100 ml)	5,200	2,300	7,00*	900		800	100	500	4,300	900	9200	10000	
E coli (#/100ml)	2,000	1,900	200	350		10	0	100	1,500	100	3000	400	

SITE NAME: FELIX TEMBO

HOUSE NUMBER: 176/8
GPS LOCATION: S 15 22 43.7 E 28 14 26.7

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	2.79	2.95	3.27	3.08		3.69	4.22	4.53	4.59	3.54	3.26	3.35	
Temperature (^{0}C)	25	23.7	23.1	22.8		23.0	24.4	24.5	24.8	24.6	24.3	24.8	
EC(uS/cm)	1827	1840	1632	1676		1840	1343	1274	1218	1218	1445	1499	
Eh(mV)	-20	-8	-16	-14		-22	-5.7	-10	-14	-10	41	34	
pH	6.94	6.43	7.15	7.10		7.21	6.93	7.27	7.43	7.64	7.13	7.66	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	1,338	1,128	998	1,066		967	1,040	801	834	715	1034	1050	
Turbidity (NTU)	0.85	0.45	4.08	0.22		0.82	0.25	3.16	0.8	0.33	0.74	0.63	
Sodium (mg/l)	91.33	118	84.19	108		39.08	50.7	45.05	43.5	40.91	72.08	79.97	
Cadmium (mg/l)	0.008	<0.002	0.110	0.003		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.16	0.16	0.13	0.41		0.22	0.09	0.16	0.16	0.18	0.31	0.38	
Total Hardness (as mg $CaCO_3$/l)	776	870	692	790		520	280	422	520	298	488	450	
Potassium (mg/l)	47.10	27.71	23.22	26.13		27.01	22.0	35.73	34.0	18.06	13.47	15.31	
Iron (mg/l)	<0.01	<0.01	2.50	<0.01		<0.01	<0.01	<0.01	0.05	0.19	0.22	0.18	
Ammonia (as NH_4^-N mg/l)	1.06	1.76	2.23	1.44		2.01	1.52	1.86	0.10	1.24	1.12	1.00	
Zinc (mg/l)	0.018	0.024	<0.001	0.067		0.009	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	273	240	155.0	190		156	116	120	100	90.0	90	145	
Nitrites (as NO_2^- N mg/l)	0.129	0.324	0.041	0.395		0.042	0.063	0.063	0.080	0.057	0.098	0.068	
Nitrates(as NO_3^- N mg/l)	5.83	32.25	42.50	9.15		17.95	14.40	21.96	27.50	43.20	17.20	7.46	
Lead (mg/l)	0.05	0.078	0.067	0.312		*	0.040	0.12	3.40	<0.01	0.25	<0.01	
Total Phosphates (mg/l)	2.56	0.40	2.75	3.81		5.04	1.15	0.13	0.85	0.22	0.77	0.60	
Magnesium(mg/l)	59.52	96.48	29.28	57.60		79.68	39.84	45.12	42.24	2.88	64.32	43.2	
Calcium (mg/l)			228.0	220		75.2	45.6	93.60	137.6	114.0	88.0	108	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	5,300	900	1,800	1,200		1,400	600	800	8,800	900	9000	7500	
Faecal coliforms (#/100 ml)	3,100	200	200	1,000		400	300	300	3,800	600	7000	5200	
E coli (#/100ml)	1,900	100	0	600		6	0	0	900	48	2000	1800	

SITE NAME: AMAKE MIRRIAM/Ms. ENNIE

HOUSE NUMBER: 192/19
GPS LOCATION: S 15 22 54.5 E 28 14 25.9

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	2.13	2.55	3.27	2.93		4.12	4.9	5.52	5.63	4.10	3.6	3.73	
Temperature (^0C)	23.8	23	23	22.9		22.7	24.1	24.3	24.2	23.8	23.7	24.0	
EC(uS/cm)	1480	1528	1571	1530		1368	1287	1263	1247	1457	1381	1438	
Eh(mV)	-24	-11	-17	-18		-25	-11.2	-12	-11	-15	38	32	
pH	7.01	6.46	7.14	7.15		7.26	7.02	7.32	7.38	7.73	7.18	7.7	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	874	1,038	941	2,082		917	1,005	783	839	772	988	998	
Turbidity (NTU)	0.19	0.99	5.01	0.10		1.52	1.26	1.96	3.2	3.15	0.38	1.37	
Sodium (mg/l)	71.02	103	77.14	99.20		33.84	47.6	41.89	42.0	40.05	66.41	73.76	
Cadmium (mg/l)	0.011	<0.002	0.006	0.033		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.18	0.13	0.15	0.26		0.14	0.10	0.17	0.11	0.14	0.19	0.21	
Total Hardness (as mg $CaCO_3$/l)	552	790	788	1,700		440	288	432	452	492	368	420	
Potassium (mg/l)	14.59	8.11	6.67	7.75		8.21	10.3	18.75	18.0	8.98	6.33	7.67	
Iron (mg/l)	<0.01	<0.01	3.20	<0.01		<0.01	<0.01	0.02	<0.01	0.12	<0.01	0.28	
Ammonia (as NH_4^-N mg/l)	0.07	0.13	0.06	0.11		0.16	1.24	2.32	1.83	1.79	0.06	<0.01	
Zinc (mg/l)	0.023	0.022	<0.001	0.022		0.006	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	158	180	100.0	156		145	108	124	105	102.0	85	135	
Nitrites (as NO_2^- N mg/l)	0.091	0.091	0.073	0.139		0.146	0.199	0.182	0.253	0.105	0.658	0.348	
Nitrates(as NO_3^- N mg/l)	7.33	30.91	29.80	13.85		12.68	15.0	23.90	26.20	40.80	26.14	14.71	
Lead (mg/l)	0.09	0.102	0.182	0.307		*	0.043	0.11	2.40	<0.01	0.09	<0.01	
Total Phosphates (mg/l)	2.01	0.28	2.30	3.81		5.68	1.10	0.16	1.35	0.15	0.76	0.74	
Magnesium(mg/l)	15.36	79.20	99.84	295		40.32	42.24	49.92	31.68	22.08	34.77	7.2	
Calcium (mg/l)			148.0	188		108.8	44.8	89.60	128.0	160.0	84.8	156	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	1,100	1,100	1,300	500		400	100	1,800	7,700	1000	8400	10000	
Faecal coliforms (#/100 ml)	400	200	200	200		200	0	700	3,800	800	6200	4200	
E coli (#/100ml)	120	100	100	100		0	0	200	1,200	56	3100	1800	

SITE NAME: AIBAKI LUNGU

HOUSE NUMBER: 194/5
GPS LOCATION: S 15 22 54.7 E 28 14 23.3

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	1.2	1.65	2.49	2.06		3.30	4.3	4.83	5.01	3.31	2.80	2.88	
Temperature (^0C)	23.5	22.8	22.3	22.0		22.2	23.6	23.6	23.6	23.5	23.5	24.6	
EC(uS/cm)	1150	1326	1362	1262		1182	1200	1215	1137	804	1000	957	
Eh(mV)	-39	-21	-29	-27		-28	-22.1	-19	-20	-31	16	13	
pH	7.26	6.62	7.35	7.31		7.31	7.20	7.45	7.54	8.01	7.55	8.01	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	675	836	779	1,121		806	955	742	771	431 433	585	677	
Turbidity (NTU)	2.53	0.11	4.96	0.13		0.81	0.56	2.23	1.5	37.6 124	3.01	3.02	
Sodium (mg/l)	66.97	92.59	67.49	88.30		28.57	45.2	39.97	44.6	33.67 33.25	55.90	118.45	
Cadmium (mg/l)	0.010	<0.002	0.013	0.026		0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.23	0.12	0.18	0.15		0.16	0.14	0.16	0.14	0.18 0.22	0.20	0.40	
Total Hardness (as mg $CaCO_3$/l)	392	600	612	590		496	238	352	516	250 290	388	370	
Potassium (mg/l)	33.04	15.07	10.24	12.14		10.76	10.4	17.45	27.0	18.19 15.52	11.88	13.14	
Iron (mg/l)	<0.01	<0.01	4.25	<0.01		<0.01	0.01	<0.01	0.09	0.11 0.07	0.46	0.26	
Ammonia (as NH_4^+N mg/l)	0.07	0.02	0.01	0.07		<0.01	0.21	0.18	0.52	0.56 0.51	1.68	1.98	
Zinc (mg/l)	0.020	0.021	<0.001	0.021		0.005	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	120	145	220.0	130		122	106	114	100	70.0 62.0	60	125	
Nitrites (as NO_2^- N mg/l)	0.648	0.047	0.038	0.038		0.046	0.087	0.044	0.920	1.065 1.090	0.314	0.282	
Nitrates(as NO_3^- N mg/l)	7.16	26.10	32.85	21.55		22.20	13.94	20.66	16.58	8.25 7.68	25.02	28.43	
Lead (mg/l)	0.05	0.086	0.457	0.169		*	0.045	0.10	2.90	<0.01	0.07	<0.01	
Total Phosphates (mg/l)	1.22	0.52	2.12	1.26		5.10	1.12	0.06	1.80	0.63 0.75	1.38	0.34	
Magnesium(mg/l)	0.96	48	67.20	48.00		30.72	23.04	32.16	47.04	28.80 45.6	67.20	40.8	
Calcium (mg/l)			132.0	156		147.2	56.8	87.20	128.0	52.0 40.0	43.2	80	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	2,000	900	700	4,000		500	500	400	9,400	8500 900	7400	8000	
Faecal coliforms (#/100 ml)	1,000	300	300	3,800		100	300	100	5,500	700 8400	5000	7700	
E coli (#/100ml)	800	100	100	480		0	5	0	1,800	428 98	1800	7600	

SITE NAME: PETER MWIINGA

HOUSE NUMBER:303/19
GPS LOCATION: S 15 23 05.3 E 28 14 25.1

	1	2	3	4	5	6	7	8**	9***	10	11	12	
PARAMETER													
Water table depth in metres	1.93	2.41	2.8	2.6		3.27	3.74	3.96	4.10	2.42	2.1	2.34	
Temperature (^{0}C)	23.5	23.1	21.9	22.0		21.2	23.6	25.8	24.3	24.2	24.6	24.6	
EC(uS/cm)	1301	1108	1087	1056		942	966	914	833	864	850	897	
Eh(mV)	-24	-13	-29	-27		-41	-11.0	-30	-25	-21	25	22	
pH	7.04	6.50	7.35	7.3		7.53	7.01	7.59	7.64	7.86	7.42	7.87	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	728	720	642	1,956		640	770	551	520	209	598	636	
Turbidity (NTU)	0.25	0.55	8.16	0.44		1.07	1.63	4.41	0.8	1.67	0.33	0.78	
Sodium (mg/l)	57.19	78.05	54.11	74.50		20.62	28.8	35.53	23.0	23.55	41.68	67.23	
Cadmium (mg/l)	0.011	<0.002	0.003	0.034		0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.17	0.06	0.14	0.10		0.18	0.15	0.16	0.18	0.14	0.14	0.55	
Total Hardness (as mg $CaCO_3$/l)	524	640	560	1,390		384	234	286	424	270	280	460	
Potassium (mg/l)	11.65	6.63	4.17	5.32		2.01	1.5	10.31	7.0	6.33	4.41	5.90	
Iron (mg/l)	<0.01	<0.01	6.99	<0.01		0.05	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	
Ammonia (as NH_4^+N mg/l)	0.01	0.33	0.02	<0.01		<0.01	0.29	1.96	<0.01	<0.01	0.06	<0.01	
Zinc (mg/l)	0.019	0.013	<0.001	0.017		0.005	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	108	130	82.0	100		85	74	92	45	50.0	75	55	
Nitrites (as NO_2^- N mg/l)	0.026	0.014	0.009	<0.01		0.010	0.254	0.056	0.290	0.031	0.016	0.016	
Nitrates(as NO_3^- N mg/l)	8.14	27.85	18.16	20.26		23.70	7.01	1.50	4.26	9.92	6.11	10.69	
Lead (mg/l)	0.05	0.060	0.136	0.263		*	0.041	0.11	2.70	<0.01	0.15	<0.01	
Total Phosphates (mg/l)	1.31	0.76	1.89	0.64		3.72	1.08	0.24	1.05	0.21	0.70	0.06	
Magnesium(mg/l)	15.36	59.52	48.00	239		67.20	9.60	29.28	35.52	9.12	21.12	43.2	
Calcium (mg/l)			144	168		41.6	77.6	65.60	110.0	92.8	76.8	112	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	2,800	0	2,800	2,200		1,500	100	0	7,200	600	4200	8200	
Faecal coliforms (#/100 ml)	1,100	0	500	2,000		900	0	0	3,600	300	3800	6400	
E coli (#/100ml)	900	0	200	960		0	0	0	800	28	1400	1400	

SITE NAME: EVERSON PHIRI

HOUSE NUMBER:217/23
GPS LOCATION: S 15 23 12.4 E 28 14 19.7

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	1.53	2.23	2.65	2.58		3.29	3.9	4.42	4.54	3.0	2.45	2.49	
Temperature (^{0}C)	25	23.6	23.3	23.1		23.0	24.3	25.1	24.7	24.5	24.4	24.8	
EC(uS/cm)	794	863	732	722		680	682	722	698	727	830	835	
Eh(mV)	-44	-27	-36	-35		-41	-27.2	-28	-21	-32	19	17	
pH	7.44	6.78	7.43	7.44		7.52	7.28	7.58	7.57	7.97	7.53	7.92	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	570	620	416	640		425	530	397	379	442	637	588	
Turbidity (NTU)	0.56	0.28	7.73	0.16		1.27	0.60	2.86	14.1	1.87	0.57	0.58	
Sodium (mg/l)	39.14	55.99	35.19	53.30		13.06	17.8	15.97	15.1	16.65	35.06	47.33	
Cadmium (mg/l)	0.007	<0.002	0.009	0.030		0.005	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.18	0.08	0.16	0.19		0.16	0.11	0.14	0.14	0.18	0.30	0.28	
Total Hardness (as mg $CaCO_3$/l)	364	560	360	390		348	190	260	388	320	264	370	
Potassium (mg/l)	10.45	5.96	3.98	4.86		3.89	4.3	6.82	8.0	5.76	4.16	5.67	
Iron (mg/l)	<0.01	<0.01	3.66	<0.01		<0.01	<0.01	<0.01	0.10	<0.01	0.18	<0.01	
Ammonia (as NH_4^-N mg/l)	<0.01	0.02	0.01	0.03		<0.01	0.10	0.06	<0.01	0.02	0.04	0.03	
Zinc (mg/l)	0.02	0.013	<0.001	0.014		0.003	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	55	80	30.0	36		35	37	38	29	30.0	75	50	
Nitrites (as NO_2^- N mg/l)	0.020	0.015	0.006	<0.001		0.007	0.006	0.007	0.038	0.014	0.017	0.006	
Nitrates(as NO_3^- N mg/l)	5.61	9.72	4.11	27.00		2.58	0.84	6.61	4.16	10.26	4.20	12.44	
Lead (mg/l)	0.03	0.045	0.796	0.216		*	0.029	0.09	2.50	<0.01	0.08	<0.01	
Total Phosphates (mg/l)	1.94	1.56	4.11	<0.01		3.00	1.01	0.05	0.50	0.25	0.91	0.92	
Magnesium(mg/l)	3.84	70.08	19.20	24.00		56.64	16.80	33.60	30.72	23.04	26.88	21.6	
Calcium (mg/l)			112.0	116		44.8	48.0	48.0	104.0	89.6	60.8	112	
Manganese (mg/l)	<0.01	<0.01	0.04	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	1,900	1,200	5,200	2,000		400	700	3,800	2,400	3500	7400	9400	
Faecal coliforms (#/100 ml)	500	500	400	700		200	400	2,400	1,400	3000	6500	4400	
E coli (#/100ml)	120	300	66	120		0	0	200	400	91	950	1100	

SITE NAME: ELINA PHIRI

HOUSE NUMBER: 560/22
GPS LOCATION: S 15 23 16.7 E 28 14 10.7

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	45+55*	1.16	2.28	1.6		2.6	3.2	3.64	3.80	1.78	1.23	2.2	
Temperature (^0C)	23.8	22.3	20.02	19.6		18.0	24.6	24.0	24.0	23.1	24.2	23.9	
EC(uS/cm)	655	510	480	563		427	552	539	561	582	585	579	
Eh(mV)	-50	-40	-47	-61		-63	-38.5	-40	-36	-56	16	-6	
pH	7.49	6.94	7.68	7.89		7.92	7.47	7.82	7.81	8.42	7.58	8.29	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	300	612	287	1,420		312	430	330	424	354	427	406	
Turbidity (NTU)	0.14	0.25	0.70	0.54		23.1	18.70	8.93	30.7	2.10	0.27	1.47	
Sodium (mg/l)	26.86	40.04	24.57	39.80		9.77	15.2	13.54	13.4	17.74	31.88	39.55	
Cadmium (mg/l)	0.009	<0.002	<0.002	0.025		0.020	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.13	0.21	0.16	0.14		0.14	0.12	0.14	0.16	0.16	0.27	0.18	
Total Hardness (as mg $CaCO_3$/l)	264	590	274	650		268	160	236	300	230	288	230	
Potassium (mg/l)	3.49	2.12	1.53	1.97		2.14	0.8	5.20	7.0	5.36	2.90	4.61	
Iron (mg/l)	<0.01	<0.01	0.11	<0.01		0.02	0.20	<0.01	0.09	<0.01	<0.01	0.06	
Ammonia (as NH_4^-N mg/l)	0.03	0.09	0.05	<0.01		<0.01	0.38	0.13	<0.01	0.10	0.11	<0.01	
Zinc (mg/l)	0.014	0.013	<0.001	0.018		0.004	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	
Chlorides (mg/l)	25	55	20.0	16		24	26	32	25	43.0	50	35	
Nitrites (as NO_2^- N mg/l)	0.061	0.021	0.022	0.114		0.045	0.089	0.022	0.081	0.073	0.035	0.032	
Nitrates(as NO_3^- N mg/l)	5.62	8.88	7.68	25.10		6.14	2.60	7.25	8.50	28.30	8.71	24.42	
Lead (mg/l)	0.03	0.050	<0.001	0.411		*	0.070	0.08	2.10	<0.01	0.08	<0.01	
Total Phosphates (mg/l)	0.91	0.48	1.41	1.30		3.44	1.01	0.02	1.35	0.19	0.63	1.04	
Magnesium(mg/l)	11.52	95.52	15.36	108		56.64	12.00	31.68	25.92	36.0	24.24	16.8	
Calcium (mg/l)			84.0	80		12.8	44.0	41.60	76.8	32.0	74.8	64	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	1,700	1,700	1,600	1,800		3,200	8,500	900	6,900	4500	9300	9000	
Faecal coliforms (#/100 ml)	600	1,000	1,000	900		1,500	5,200	700	3,200	3600	7400	6300	
E coli (#/100ml)	188	500	10	260		14	400	100	600	96	820	1600	

SITE NAME: ANDREW MAKWAYA

HOUSE NUMBER:17/05
GPS LOCATION: S 15 23 01.4 E 28 13 58.9

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	2.22	2.73	3.11	2.93		3.43	4.32	4.7	4.87	2.79	2.35	2.44	
Temperature (^0C)	25	21.5	20.3	20.4		20.4	23.2	23.2	23.6	22.9	22.8	23.4	
EC(uS/cm)	695	740	715	758		684	655	738	670	736	775	407	
Eh(mV)	-51	-26	-47	-49		-46	-26.7	-33	-29	-26	16	12	
pH	7.47	6.68	7.6	7.67		7.61	7.27	7.72	7.69	7.92	7.57	8.03	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	509	684	420	1,760		454	542	390	924	462	533	544	
Turbidity (NTU)	0.25	0.58	0.51	0.41		0.91	1.33	3.45	10.5	0.92	0.86	0.68	
Sodium (mg/l)	40.74	59.91	38.59	55.94		14.02	18.1	15.49	14.1	18.81	38.85	43.60	
Cadmium (mg/l)	0.007	<0.002	<0.002	0.007		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.19	0.18	0.11	0.42		0.16	0.12	0.16	0.22	0.17	0.42	0.33	
Total Hardness (as mg $CaCO_3$/l)	328	610	400	1,000		336	172	288	360	228	292	380	
Potassium (mg/l)	0.61	0.62	0.63	0.72		0.71	4.4	1.28	3.0	1.26	0.47	0.82	
Iron (mg/l)	<0.01	<0.01	0.16	<0.01		<0.01	<0.01	0.18	0.11	0.03	<0.01	0.13	
Ammonia (as NH_4^-N mg/l)	<0.01	0.01	0.02	<0.01		<0.01	0.13	0.09	<0.01	0.02	0.03	0.03	
Zinc (mg/l)	0.013	0.013	<0.001	0.017		0.003	0.015	<0.01	<0.001	<0.001	Xxx	Xxx	
Chlorides (mg/l)	46	80	40.0	138		41	40	44	35	35.0	25	50	
Nitrites (as NO_2^- N mg/l)	0.006	0.002	0.006	<0.0014		0.003	0.010	0.006	<0.001	0.002	0.009	0.001	
Nitrates(as NO_3^- N mg/l)	6.91	1.20	3.38	10.18		4.20	<0.01	0.77	2.05	2.55	4.26	19.91	
Lead (mg/l)	0.03	0.074	0.116	0.319		*	0.041	0.10	3.20	<0.01	0.12	<0.01	
Total Phosphates (mg/l)	2.12	0.66	3.38	2.36		2.66	0.98	0.11	0.10	0.12	0.94	0.26	
Magnesium(mg/l)	11.52	63.36	40.80	175		53.76	5.28	32.64	24.96	10.56	46.08	28.8	
Calcium (mg/l)			92.0	108		44.8	60.0	60.8	102.4	73.6	40.0	104	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	200	600	800	1,500		400	500	600	4,100	4500	9000	7700	
Faecal coliforms (#/100 ml)	0	100	200	700		400	300	500	2,800	3000	7000	6000	
E coli (#/100ml)	0	50	100	420		7	10	10	400	48	500	2100	

SITE NAME: JOYCE MBEWE

HOUSE NUMBER:175/3
GPS LOCATION: S 15 22 43.2 E 28 14 09.2

	1	2	3	4	5	6	7	8	9	10	11	12	
PARAMETER													
Water table depth in metres	1.34	1.39	1.59	1.48		1.9	2.25	2.52	2.44	1.62	1.56	1.54	
Temperature (^{0}C)		22.5	22.5	22.1		22.5	24.1	24	24.0	23.6	23.4	23.8	
EC(uS/cm)	1333	1368	1348	1360		1339	1313	1349	1314	1369	1348	1355	
Eh(mV)	-22	-05	-17	-19		-20	-9.6	-12	-11	-8	45	39	
pH	6.92	6.68	7.14	7.17		7.18	7.0	7.3	7.38	7.60	7.05	7.57	
Arsenic (mg/l)	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Total Dissolved Solids (mg/l)	960	896	803	1,822		835	1,038	859	371	881	956	969	
Turbidity (NTU)	0.36	0.71	0.62	0.43		0.39	1.54	1.17	0.50	0.39	0.89	0.60	
Sodium (mg/l)	65.50	94.41	7.50	90.88		30.08	46.4	41.14	40.2	43.68	67.15	75.74	
Cadmium (mg/l)	0.013	<0.002	0.007	0.008		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	
Fluoride (mg/l)	0.22	0.10	0.17	0.19		0.18	0.13	0.19	0.18	0.17	0.28	0.28	
Total Hardness (as mg $CaCO_3$/l)	460	820	640	1,400		512	274	488	660	298	340	390	
Potassium (mg/l)	15.27	7.53	5.40	6.55		4.99	0.70	6.04	15.0	6.23	5.12	6.63	
Iron (mg/l)	<0.01	<0.01	0.53	<0.01		0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Ammonia (as NH_4-N mg/l)	0.18	0.13	0.15	<0.01		<0.01	0.13	0.07	<0.01	0.03	0.12	0.08	
Zinc (mg/l)	0.014	0.013	<0.001	0.074		0.006	0.004	<0.01	<0.001	<0.001	Xxx	Xxx	
Chlorides (mg/l)	145	190	120.0	132		118	116	126	120	135.0	100	105	
Nitrites (as NO_2^- N mg/l)	0.120	0.093	0.045	0.047		0.058	0.077	0.100	0.082	0.045	0.060	0.043	
Nitrates(as NO_3^- N mg/l)	2.61	31.50	32.65	20.12		8.54	15.34	25.35	27.20	41.60	9.92	17.71	
Lead (mg/l)	0.02	0.088	<0.001	0.263		*	0.055	0.09	2.60	<0.01	0.04	<0.01	
Total Phosphates (mg/l)	1.86	2.18	2.39	2.91		5.04	1.16	0.09	2.05	0.23	1.27	1.96	
Magnesium(mg/l)	1.92	95.04	45.60	257		48.00	24.96	49.92	65.28	29.28	23.04	31.2	
Calcium (mg/l)			180	132		124.8	68.0	112.0	155.20	70.4	97.6	104	
Manganese (mg/l)	<0.01	<0.01	<0.01	<0.01		*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Bacteriological													
Total coliforms (#/100 ml)	2,500	2,100	2,100	4,200		3,000	1,300	1,300	3,500	5200	8800	8600	
Faecal coliforms (#/100 ml)	600	1,200	500	1,200		500	700	600	2,500	3500	7900	4800	
E coli (#/100ml)	400	800	100	900		0	50	100	188	186	940	1000	

LWSC Borehole # 4 (30^{th} April 2007)

Temperature (^0C)	17.8				
EC(uS/cm)	824				
Eh(mV)	25				
pH	7.85				
Arsenic (mg/l)	<0.001				
Total dissolved solids (mg/l)	315				
Turbidity (NTU)	2.94				
Sodium (mg/l)	17.7				
Cadmium (mg/l)	<0.002				
Fluoride (mg/l)	0.19				
Total hardness (as mg $CaCO_3$/l)	290				
Potassium (mg/l)	2.9				
Iron (mg/l)	<0.01				
Ammonia (as NH_4-N mg/l)	0.03				
Zinc (mg/l)	0.049				
Chlorides (mg/l)	36				
Nitrites (as NO_2–N mg/l)	0.006				
Nitrates (as NO_3–N mg/l)	11.34				
Lead (mg/l)	0.01				
Total phosphates (mg/l)	<0.01				
Magnesium (mg/l)	31.68				
Calcium (mg/l)	63.2				
Manganese (mg/l)	<0.01				
Bacteriological Results					
Total coliforms (#/100 ml)	800				
Feacal coliforms (#/100 ml)	300				
E.coli (#/100 ml)	100				